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Characterization of soils of Amensis sub-catchment of Hirna Watershed in Western Hararghe Region, Ethiopia

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Abstract: Soils in three toposequences of Amensis sub-catchment of Hirna watershed were characterized and classified. Soils in the steep slopes were shallow whereas they became deep along the topographic lows. The clay texture was common due to basaltic parent material. Soil colour often changed towards red hue on moistening. These soils were neutral to alkaline in reaction. The C:N ratio for all the soils was relatively high and in some cases, it was much higher than the optimal. The soils on mountainous landscape (backslope) were gravelly and eroded particularly on steep slopes. All soils had appreciable amount of organic carbon showing mollic features in the surface horizons. Biotic activities were prominent in some soils. Vertic features under differing moisture regimes were recorded particularly in soils of the foothill and lowlying areas.

Additional key words: *Basaltic parent materials, topographic positions, soil characterization*

Introduction

Amensis is a sub-catchment of the Hirna watershed in the western Hararghe region of Ethiopia under Tulo wareda (district) and bounded by a series of hills and mountains. Being close to the main town of Hirna and connected to the main highway, there is ample opportunity for economic agricultural production in this part of the watershed. However, the lands occur in different topographic positions *viz.* summit, shoulder slope, backslope, upland, midland and lowland are not equally suitable for agricultural activities (Mishra *et al.* 2002, 2004). The agricultural activities are intense, *eg.*, on the top of the mountains, farmers are growing different field crops under rainfed condition. In the sloppy part of the landscape particularly backslope, lands are eroded and soil depths are shallow, which are often used for grazing or afforestation. From the foothill to the extreme lowest landscape, lands are used normally for crop cultivation but inputs like irrigation makes the land distinctive to different land uses. Changes in the landuse systems including deforestation could have brought significant pedogenic modifications (Dawit Solomon *et al.* 2002; Mishra *et al.* 2002; Wakene Negassa and Heluf Gebrekidan 2003;). Obviously, there is need to evaluate the lands occurring in different topographic units to suggest proper landuse planning in terms of management and conservation. Information in th regard is virtually meagre (Heluf Gebrekidan and Mishra 2004; Mishra *et al.* 2004). However, the present study was conducted as a first hand report to characterize the soils in different toposequences of the catchment.

Materials and Methods

The Amensis sub-catchment lies within the geographic boundary of latitudes and longitudes of N9°12.985'/E41°5.458', N9°12.907'/E41°5.176', N9°13.108'/E 41°4.974', N9°13.177'/E41°4.945'/N9°13.269'/E41°5.147' and N9013.686'/E41°5. 110' between the altitudes of 1809 m and 1978 m above MSL. The study site is the western part of the Hirna river bounded by a series of hills and the landscape's relief covers the study area within the elevation difference of 169 m. The Hirna river is actually the common drainage point, in which runoff water from all sides meets and flows towards the slope. The whole catchment forms a very typical watershed and the Amensis sub-catchemnt is the part of this, but it represents the whole.

The catchment was initially subject to volcanism. Presence of silicified wood (wood stone) on the top of the hill indicated that the volcanism took place well after the establishment of the forest in the area (Heluf Gebrekidan and Mishra 2004, Mishra *et al.* 2004). Basalt is the main rock type occurring as the mountain cap followed by sandstone and limestone. However, sandstone and limestone were just near the foothill or even below. The basalt on the top indicated brownish colour when dry and reddish brownish when moist or after rain. Forest is almost rare in the area, through some bushes and shrubs were commonly seen particularly on the sloppy landscape (backslope).

The mean annual rainfall (1999-2003) of the area is 1035.4 mm, whereas the mean maximum and minimum temperatures are 31.5^{0}C and 18^{0}C, respectively. Based on the moisture index value, the climatic zone falls under slightly dry region. The average air temperature being 24.7^{0}C indicates mild air temperature class, whereas the trend of rainfall distribution is very specific to this area. The period between March and June with rainfall distribution of 50 to 100 mm per month for three consecutive months suggests that only the low water requiring crops such as field-bean and grasses can be grown and during the period between July and September (100-300 mm rainfall/ month), crops like maize, blackgram, sorghum, pearlmillet and small millet may be suitable. However, during November and February, when the rainfall is below 50 mm per month, no crop can practically be recommended to grow profitably. Such rainfall based temporal crop zonation actually depends upon the potentiality and productivity of the soils.

Three toposequences were identified on the basis of physiographic positions. Altogether eleven profiles were exposed in three different toposequences for morphological descriptions. Horizon-wise soil samples were collected, air dried, ground and processed through 2 mm sieve for analysis for some selected properties following standard methods. Relevant secondary data were used for soil characterization. The soils had normally more than 60 per cent base saturation, 40 $cmol_c\ kg^{-1}$ cation exchange capacity and COLE values were more than 1.1 (except pedons 1,2 and 3 of the first toposequence and pedons 2 and 3 of the third toposequence). Soils were classified according to Keys to Soil Taxonomy (Soil Survey Staff 1998).

Results and Discussion

Soil characterization

The data pertaining to soil-site characteristics, relevant morphological features and some selected chemical properties for soils of the three toposequences are presented in Tables 1-3.

Toposequence 1

Altogether four profiles were studied on backslope and foothill occurring in slope gradient of 70, 88, 60 per cent in backslope and 10 per cent in foothill with east-south facing aspect (Table 1). The soils were shallow in depth, sedentary in nature and were associated with severe erosion hazard and excessive stoniness. The sub-surface drainage condition is well to excessive. Except for sparse bushes, there was virtually no forest in this landscape. Forest was cleared long back in this hilly terrain particularly from the top and the sloppy landscapes. The first three profile sites were practically virgin and used for grazing but pedon 4 in foothill was under cultivation (Table 1) showing about 20 per cent stones (basalt). The parent material is, of course, basalt with traces of quartz grains. Some evidence of zeolite was also recorded in the form of white material in the cavities of some basalt (Mishra *et al.* 2004; Heluf and Mishra 2004).

The soils (dry) of backslope indicated soil colour (10YR) with some yellowish shade and changed to redder ones (5YR) in soils along the topographic lows (Table 2). The soil texture changed from coarser to finer one and structure from granular to blocky towards topographic lows. Some mottles alongwith root channels were recorded, only in the foothill soils. The surface layer of the third pedon (backslope) indicated prominent biotic activities as evident by the presence of many golden coloured insect eggs (0.4-0.5 mm size). The surface soils in all the pedons were invariably granular in structure. Basaltic parent material would have been transformed to smectite, which might have formed the complex due to interactions with organic materials including grassy vegetation induced by congenial environment. Krotovinas was evident in the sub-soil of foothill pedon. The clay skin was recorded on the ped faces of this pedon and was generally characteristic to the presence of blocky structure.

There was decrease in the amount of gravels of basalt as a result of weathering and chemical transformation along the slope and very little coarse fraction was recorded in the foothill soils (Table 3). The change in soil pH was somehow irregular along the slope, though the soil pH in KCl suspension was often increasing along the slope. The difference of pH_{H2O} and pH_{KCl} were positive which indicated the net negative charge on the exchange sites of the soils. The EC values were far below the salinity level but showed a tendency to increase along the slope. The organic carbon contents of the soils were more than 2 per cent and increased along the slope. There was also increase in the total nitrogen contents along the slope. The C:N ratios were high in all the soils and decreased along the slope until pedon 3 (Table 3). Such high C:N ratio of the soils indicated that the soil organic matters were not fully decomposed and nitrogen loss was apprehended. Further systematic investigation needs to be carried out to explain the mechanism involved. The shrink-swell properties of the soils suggest that smectite could be the probable clay minerals which might have been complexed chemically with the organic matter at some stage of their decomposition and prohibited further decomposition. The nitrogen already present in soils might have been arrested in the complexed form and could not be made available to the crops for their uptake. Possibly due to this reason, the crop response to nitrogen in these soils are very significance as recorded by Heluf Gebrebidan (unpublished). However, the differential chemical behaviours of the foothill soils could be due to management through cultivation and so. Wakene Negassa and Heluf Gebrekidan (2003) reported the changes in soil features due to varying landuse systems.

Toposequence 2

This toposequence is practically situated in the topographic low position stretching south-eastward across the Hirna river, which is the common drainage point of this watershed basin. Three profiles were studied in upland, midland and lowland (Table 1). The soils were derived from basaltic parent material with a general slope gradient of 5-9 per cent showing moderate permeability. Erosion was moderate and stoniness varied from less than 15 per cent in upland to less than 5 per cent in midland. The soils were very deep and well drained to moderately well drained. The landform was virtually rolling in east-south facing aspect with low to moderately high water-table under intensive crop and vegetable cultivation.

The soils of all three pedons in the second toposequence indicated fine texture (clay) and gray colour with reddish shade (5YR), which remained consistent on moistening. The surface soils were invariably granular in all the pedons but the sub-soils showed mottles, concretions (conca and consir), krotovinas throughout the profiles and clay skin on the ped faces below the surface. Slickensides were observed in the sub-soils of midland and lowland pedons. The vertical cracks were also prominent down the depth as shown in table 2 and were more widened in the lowland pedon.

A perusal of data (Table 3) indicates that the soils of this lowland toposequence were neutral to slightly alkaline in reaction with appreciable amount of organic carbon, which showed irregular depthwise distribution. Such irregular depthwise distribution of organic carbon indicated the evidence of fluventic type of soil formation (Soil Survey Staff 1975). Besides, the soils indicated the strong evidence of vertic properties like shrink-swell, vertical cracks and slickensides particularly in the sub-surface layers. The blocky structure was showing prominent shining clay coatings on ped faces. The nitrogen contents as compared to organic carbon was much lower and accordingly the C:N ratio was much higher in these soils too possibly due to the reasons discussed elsewhere.

Toposequence 3

This toposequence starts from the foothill of the mountain to the topographic lows in the east north facing aspect stretching to the common drainage point (Hirna river), wherein different crops are grown under different management systems. Four profiles each in foothill, upland, midland and lowland were studied (Table 1). They were deep, well drained with slight to no stoniness and rapid to moderate permeability. The soils were formed on basalt and sandstone showing slight to severe erosion and very low to very high water tables as one move towards topographic lows.

Table 1. Soil-site characteristics (toposequence) of the study area

Toposequence / Pedon	Location		Altitude (m above MSL)	Slope (%)	Topography	Physiography	Aspect (facing)	Perme-ability	Parent rock	Erosion	Surface stoniness (%)	Drainage	Water table (m)	Soil depth (cm)	Land use
	Latitude	Longitude													
1/1 (backslope)	N9°13.177"	E41° 4.955'	1970	70	Steep sloppy	Backslope E-S	Rapid	Basalt/quartz		Severe	Excess (50)	Excess	-	75	virgin
							grain								
1/2 (backslope)															
1/3(backslope)	N9° 13.160'	E41° 4.972'	1936	88	Steep sloppy	Backslope E-S	Rapid	Basalt	Severe	Excess (60)	Excess	-	35	virgin	
1/4 (foothill)	N9° 13.127"	E 41° 4.967"	1959	60	Steep sloppy	Backslope E-S	Rapid	Basalt	Severe	Excess (40)	Excess	-	90	virgin	
2/1(upland)															
2/2 (midlow)	N 9° 13.116'	E 41° 5.035'	1906	10	Mod. sloppy	Foot-hill E-S	Rapid	Basalt	Moderate	Moderate (20)	Mwd	V. low	200	Cropland	
2/3 (lowland)	N9°13.100'	E41°5.191'	1872	9	Upland	Valley basin	E-S	Moderate	Basalt	Moderate	Slight (<15)	Mwd	Low	>190	Cropland
3/1 (foothill)	N9°13.151'	N41°5.333'	1845	7	Midland	Valley basin	E-S	Moderate	Basalt	Moderate	Slight (<5)	Mwd	Mid	>180	Cropland
	N9°13.239'	E41°5.404'	1820	5	Lowland	Valley basin	E-S	Moderate	Basalt	Moderate	-	Mwd	High	>150	Cropland
	N90 13.346'	E410 5.085'	1891	20	Foot-hill	Sloppy hill E	Rapid	Basalt+	Severe	Slight (<15)	Wd	V. low	>200	Cropland	
3/2 (upland)								sandstone							
	N9°13.460'	E41°5.820'	1880	10	Upland	Valley basin	E	Moderate	Basalt +	Moderate	Slight (<15)	Mwd	Low	>195	Cropland
								sandstone+							
3/3 (mid low)								limestone							
	N90 13.390'	E410 5.213'	1850	8	Midland	Valley basin	E	Moderate	Basalt +	Moderate	-	Mwd	High	>200	Cropland
								sandstone+							
3/4 (lowland)								limestone							
	N90 13.424'	E410 5.282'	1835	5	Lowland	Valley basin	E	Moderate	Basalt +	Slight	-	Mwd	V. high	>190 v. deep	Cropland
								sandstone+							
								limestone							

Excess - Excessive; Wd - Well dvouined ; Mwd - Moderately well drained

Table 2. Relevant morphological features of profiles in toposequences of Amensis sub-catchment*

Depth (cm)	Horizon	Boundary	Munsell colour Dry	Moist	Texture	Structure	Consistence	Mottle	Effervescence	Nodule/ concretion	Krotovinas	Clay skin	Slickenside	Vertical crack width (cm)	Root	Remarks
Toposequence 1: Backslope-up (Mollic Udarent)																
0 – 25	A	gs	10YR4/4	5YR3/4	sil(gr)	f1(sg - gr)	l, fr, s,p	-		-	-	-	-	-	mc	bleached, when dry.
25 – 55	AC	ga	10YR3/2	10YR4/2	sil(gr)	m1 sg(gr)	l, fr, ss, sp	-		-	-	-	-	-	cf	-
55 – 75+	C	-	10YR4/2	5YR3/2	sil(gr)	m1 sg(gr)	l, fr, so, po	-		-	-	-	-	-	fc	-
Toposequence 1: Backslope-mid (Mollic Lithic Udarent)																
0 – 15	A	Cs	10YR4/3	10YR4/2	sil(gr)	c1gr-sg	l,fr,ss,sp,	-		-	-	-	-	-	fc	eroded
15 – 35	AC	ga	10YR4/4	5YR3/2	sil (gr)	c1sg	l,fr,sopo	-		-	-	-	-	-	mc	-
35+	C	-	-	-	-	-	-	-	-	-	-	-	-	-	fm	soil materials in rock's cracks
Toposequence 1: Backslope-mid (Haplic Vermudoll)																
0 – 25	A	gs	5YR3/2	5YR2.5/2	sic(gr)	m1gr	l,vfr,ssp	-		-	-	-	-	-	fc	golden insect eggs (many)
25 – 60	Bt	ga	5YR2.5/1	5YR2.5/2	sic(gr)	f1gr	l,vfr,sp	ffd,10YR6/3		-	-	-	-	-	cm	basalt gravel (5YR7/6)
60 - 90	BC	-	5YR3/3	5YR3/3	c	c1gr-bk	sl,vfr,ss,sp	cfd 10YR5/6		-	-	-	-	-	mc	along the root channels
Toposequence 1:Foothill (Vertic Paleudoll)																
0 35	A	gs	5YR3/2	5YR2.5/2	sic(gr)	f1gr	l,fr,ss,sp	-		-	-	.	-	-	mc	-
35 – 110	AB	gs	5YR3/2	5YR3/2	c	c1abk	l,vfr,vs,vp	fcd,5YR7/6		-	f,pr	thin,5YR3/1	-		mc	(5YR7/6)
110 - 160	Bt	cs	10YR3/3	10YR3/4	c	f1sbk	l,vfr,sp	mcd,10YR5/6		-	f,pr	thin,5YR3/1	-		ff	(10YR5/6)
160 - 200	BC	-	10YR4/3	10YR2/2	sic(gr)	f1gr	l,vfr,s,p	ffd,10Yr2/1		-	f,pr		-	-	vff	-
Toposequence 2: Upland (Vertic Hapludoll)																
0 – 25	A	gs	5YR3/1	5YR2.5/1	c	f1gr	l,vfr,vs,vp	Decaying roots		f,consn	f,pr	Thin, broken	-		mc	stones/boulders on surface
25 - 60	Bt1	gs	5YR2.5/1	5YR2.5/1	c	m1bk	h,vfr,vs,rp			-	-	thin, 5YR2 5/1		1.0	mf	
60 – 110	Bt2	gs	10YR3/1	5YR2.5/1	c	c2abkgr	h,vfr,vs,vp	fld5YR4/3		f, consir	-	thin,5YR2.5/1	-	1.5	ff	granular to blocky
110– 140	Bt3	gs	10YR2.5/2	5YR2.5/2	c	c2abt	h,fr,vs,vp	flf,black(consir)	ev	f, consir	f,pr	thin, 5YR3/1	-	1.5	vff	argillan prominent
140 - 190	BC	-	5YR2.5/1	5YR2 5/2	c	c2abk	h,vfr,vs,vp	f2f, (5YR4/4)	es	vf,consir	f,pr	thin,5YR3/1	-	0.75	vff	argillan Prominent
Toposequence 2: Mid land (Alfic Vertic Argiudoll)																
0 – 25	A	gs	5YR2.5/1	5YR2.5/1	c	f1gr	l,vfr,vs,vp	-		-	f,pr	thin, 5YR2.5/1	weak	1.0	mc	-
25 – 65	Bt1	cs	5YR3/1	5YR2.5/2	c	m2bk	vh,vfr,vs,rp	-		-	f,pr	thin, 5YR3/1	pr	1.5	fm	-
65 – 95	Bt2	cs	5YR4/2	5YR3/1	c	c3bk	h,sfir,s,p	fl15YR2.5/1/5YR5/6	es	consir	f,pr	med, 5YR3/1	pr	1.5	ff	-
95 – 140	Bt3	gs	5YR3/3	5YR3/4	c	c3bk	h,fr,vs,vp	flp10YR4/4/5YR5/6	es	consir	f,pr	thin. 5YR3/1	weak	0.75	vff	cutan dominant
140 - 180	BC	-	5YR2.3/3	5YR3/3	cl (gr)	c1bk	h,fr,ss,sp	fld5YR2.5/1	ev	consir/conca	-	-	ploughed		vff	cutan,basaltgrains
Toposequence 2: Low land (Aquertic Argiudoll)																
0 - 20	A1	gs	5YR2.5/1	5YR2.5/1	c	m3gr	sl, fr, vs,vp	-	es	-	f, fine	-	-	0.3	cc	ploughed
20– 45	A2	gs	5YR2.5/2	5YR2.5/2	c	m3bk	sh, fr, vs, vp	-	es	-	f, pr	thin,5YR2.5/1	w	3.0	cf	krotovinas filled with black materials
45 – 80	Bt1	gs	5YR3/1	5YR2.5/1	c	c3abk	h, vfr, vs, vp	-	es	-	-	thin,5YR2.5/1	pr	1.0	ff	slickensides in bottom layers
80 – 130	Bt2	gs	5YR3/1	5YR3/1	c	c3abk	h,vfr,vs,vp	fld5YR5/8	es	-	f, pr	thin,5YR2.5/1	pr	0.5	mf	cutan prominent,
130 150	Bt3	ds	5YR3/1	5YR3/1	c	m3abk	h,vfr,vs,vp	c2p5YR6/8	es	-	f, pr	thin,5YR2.5/1	pr	wet	ff	shining pedface
150+	C		5YR4/1	10YR3/2	c	m1abk	h,fr,vs,vp	f3f2.5YR2.5/fld5YR6/6es		conca	f, pr	thin,5YR3/1	pr	wet	ff	high water table

Contd..

Toposequence 3: Foothill (Oxiaquic Vertic Hapludalf)																
0 – 25	A	Cs	10YR4/3	5YR3/4	sil	f1gr	l, vfr, sp	-		consir	-	-	-	-	mc	
25 – 45	Bt1	gs	10YR3/3	10YR3/2	c(gr)	f1gr-bk	h, vfr, sp	ffd5YR5/6		consir	-	-	-	fine	ff	
45 – 70	Bt2	gs	5YR3/2	5YR3/2	c	m1abk	h, fr, vs, vp	ffd5YR4/6		consir	few,fine	thin,5YR3/1	faint	0.5	ff	ped surface with clay skin
70 – 95	Bt3	gs	5YR3/3	5YR3/2	c(gr)	m1abk	h,sfir,sp	-		consir	fine,few	v.fine, "	-	-	vff	thin argillan, 2.5YR3/0
95 – 145	BC	cs	5YR3/3	5YR3/3	c	m2abk	h,vfirvs,vp	fmf5YR5/6		consir	f, pr	fine,5YR2.5/1	-	-	vff	thin argillan, 5YR3/1
145 - 200	C	-	5YR3/4	5YR3/3	c(gr)	m1abk	h,fr,vs,vp	-		consir	f, pr	thin, 5YR3/2	-	-	vff	
Toposequence 3: Upland (Oxyaquic Hapludert)																
0 – 30	A1	gs	5YR3/2	5YR2.5/1	sicl	c1gr-bk	sh, fr, ss, sp	-		-	-	-	-	-	mc	-
30 – 70	AB	gs	5YR3/1	5YR2.5/1	c	f1gr-abk	l,vfr, vs, vp	ffd,5YR5/6		consir	f.f	fine, v.thin	-	fine	mf	-
70 – 105	Bt1	gs	5YR3/2	5YR2.5/1	c	c1abk	h, vfr,sp	ffd5YR4/4		-	f.pr	v.thin, 5YR3/1	-	2.0	ff	krotovinas (5YR2.5/2)
105 – 140	Bt2	cs	5YR3/2	10YR3/2	c	c1abk	h, vfr, vs, vp	ffv5YR5/8 - 4/6		-	f.pr	few,5YR2.5/1	-	0.5	vff	
140 - 195	BC	-	5YR4/3	5YR3/3	c	c3abk	sh, fr,vs,vp	mfd5YR5/8/ffd5YR2.5/1		-	m.pr	-	-	-	-	variegated colours
Toposequence 3: Mid land (Mollic Oxyaquic Hapludert)																
0 – 30	A1	gs	5YR2.5/2	5YR2.5/2	c	f3gr	h,vfr,vs,vp	-	eo	-	few, filled	-	-	0.5		-
30 – 100 structure	A2	gs	5YR3/2	5YR2.5/2	c(g)	c3bk	h,fr,vs,vp	fld,red	eo	-	few,pr	thin,5YR2.5/1	pr	0.5		prismatic
100 – 140	Bt	ds	5YR3/2	5YR2.5/2	c	c3pr	h,fr,vs,vp	fld,10YR4/6	es	-	pr. filled	-	pr	0.5		Many Mn-concretions with conea.
140 - 200	BC	-	5YR3/2	5YR3/2	c	c2abk	h,fr.vs,vp	fld,2.5YR2.5/0	ev	consir,conca	few, fine	thin,5YR2.5/2	pr	-		
Toposequence 3: Low land (Vertic Paleudoll)																
0 – 30	A	gs	5YR2.5/1	5YR2.5/1	c	c3gr-bk	l,vfr,vs,vp	-	eo	-	-	-	-	ploughed		
30 – 75	Bt	gs	5YR2.5/1	5YR3/1	c	c3abk	l,fir,vs,vp	ffd,5YR5/8	eo	-	f, filled	thin, broken	-	2.5		Mn/Fe concretions
75 – 190	BC	-	5YR3/1	5YR2.5/1	c	c3abk	vh,fr,vs,vp	-	eo	consir	f, filled	thin, 5YR2.5/1	pr	1.5		-

* Notation as per Soil Survey manual (Soil Survey Staff 1951)

Table 3. Some relevant soil properties

Depth (cm)	Coarse fraction (V/V)*	Moisture (%)	pH (H_2O)	pH (KCl)	ΔpH	EC dS m^{-1}	OC (%)	Total N (%)	C:N ratio
Toposequence 1: Backslope-up									
0 – 25	37.55	9.78	7.28	5.77	1.51	0.04	2.14	0.038	56.32
25-55	20.33	9.30	7.53	5.85	1.68	0.06	2.13	0.107	19.91
55-75	17.19	11.91	7.65	6.00	1.65	0.06	2.23	0.071	31.41
Toposequence 1: Backslope-mid									
0 - 15	37.75	12.38	6.89	6.66	0.23	0.06	4.25	0.197	21.57
15-35	33.17	12.28	7.00	5.82	1.18	0.04	2.76	0.079	34.94
Toposequence 1: Backslope-mid									
0 - 25	18.29	11.25	7.55	5.79	1.76	0.07	4.42	0.272	16.25
25-60	24.08	10.67	6.97	5.95	1.02	0.09	4.14	0.147	28.16
60-90	3.57	5.16	7.70	6.31	1.39	0.12	2.05	0.125	16.40
Toposequence 1: Foothill									
0 - 35	12.55	9.12	7.01	5.49	1.52	0.08	2.89	0.137	21.09
35-110	0.42	9.60	7.10	5.59	1.51	0.07	2.35	0.123	19.10
110-160	8.99	10.67	7.68	5.76	1.92	0.09	2.20	0.039	56.41
160-200	1.54	9.58	7.98	6.44	1.54	0.24	0.80	0.054	15.00
Toposequence 2: Upland									
0 - 25	-	6.13	7.02	5.87	1.15	0.15	1.66	0.089	18.65
25 - 60	-	12.41	6.93	5.67	1.26	0.09	3.59	0.086	41.74
60 - 110	-	8.46	7.49	5.78	1.71	0.10	2.54	0.083	30.60
110-140	-	7.45	8.04	6.42	1.62	0.17	1.63	0.090	18.11
140-190	-	6.36	7.91	5.60	2.31	0.25	1.49	0.067	22.24
Toposequence 2: Midland									
0 - 25	-	8.71	6.95	5.65	1.30	0.11	1.23	0.137	8.98
25 - 65	-	6.80	7.20	5.50	1.70	0.08	2.46	0.052	47.31
65 - 95	-	10.74	7.64	6.05	1.59	0.10	2.25	0.046	48.91
95 - 140	-	11.25	8.23	6.67	1.56	0.28	1.30	0.086	15.12
140-180	-	9.30	8.44	7.16	1.28	0.23	1.41	0.023	61.30
Toposequence 2: Lowland									
0 - 20	-	9.79	7.02	5.63	1.39	0.13	3.08	0.084	36.67
20 - 45	-	6.78	7.08	5.47	1.61	0.08	2.99	0.112	26.70
45 - 80	-	11.51	7.46	5.97	1.49	0.09	3.00	0.109	27.52
80 - 130	-	11.12	8.37	6.85	1.52	0.27	1.73	0.093	18.60
130-150	-	11.57	8.22	6.82	1.40	0.28	196	0.086	22.79
150+	-	13.52	8.13	6.86	1.27	0.28	1.90	0.032	59.37
Toposequence 3: Foothill									
0 - 25	21.15	7.43	6.66	5.45	1.21	0.07	1.68	0.090	18.67
25 - 45	5.59	7.13	6.74	5.27	1.47	0.05	2.76	0.060	46.00
45 - 70	2.73	8.34	6.99	5.32	1.67	0.05	2.58	0.076	33.95
70 - 95	-	8.20	6.97	5.47	1.50	0.06	2.15	0.098	21.94
95 - 145	0.83	12.36	7.34	5.67	1.67	0.05	2.37	0.079	30.00
145-200	5.93	9.02	7.45	6.12	1.33	0.09	1.70	0.084	20.24
Toposequence 3: Upland (AU Experimental Plot)									
0 - 30	-	10.28	6.78	5.72	1.06	0.09	4.12	0.197	20.91
30 - 70	-	5.31	7.11	5.86	1.29	0.09	3.04	0.103	29.51
70 - 105	-	4.45	7.61	6.16	1.45	0.07	2.32	0.146	15.89
105-140	-	8.06	8.13	6.65	1.47	0.11	1.47	0.015	98.00
140-195	-	11.27	8.10	6.74	1.36	0.18	1.21	0.031	39.03
Toposequence 3: Midland									
0 - 30	-	9.30	6.66	5.52	1.15	0.09	3.03	0.115	26.35
30 - 100	-	10.51	7.56	5.87	1.69	0.09	1.77	0.093	19.03
100-140	-	11.78	7.02	6.72	0.30	0.22	1.61	0.039	41.28
140-200	-	5.64	8.19	7.08	1.11	0.25	0.74	-	-
Toposequence 3: Lowland									
0-30	-	6.21	6.80	5.57	1.23	0.10	4.14	0.156	26.54
30-75	-	10.63	6.89	5.47	1.42	0.07	3.15	0.101	31.19
75-180	-	10.55	7.94	6.33	1.61	0.13	2.89	0.131	22.06

*Coarse fraction (> 2 mm) is excluded

All the four pedons in this toposequence indicated coarser to finer texture down the depth within the pedons and among pedons. The soil colour varied from 10YR to 5YR with varying values and chromas. The foothill pedon indicated concretions (conca) throughout the profile whereas only a few sub-soil layers indicated consir or/and conca in other pedons (Table 2). The krotovinas in all the pedons were prominent. The clay skin on ped faces was recorded only in the sub-surface layers of pedons of both midland and lowland. The vertical cracks were prominent in the sub surface layers of upland, midland and lowland. Prismatic structure was prominent in the third layer of the midland pedon, though there was no indication of sodicity in the soil.

The foothill soil of this toposequence indicated some coarser material because of its location near the hill which showed sandstone just below the basalt (Table 3). The pH in all the surface soils was comparatively lower than those of second toposequence. In the foothill soils, the organic carbon contents were irregularly distributed in the profile likely due to their colluvial nature. Besides, biological activities forming open channel (krotovinas), vertic features forming cracks could also have likely caused downward migration of organic matters resulting into their irregular distribution in the profile. However, the soils of the foothill indicated the presence of some consir (iron/manganese concretions) likely due to poor drainage condition. In other pedons, organic carbon content decreased with depth (Table 3). The nitrogen contents in this sequence were irregularly distributed and their values were comparatively much lower and thus the values for C:N ratios of these soils were also much higher like the soils of the second toposequence.

Soil classification

Based on morphological, physical and chemical properties, the soils have been classified according to the Keys to Soil Taxonomy (Soil Survey Staff 1998) and presented in table 4. In classifying the soils, some secondary data have been used particularly for cation exchange capacity, base saturation, COLE values, particle-size distributions in the profiles. In the first toposequence, classification of soil (pedon 2) is suggestive and has been placed in the Mollic-Lithic Udorthent, since the soil indicated prominent mollic properties with lithic contact and Lithic Udorthent as suggested in Soil Taxonomy (Soil Survey Staff 1998). As such, the extragrade Mollic-Lithic was suggested to this soil at sub-group level. The vertic features in most of the soils are inherited due to parent materials (basalt), which yielded smectite as dominant clay mineral; but the moisture regime is aquic. Both features were subordinate over mollic and argillic characteristics in some of the profiles. In fact, Soil Taxonomy seems to be biased to classify some of the soils, which have been developed on basalt under sub-temperate climates. Vertic features with varying degree are common in these soils, but Gilgai micro-relief was, however, not observed. India is pioneer in discovering such vertic soils derived from basalt. Such soils (Vertisols) are commonly known as black cotton soils or *Regur* in central India or *Karail* in the lower Gangetic plain and *Bhal* in Gujarat (Sehgal 1996). Shallow to deep black and their associated mixed red and black soils occupy a large area in the Deccan Trap of India (Raychaudhari and Govindarajan 1971). However, Ethiopian soils developed on similar parent materials (basalt) are different in some of the properties due to sub-temperate climate. Detailed investigation is on way under the project sponsored by the Ethiopian Agricultural Organization.

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