SINET: *Ethiop. J. Sci.*, 25(1):45–70, 2002
 ISSN: 0379-2897

CHARACTERISTICS, CLASSIFICATION AND POTENTIALS OF SOILS IN WERKARYIA AREA, SOUTH WELO, ETHIOPIA

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ABSTRACT: This paper examines the morphological, physical, chemical and biochemical characteristics of soils and maps the soil units of Werkaryia area, Kutaber wereda, south Welo. Moreover it examines the potential and constraints of soils for crop cultivation. The characteristics of soils were determined based on field survey and laboratory analysis. The classification of soil was based on the FAO/UNESCO Revised Legend (1990). Eutric Vertisol, Haplic Phaeozem, Luvic Phaeozems, Mollic Gleysols, Mollic Fluvisols and Mollic, Lithic, and Eutric Leptosols are the major soil units identified in the area. Vertisols occur on the gently to strongly sloping alluvial toeslope and footslope. They are marked by high clay content, cracks, slickensides and gilgai topographic features. Cambic B and argic B of the Haplic Phaeozems and Luvic Phaeozems underlain the Mollic A of Phaeozems, respectively. Mollic Gleysols developed on alluvium deposition while Mollic Fluvisols on stratified deposition of the toeslope. Both Fluvisols and Gleysols are marked by gleyic and stagnic conditions. On the other hand, Leptosols are formed over the residuals of the trachyte of the upper slopes. They are characterized by shallow soil depth, below 30 cm. As a result of the parent materials, the soils of Werkaryia in general are characterised by high nutrient status and retention capacities. The pH of the soils is also favourable for crop cultivation. However, crop cultivation in the area is limited by low organic matter and total nitrogen of Vertisols and Phaeozems, by the poor drainage of Vertisols, the shallow depth and the high erosion rate in Leptosols, the high water table of Fluvisols and Gleysols, and the imbalance of nutrients and deficiency of some of the nutrients in almost all of the soils.

Key words/phrases: Soil characteristics, soil classification, soil constraints, soils potentials, Welo

INTRODUCTION

The average land-holding and crop yield of a household in Kutaber wereda in 1996 were estimated to be 0.89 hectare and 3.8 to 7.6 quintals, respectively (AOK, 1996). The high pressure on land resources and the subsequent uninterrupted cultivation of land are the main factors, among others, for low agricultural productivity in the area. As a result the region Welo, in general, and the wereda, in particular, are affected by serious food deficit and acute food security problems. A major challenge in the region is therefore production of more food to feed the rapidly growing population while maintaining the environment. In order to release the pressure and raise food production by intensification and/or expanding the cultivated land, understanding of the characteristics and types of soils is very crucial. The measures to be taken should also be in accordance with the constraints and potential of each soil type for cultivation of crops, which require research on soil types and their characterstics.

There are only few soil resource studies that have been carried out in Welo region. The few studies so far undertaken only constiture not more than 5% of the upland (elevation 1500 masl) of the region (EHRS, 1985; Berhanu Debelle, 1994). Of the studies, the soil survey of Borkena area to prepare the soil map on a scale of 1:50,000 covering an area of 300,000 ha (Paris, 1985) is an important resource. The other detailed studies on characteristics and classification of soils in the region are the soil survey of the Maybar area by Weigel (1986) and that of the Wurgo catchement by Belay Tegene (1995). With such limited information on soils, decision making on the proper usage of soils for agricultural development and for resource management seems to be difficult. Hence more detailed studies are required in the region, in general, and in the wereda, in particular where no studies of soils have yet been undertaken.

This paper attempts to generate information on types, properties and fertilities of soils in Workariya area to contribute to the recognition of the problems of soils and the interacting factors in the use of soils. The paper has the following objectives: to investigate the diagnostic horizons and diagnostic properties of soils and to classify and map the soil units of the area, and to assess the potentials and constraints of soils for cultivation.

MATERIALS AND METHODS

Description of the study area

The study site, "Werkaryia", is situated in Kutaber wereda, south Welo (Fig. 1). It is located about 15 km due north-northwest (NNW) of Dessie, along the road from Dessie to Wadla Delanta. The study site roughly lies at 11° 12' 45"–11° 15' 30" N and 39° 34'30"–39° 36'30" E and covers an area of 1170 ha. It has an altitude ranging from 2650–3005 masl.

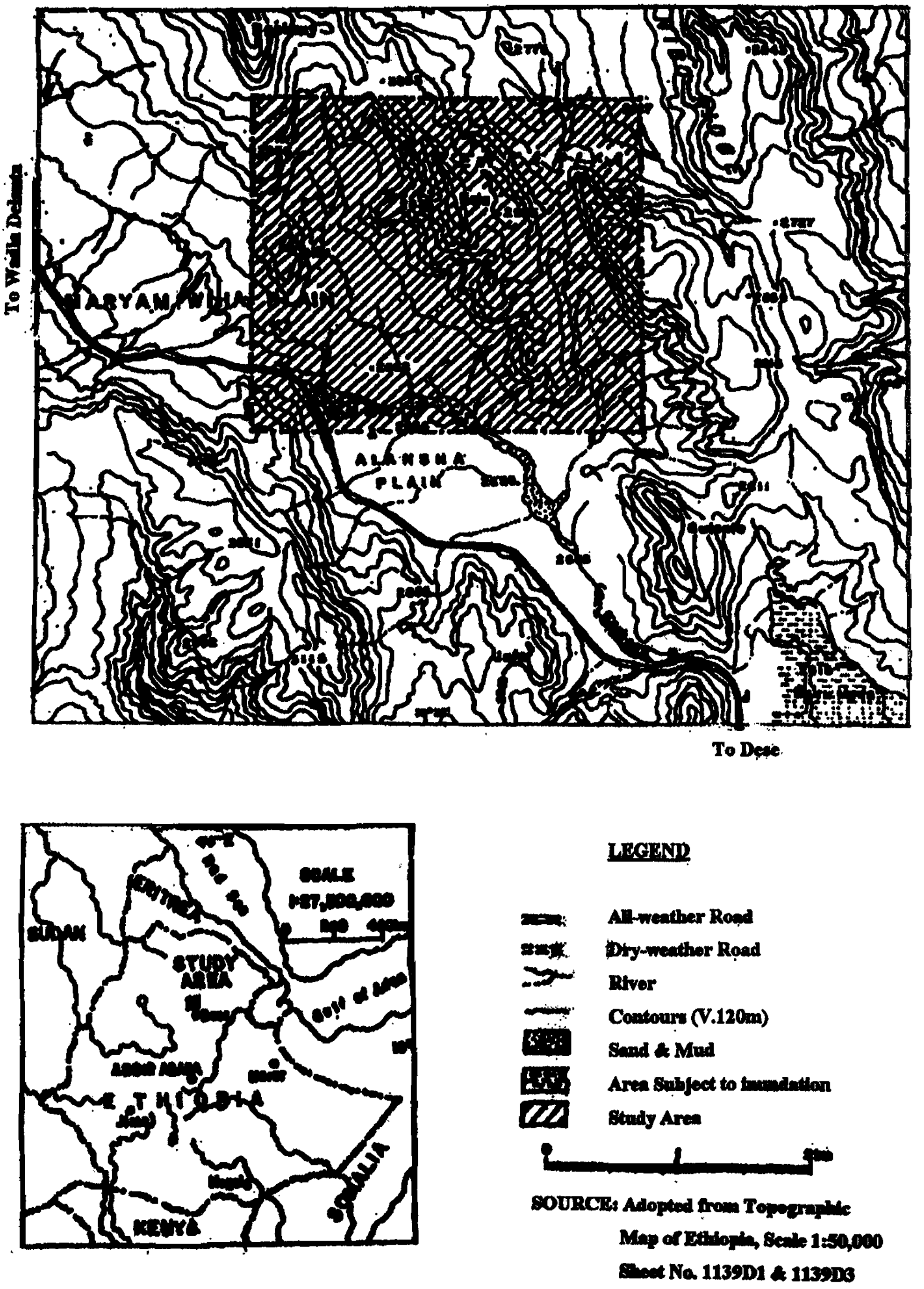

Fig. 1. Location map of the study area.

Slopes ranging from flat to steep slope characterize the study area, which account for 7% and 24% of the total area, respectively. A good proportion of the area (64%) has a general slope of 5–30%. Of the different groups of Lava, Termaber basalt covers the region around Dessie. The dominant rock of this group is the alkaline basalt, which falls within the age range of 26–22 million years (Mohr, 1983). Along the road from Haiq to Kombolcha through Dessie, violet and coarse-grained pyroclasts are well exposed together with fine light grey tuffs. In addition to these tuffs, basalt mainly of lava flows occurs. The dominant rock type of Werkaryia is trachyte.

The area is characterized by sub-humid climate. The mean annual rainfall, based on records from Borumeda (located about 5 km south of Werkâryia and at an altitude of 2720 m), is approximately 1185 mm. The area is marked by two rainy seasons (bimodal pattern). The main rainy season extends from July to September (Kiremt) and a small rain season from March to May (Belg). The highest monthly rainfall, which occurred in August, has been recorded to be 290 mm, while during Belg the peak rain in April amounted to 100 mm (National Meteorological Service Agency). The mean monthly temperature ranges from 12.5° C (November) to 17° C (July). The lowest temperature occurs during the dry season (October through February) (based on the records of Dessie with an altitude of 2540 m) (EHRS, 1985). Due to the high altitude frost is a serious and frequent hazard in the area, particularly in November and December.

The major land-use and land-cover units distinguished in the study area in 1996 were: grassland, cultivated land, wood land, bush land and shrub land with respective averages of 40.34%, 33.7%, 9.3%, 8.9% and 5% (Engdawork Assefa, 2000). The major types of crops that grow in the area, in order of importance are: barley, wheat and maize. Since the early 1970s the cultivation of maize has increasingly expanded mainly due to its drought resistant nature and less labour and cost involvement.

Methods and procedures

The base map of the area from the Ethiopian Mapping Agency with scale of 1: 50000 was enlarged to 12500 scale and divided into grids. The auger holes on each grid were fixed. The location of traverse lines (transect) which runs along longitudinal slope, was determined and sites for soil profile description were marked (Fig. 2). On the whole, flexible survey, which is a combination of grid, free survey and transect survey was carried out depending on the nature of topography.

The soil was described and samples were collected following the Guideline for Soil Description of FAO (1990). Soil colour was described using soil colour charts (Munsell Colour, 1975). The soil classification was based on the FAO/UNESCO Revised Legend (1990).

Field survey

About 210 auger holes were observed to depths of 100 cm and individual soil properties, site characteristics and land-use/land-cover were recorded on standard form for soil description and mapped parametrically. Twenty three representative profiles on six transects (located on summit, shoulder, back slope, foot slope and toe slope) were described to depths of 200 cm and soil samples were taken (Fig. 2). About one kilogram of soil sample was taken in equal proportion from the whole horizons of the described profile, excluding the boundary of the horizon.

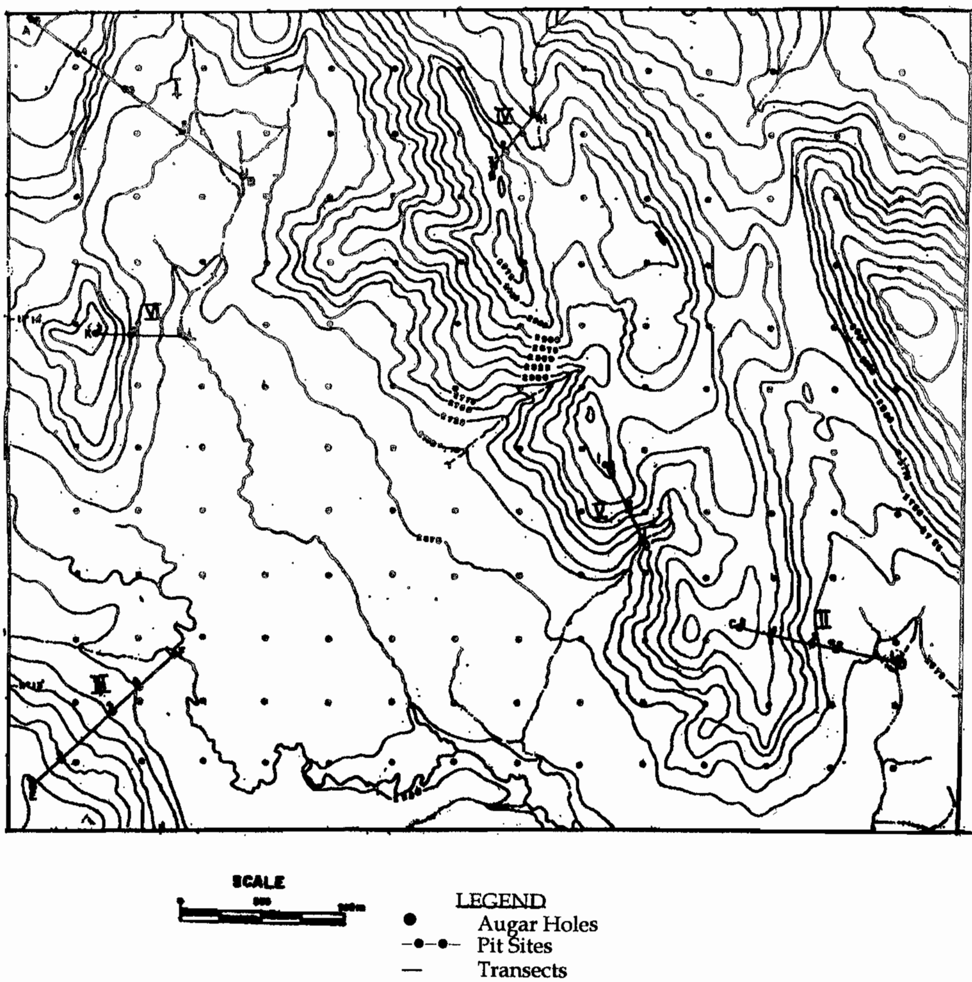

Fig. 2. Auger holes, pit sites and transects of location map of Werkaryia. (Contours are at 25 m vertical intervals.)

Laboratory analysis

The collected soil samples were analysed at the National Soil Research Centre Laboratory, Ethiopian Agricultural Research Organization. The soil samples were air-dried at room temperature by spreading on polythene sheets. On drying they were crushed in metal mortar and pestle and sieved through a 2 mm sieve. Texture was determined based on the principles of dispersion and sedimentation. A hydrometer was used to determine the density of suspension at any given time (Baruah and Barthakur, 1997). The particle size was based on the USDA classification system, in which the particle size of sand is (2.0–0.05mm), silt (0.05–0.002) and clay (<0.002mm). Soil *pH* was measured by potentiometerically in a 1:2.5 ratio of soil and water. Organic carbon was determined by following the Walkley and Black method as described by Sahlemedhin Sertsu and Taye Bekele (2000). The percentage of organic matter was estimated by multiplying the organic carbon by 1.724. The Kjeldhal method was used to determine the total nitrogen. Available phosphorus was determined following Olsen`s method as described by Sahlemedhin Sertsu and Taye Bekele (2000). Exchangeable cations (Ca, Mg, Na, and K) in the soil were determined by ammonium acetate method. Sodium and potassium in the ammonium acetate leachate were measured by flame photometer while calcium and magnesium were determined by spectrophotometer. Cation Exchange Capacity (CEC) was determined by percolating with ammonium acetate solution, which was followed by removal of salts by ethanol. The ammonium was determined by distillation (Sahlemedhin Sertsu and Taye Bekele, 2000). Percent base saturation (%BS), the percentage of the cation exchange capacity occupied by basic cations, was calculated as:

$$\frac{C_a + M_g + K + N_a}{CEC} \times 100.$$

RESULTS AND DISCUSSION

The major soils of Werkaryia area were identified as Eutric Vertisols, Haplic Phaeozems and Luvic Phaeozems, Mollic Gleysols, Mollic Fluvisols and Eutric, Mollic and Lithic Leptosols (Fig. 3).

Eutric Vertisols

In Werkaryia area, Vertisols are the most important soil, covering 17% of the total area. Vertisols mantle the toeslope and lower footslope with slope gradient of 5 to 16 per cent (gently slopping to very slopping). The alluvial and colluvial materials, which are derived from trachyte rocks, are the parent materials on which the Vertisols have developed. Vertisols on the plains and the depressions are under grassland while those on the upper footslope are used for cultivation of barley, wheat and maize. Almost all the Vertisols are marked by very deep solum.

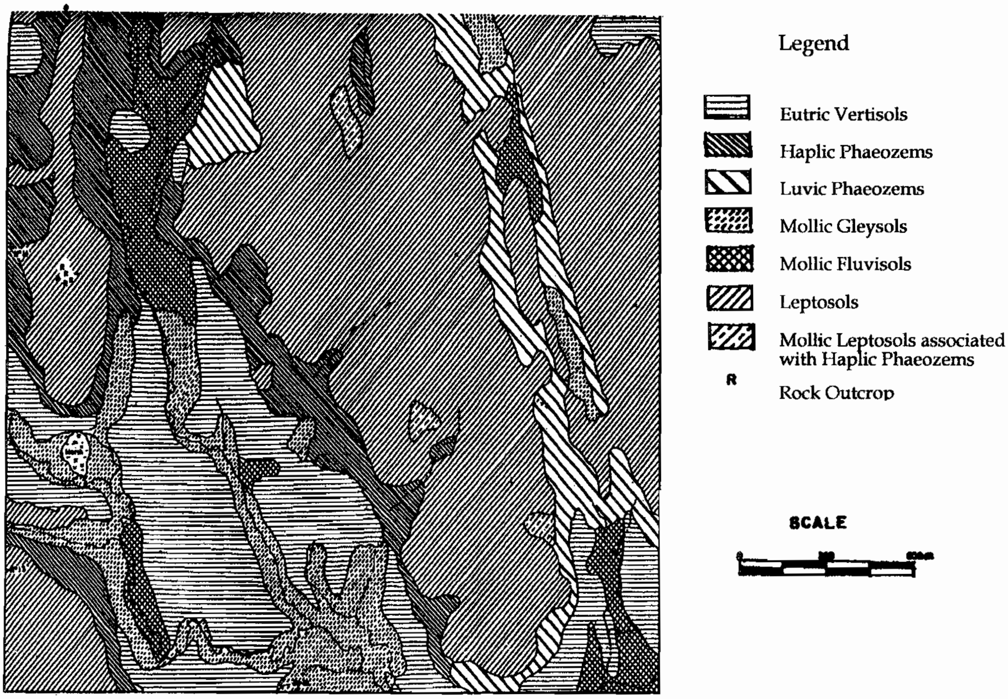

Fig. 3. Soil map of Warkaryia.

Morphological and physical characteristics

The abbreviated morphological and physical properties are presented in Tables 1 and 2. The soils in general are characterized by very dark grey (10YR3/1) colour. The pedoturbation of soil is perhaps responsible for the uniform black colour extending to depth (Belay Tegene, 1996). Moreover, the effect of churning may have hindered the development of the B and C-horizons, and consequently the soil horizons in most cases comprise of the plough and the deep A horizons.

The soils are marked by strong coarse to very coarse subangular blocky, and very sticky and very plastic wet consistence throughout the profiles. Poor internal drainage of Vertisols impedes the development of roots, hence fine roots are confined to the surface layers.

The deep, wide cracks and the slickensides are typical characteristics of Vertisols, which are evidences of the significance of the shrink and swell activities resulting from the predominant montomorillonitic clay minerals. During the dry season the cracks are open upto a width of 3 cm and extend to depths of 61 cm. Slickensides (shiny ped surfaces) were also observed to a depth of 160 cm.

Table 1[a]. Selected morphological and physical characteristics of Eutric Vertisol.

Depth(cm)	Horizon	Colour (moist)	Texture class	Structure	Consistence	Boundary	Plant roots[b]
Profile TI-2, Slope 16%							
0–18	Ap	10YR3/1	C	3-csbk	wvs,wvp	cs	vff
18–45	A2	10YR2/1	C	3-vcsbk	wvs,wvp	cs	-
45–200	A3	10YR2/1	C	3-vcsbk	wvs,wvp	-	-
>200 A horizon continues below 200 cm							
Profile TII-2, Slope <1%							
0–8	Ap	10YR3/1	c	3-csbk	wvs,wvp	cs	fwf
8–25	A2	10YR3/1	c	3-csbk	wvs.wvp	cs	fwf,vfmd
25–43	A3	10YR3/2	c	3-csbk	wvs,wvp	cs	vfc
43–160	A4	10YR4/2	c	3-csbk	wvs,wvp	-	-
>160 A horizon continues below 160 cm							
Profile TVI-1, Slope 10%							
0–18	Ah	10YR3/1	c	3-csbk	wvs,wvp	cs	fwf
18–73	A2	10YR3/1	c	3-csbk	wvs,wvp	as	-
73–160	Bb	10YR5/1	c	3-csbk	wvs,wvp	-	-
>160 Bb horizon continues below 160 cm							

Source: AOK (1996).

a) Abbreviations are according to those given in soil survey manual (Soil Survey Staff, 1969).
b) Abbreviations for roots after Belay Tegene (1997): vfq-very frequent; fq- frequent; cm-common; fw-few; vf- very few; f-fine; md- medium.

Gilgai topography is a conspicuous feature of the Vertisols on the uncultivated area and grassland. The formation of gilgai topography is the result of the movement of clay from the high pressure to the low-pressure sites. The movements of clay are due to the variation in density which are caused by repeated cycles of drying and wetting (Challa, 1993).

Vertisols are characterized by heavy texture. The average clay content of a solum is 56%. The range of the clay of the surface soil is 53 to 51% and at the subsurface 69 to 51%. The average silt-clay ratio of the soil is 0.56. The range of the ratio for top soil is 0.60–0.67%, and for subsoil from 0.29 to 0.67%. This low ratio suggests the more intensive weathering of the soils compared to the other soil units in the area.

Chemical and biochemical characteristics

The chemical and biochemical characteristics of Vertisols are given in Tables 2 and 3. The soil is characterized by medium pH value (the average for the solum is 6.59). The average organic carbon and total N of the solum are 1.64 and 0.14, respectively. As expected, they decline in depth in all the profiles, although there is variation in the content as well as in the rate of change among the profiles. Broadly, the low organic carbon in the soil is mainly due to the advanced rate of decomposition and humification of the organic matter as observed in the carbon nitrogen ratio (C/N).

Table 2. Particle size distribution, pH, organic matter, total nitrogen and available phosphorus for Eutric Vertisol.

Depth (cm)	Texture %			Silt: Clay ratio	pH H_2O 1:2.5	Org Mat (%)	Org. C	Total N (%)	C/N	Avail P mg(kg) $^{-1}$
	Sand	Silt	Clay							
Profile TI-2										
0- 18	15	34	51	0.67	6.08	3.20	1.86	0.18	10	5.60
18- 45	11	22	67	0.33	6.40	2.24	1.30	0.14	9	4.12
45-200	11	20	69	0.29	6.63	1.72	0.99	0.10	10	0.96
Profile TIII-2										
0- 8	15	34	51	0.67	6.29	4.82	2.79	0.18	16	7.70
8- 25	15	28	57	0.49	6.14	1.89	1.09	0.13	9	2.88
25- 43	15	34	51	0.67	6.23	1.35	0.76	0.08	9	2.94
43-160	11	24	65	0.36	6.68	0.58	0.34	0.04	11	1.26
Profile TVI-1										
0- 18	15	32	53	0.60	6.90	0.86	0.49	0.17	3	21.76
18-73	19	30	51	0.59	7.41	0.52	0.29	0.06	5	2.26
73-160	13	34	53	0.64	7.38	0.34	0.20	0.10	2	1.44

Table 3. Cation exchange capacity exchangeable basic cations and percentage base saturation for Eutric Vertisol.

Profile	Depth (cm)	CEC* [cmol (+)/kg]		Exchangeable cations [cmol (+)/kg soil]				BS** (%)	EPP***	Ca:Mg ratio
		Soil	Clay	Na	K	Ca	Mg			
Profile TI-2	0- 18	64.9	114	0.35	0.47	29.4	6.5	57	0.72	4.53
	18- 45	63.5	88	0.58	0.52	35.4	7.1	69	0.82	5.00
	45-200	61.5	84	0.97	0.54	39.4	6.6	77	0.88	5.99
Profile TIII-2	0- 8	49.6	78	0.39	0.67	37.4	14.9	108	1.35	5.03
	8- 25	52.0	85	0.70	0.52	31.4	12.3	87	1.00	4.91
	25- 43	57.8	108	0.54	0.53	35.4	12.9	86	0.92	5.27
	43-160	51.8	78	0.93	0.69	37.9	13.6	103	1.33	5.86
Profile TVI-1	0-18	54.0	99	0.84	1.18	37.4	18.2	107	2.20	2.61
	18-73	54.0	104	1.15	0.70	43.4	17.2	116	1.30	2.48
	73-160	51.8	96	1.13	0.83	36.9	15.8	106	1.60	2.52

*CEC, Cation exchangeable capacity; ** BS(%), percentage base saturation; ***EPP, Exchangeable potassium perçentage.

Furthermore, the high intensity of cultivation and degradation of carbon also contributes to the low organic matter content of the soil. The low organic matter in the soil is also the principal feature of Vertisols in Ethiopia (Berhanu Debelle, 1985).

The low available phosphorus in the soil (average of the soil is 6.96 mg$(kg)^{-1}$) is consistent with the level of phosphorus of Vertisols reported in Ethiopia (Berhanu Debelle, 1985) and registered also in others studies (Weigel, 1986 and Belay Tegene, 1996). The probable reasons of the low levels of available phosphorus in many tropical soils are the effects of the combination of the large proportion of inorganic phosphorus with soluble Al and Fe.

The soil is also marked by the deficiency of potassium, as indicated by exchangeable potassium percentage (EPP) values which are less than 2% (Landon, 1991). This results from the fixation of potassium which is correlated with the clay content of the soil, the highest in Vertisols (Tekalign Mamo, 1988).

The soil is naturally fertile as shown by the high cation exchangeable capacity (CEC) and base saturation. In the exchangeable cations, Ca is dominant accounting for 72.4 % of the total basic. The large presence of soluble Ca causes the total exchangeable bases to exceed the cation exchangeable capacity of the soils. Generally, the high cation exchangeable capacity of soils is due to the large clay content and the predominance of montomorillonite clay minerals.

Basis of classification

The soil discussed above showed high percentage base saturation (above 50%) as well as high clay content (above 50%) throughout all the horizons. It is also marked by cracks 1.5–3 cm wide reaching a depth of 61 cm. The slickensides were also typical of the subsurface soils. The gilgai microrelief was also a conspicuous feature of the soils, particularly on uncultivated and grasslands. These properties qualify the soils for Vertisols of the FAO/UNESCO (1990).

Potential and constraints

Vertisols are the most important agricultural soils in Werkaryia area. The morphological, physical and chemical characteristics bear favourable effects on the use of soils for cultivating different types of crops. One of the important features of Vertisols is low slope gradient (level to gently slopping) and its deep solum. The high cation exchangeable capacity also allows the soils to retain added nutrients as well as those released from the parent materials.

However, the most serious problem with the Vertisols is its poor drainage. The heavy texture and expanded clay of Vertisols result in low infiltration capacity and lead to waterlogging problem (Asnake Woldeab, 1987). Thus plants cannot grow on this soil, with the exception of water-tolerant crops. However, the yields of these crops are low. The other problems associated with excessive moisture and stress are the crack formation and wet consistency. These impose difficulty on traditional ploughing when the soil is dry. The soil is also sticky to plough when wet.

The nutrient limitation of Vertisols, particularly the low available phosphorus and nitrogen due to degradation of organic matter and denitrification processes under anaerobic condition, is the second problem of Vertisols. The organic matter of Vertisols is also affected by erosion losses especially when they occur on slopes. Vertisols can be severely eroded even on slope gradients of as low as one per cent (Young, 1978). The low organic matter also affects the structure of the soil. The structure of the soil influences a number of other properties and processes.

There is also significant disproportion among the exchangeable basic cations in Vertisols. One of the most serious imbalances is observed in the exchangeable potassium percentage (EPP). In almost all of the Eutric Vertisols, the exchangeable potassium percentage (EPP) is less than 2 per cent, suggesting that these soils have serious deficiency of potassium. The other imbalance arise from the low Ca/Mg ratio (mostly less than 3 and above 5). The optimum range of Ca/Mg ratio for most crops is from 3 to 4 (Landon, 1991).

Haplic Phaeozems and Luvic Phaeozems

Phaeozems in Werkaryia are the most important soils for cultivation, (covering about 18% of the total area). Phaeozems occur on upper footslope/ lower backslope, on terraces as well as on the upper backslope, with slopes ranging from slopping to steeply dissected (12–44%). In the upper backslope it occurs in association with Leptosols. The parent materials vary following the landscape positions. On the upper slopes the soils are derived from residual while the lower part are derived from colluvial parent materials.

The land use of soils also varies according to the landscape position. The soils on the upper backslope are covered by trees and grasses while those on the foot slopes are under intensive crop cultivation. The cultivated soil surface is covered by many rock fragments (up to 36%) and is marked by deep solum (reaching up to 200 cm).

Morphological and physical characteristics

The abbreviated morphological and physical characteristics are presented in Table 4. The Ap/Ah horizon of Phaeozems with depth of 0–10/35 cm are characterized by dark brown (7.5 YR 3/2), very dark grey (10YR 3/1), and dark brown (10YR 3/3) colours. The structure is strong fine medium to course sub-angular blocky. The wet consistency of the soil is non sticky to sticky and non-plastic to plastic. The common feature in most of the soils was that these horizons were underlain by a cambic B-horizon. In most cases the cambic B-horizons are found overlaying buried B horizons.

However, the Ah horizon of transect II profile 2 (TII-2) is underlain by the argic B (Bt), which is characterized by higher clay content and exceeds the overlain Ah horizons by 17%. It is also marked by very sticky and very plastic wet consistency.

The proportion of the clay at the surface ranged from 19–47%, while in the B-horizon it ranged from 21 to 61%. The average silt-clay ratio of the surface soil is 1.32. This value indicates the presence of a good proportion of weatherable materials in the soils. Moreover, the subsurface of the soils is also marked by considerable amounts of gravels and rock fragments.

Chemical and biochemical characteristics

The chemical and biochemical characteristics are presented in Tables 5 and 6. The pH value of the surface soil varies from 6.2–6.8 and there is rare change in depth. The organic carbon content of the surface soil ranges from 3.63 to 0.68 per cent. The C/N ratio is from 15 to 7, which suggests a lower degree of humificaiton and deficiency of N. The general low organic matter and total nitrogen of a soil in northern highlands of Ethiopia are due to the long time of practice of traditional cultivation, without replenishing the organic carbon fracture by leaving residues, harvests or manuring, and the consequent result of intense degradation of soil (Belay Tegene, 1996).

The average available P in the Phaeozems is 14.2 mg(kg)$^{-1}$. However, there is a wide variation of available P ranging from 87 to 4.2 at the surface and from 45 to 2 in the subsurface horizons. In general the medium level of available P suggests some response of the soils to P fertilizer.

Table 4*. Selected morphological and physical characteristic of Haplic and Luvic Phaeozems.

Depth (cm)	Horizon	Colour (moist)	Texture class	Structure	Consistence	Boundary	Plant roots
Profile TI-3; Haplic Phaeozem; Slope 18%							
0-18	Ap	10YR3/1	c	3-csbk	ws,wp	cs	fwf
18-60	A2	10YR3/2	c	3-csbk	wss,wsp	cs	vff
60-115	Bb	10YR3/1	c	3-csbk	ws,wp	-	-
Profile TII-2; Luvic Phaeozem; Slope 17%							
0-15	Ap	10YR3/2	cl	3-csbk	wss,wsp	cs	fwf
15-67	A2	10YR3/1	cl(g)	3-csbk	wvs,wvp	cs	vff
67-100	Bt1	10YR3/2	c	3-csbk	wvs,wvp	ds	-
100-145	Bt2	10YR3/2	c	3-vcsbk	ws,wp	cs	-
>145	C						
Profile TII-3; Haplic Phaeozem; Slope 37%							
0-15	Ap	7.5YR3/2	l(vg)	3-csbk	wso,wpo	cs	fwf&md
15-60	A2	7.5YR3/2	l(vg)	3-csbk	wso,wpo	cs	
>60	R						
Profile TIII3; Haplic Phaeozem; Slope 26%							
0-18	Ah	10YR3/2	c(g)	3-csbk	wss,wsp	cs	fwf&md
18-57	A2	10YR3/1	c	3-msbk	ws,wp	cs	-
57-90	Bw	10YR2/1	c	3-csbk	wss,wsp	cw	-
90-100	Bb1	10YR3/1	c	3-csbk	ws,wp	cw	Cmf
100-200	Bb2	10YR3/1	c	3-msbk	wss,wsp	-	Fwf
Profile TIV-1; Haplic Phaeozem; Slope 16%							
0-10	Ah	10YR3/3	l(g)	3-csbk	wss,wsp	cs	fqf,cmmd
10-43	Bw1	10YR3/2	cl(sg)	3-msbk	wss,wsp	cs	fwf&md
43-75	Bw2	10YR3/2	cl(sg)	3-msbk	ws,wp	cs	-
75-150	Bb1	10YR3/2	c	3-vcsbk	ws,wp	-	
Profile TIV-2;Haplic Phaeozem; Slope 37%							
0-25	Ah	10YR3/2	l(vg)	3-fsbk	wss,wsp	cw	cmf,fwmd
25-37	AC	10YR3/2	cl(g)	3-fsbk	wss,wpo	cw	-
>37	C	10YR3/2					
Profile TV-2; Haplic Phaeozem; Slope 70%							
0-35	Ah	7.5YR3/3	cl(vg)	3-msbk	wss,wsp	cs	fqf,vfmd
35-80	A2	7.5YR3/2	cl(g)	3-csbk	wss,wsp	cs	vff,fwmd
>80	CR	7.5YR7/1					
Profile TV-3; Haplic Phaeozem; Slope 44%							
0-13	Ah	7.5YR3/2	l(vg)	3-msbk	wso,wpo	cs	vff
13-68	Bw1	7.5YR3/3	l(vg)	3-csbk	wso,wpo	cs	fwf
68-140	Bw2	7.5YR3/2	l(g)	3-csbk	wss,wsp	cs	Vff
>140	R	10YR7/6					

Source: AOK (1996).
*Abbreviations for profile and root descriptions are as for Table 1.

The cation exchangeable capacity value of the surface soil ranges from 45.0 to 62.8 (90 to 238 cmol(+)/kg clay) and the subsurface soil from 46.2 to 66.2 (80 to 221 cmol(+)/kg clay). These high cation exchangeable capacity values might have been caused by the presence of considerable amount of high exchange capacity clay such as montomorillonite and allophane in the fine earth fraction. The high base saturation reflects the large amount of weatherable minerals in the soils. The principal exchangeable cation is Ca, followed by Mg. The ratio of Ca to Mg in most cases was below 3, which indicates an imbalance of Ca and Mg.

Table 5. Particle size distribution, pH, organic matter, total nitrogen and available phosphorus for Haplic and Luvic Phaeozems.

Horizon	Depth (cm)	Texture (%)			Silt: Clay ratio	pH H_2O 1:2.5	Org Mat (%)	Org. C (%)	Total N(%)	C/N	Avail P mg (kg)-1
		Sand	Silt	Clay							
Profile TI-3	0-18	19	34	47	0.72	6.80	2.89	1.68	0.18	9	87.02
	16-60	21	30	49	0.61	6.48	2.06	1.19	0.15	8	33.04
	60-115	17	22	61	0.36	6.69	1.27	0.74	0.11	7	44.92
Profile TII-2	0-15	25	42	33	1.27	6.08	2.82	1.64	0.11	15	17.00
	15-67	29	36	35	1.03	6.40	1.58	0.91	0.09	9	5.28
	67-100	25	34	41	0.83	6.63	0.89	0.52	0.06	9	3.48
	100-145	25	34	41	0.83	6.80	0.89	0.52	0.06	9	8.98
Profile TII-3	0-15	35	38	27	1.41	6.48	4.02	2.33	0.18	13	5.18
	15-60	35	38	27	1.41	6.69	2.34	1.36	0.17	8	7.06
Profile TIII-3	0-16/18	19	34	47	0.72	6.52	1.99	1.16	0.14	8	20.05
	16/18-57	23	32	45	0.71	6.29	1.65	0.96	0.11	9	25.30
	57-80/90	31	28	41	0.68	6.64	2.19	1.22	0.14	9	18.84
	80/90-100	27	28	45	0.62	7.46	2.44	1.42	0.15	9	15.08
	100-200	27	28	45	0.62	7.66	2.34	1.36	0.16	10	5.20
Profile TIV-1	0-10	34	43	23	1.87	6.43	2.30	1.34	0.14	10	5.20
	10-43	31	32	37	0.86	6.93	1.69	0.98	0.11	9	2.76
	43-75	27	34	39	0.87	7.06	1.69	0.98	0.11	9	1.65
	75-150	27	30	43	0.70	6.81	1.41	0.82	0.08	10	2.56
Profile TIV-2	0-20/25	41	34	25	1.36	6.21	1.16	0.68	0.29	2	7.22
	20/25-37	43	26	31	0.84	5.95	6.54	3.79	0.21	8	1.94
Profile TV-2b	0-35	33	44	23	1.91	6.44	6.26	3.63	0.39	9	4.20
	35-80	29	42	29	1.45	6.80	4.29	2.49	0.31	8	2.82
Profile TV-3	0-13	49	32	19	1.68	6.75	2.54	1.48	0.18	8	18.64
	13-68	49	30	21	1.43	6.65	2.24	1.29	0.11	12	9.36
	68-140	45	30	25	1.20	7.14	1.44	0.84	0.11	7	2.52

Basis of classification

The A horizons are generally marked by Mollic A, although some of the soils have already lost their Mollic A due to accelerated erosion. The surface horizons of the TII-2 was underlain by the argic B (Bt), while the Mollic A of the rest soils overlay the cambic B horizon (Bw). These diagnostic horizons with the physical and chemical characteristics described above qualify the soils for Luvic Phaeozem in the case of transect II Profile 2 and Haplic Phaeozem for the remaining soils of FAO/UNESCO (1990) classification systems.

Table 6*. Cation exchange capacity, basic cations and percentage base saturation for Haplic and Luvic Phaeozems.

	Depth (cm)	CEC CMOL(+)KG		Exchangeable basic cations Cmol(+)kg soil				BS (%)	EPP	Ca:Mg ratio
		Soil	Clay	Na	K	Ca	Mg			
Profile TI-3	0-18	48.0	89.8	0.89	3.47	21.5	4.0	62	7.23	5.4
	16-60	50.0	93.6	0.74	1.36	19.5	4.5	52	2.72	4.3
	60-115	51.4	80.0	1.05	0.81	24.0	5.7	61	1.57	3.1
Profile TII-2	0-15	58.9	161.0	0.35	0.45	32.9	6.6	68	0.76	4.9
	15-67	64.7	175.0	0.35	0.32	38.4	8.0	73	0.49	4.8
	67-100	52.4	123.0	0.43	0.27	31.4	6.0	73	0.52	5.2
	100-145	47.2	111.0	0.31	0.30	42.4	16.9	127	0.63	2.5
Profile TII-3	0-15	45.0	137.0	0.24	0.73	38.9	12.6	117	1.62	8.1
	15-60	49.0	164.0	0.24	0.30	40.9	15.3	116	0.61	5.2
Profile TIII-3	0-16/18	49.6	95.0	0.31	0.75	31.9	14.5	96	1.51	7.0
	16/18-57	51.4	114.8	0.39	0.64	35.9	16.6	104	1.25	3.8
	57-80/90	52.4	117.0	0.70	0.57	35.4	16.6	102	1.09	3.8
	80/90-100	59.6	123.4	0.54	0.69	34.9	16.3	88	1.16	3.8
	100-200	58.0	118.5	0.93	0.72	36.9	17.7	97	1.24	3.1
Profile TIV-1	0-10	54.8	218.0	0.55	0.28	26.5	19.0	84	0.51	2.3
	10-43	51.4	130.0	0.31	0.27	26.0	14.3	79	0.52	2.7
	43-75	53.0	127.0	0.39	0.29	30.9	16.7	91	0.55	2.7
	75-150	50.0	110.0	0.62	0.28	31.9	17.3	100	0.56	3.1
	0-20/25	61.5	238.0	0.47	0.48	37.9	18.2	92	0.61	2.1
	20/25-37	66.2	171.0	0.47	0.25	40.9	21.1	95	0.38	1.9
Profile TV-2b	0-35	62.8	219.0	0.55	0.38	46.4	14.2	98	0.60	7.9
	35-80	59.0	174.0	0.23	0.30	43.9	14.7	100	0.51	3.9
Profile TV-3	0-13	46.2	216.0	0.46	0.55	34.4	14.3	108	1.19	2.8
	13-68	50.8	221.0	0.46	0.73	31.9	12.8	90	1.44	2.8
	68-140	49.0	184.0	0.39	0.33	31.4	11.8	90	0.67	2.8

*Abbreviations are as for Table 3.

Potential and constraints

The cultivated Haplic and Luvic Phaeozems are considered as the most valuable soils in the area. The loam to clay loam texture, the excellent structure and the relatively deep soil profile provide favourable condition for plant growth. These properties allow free drainage, proper aeration, ready infiltration of water and high available water holding capacity. The large amounts of weatherable minerals serve as store houses from which the soils draw plant nutrients and replace those lost through leaching. The soils are also characterized by high nutrient retention and base saturation. Moreover, they are also marked by moderately high available phosphorus and medium pH. Thus the soils are ideal for plant growth. However, the favourable characteristics of Phaeozems for crop cultivation is influenced by the low organic matter, total nitrogen, imbalances of nutrients and deficiency of potassium.

Mollic Gleysols

In Werkaryia area Mollic Gleysols are developed on the alluvium toeslope, with the slope ranging from very gently sloping to gently sloping and account for 9.2% of the total area. The relative lower altitude and lower slope position are attributed to the poor drainage of the soil. As a result, most parts occupied by Gleysols are semi-permanently flooded and some other parts become permanently waterlogged (marshy area). Although the Gleysol area was in the past exclusively left for grazing, at present it is used for cultivation.

Morphological and physical characteristics

The salient morphological and physical features of the soils are presented in Tables 7 and 8. The soil matrix colour varies from very dark greyish brown (10YR3/2) to very dark grey (10 YR 3/1) with the presence of prominent mottles. This suggests the gleyic and stagnic condition of the area and indicates prolonged period of anaerobism. The gleyic condition is due to the lower end of the slope position where water table comes near to the surface. The soil is marked by strong coarse subangular blocky structure and slightly sticky to sticky, slightly plastic to plastic consistence. There are common fine roots at the surface layer which are typical to Gleysol and indicates the presence of water loving grasses.

The surface texture of the soil is loam, and there is a gradual increase of clay at the lower subsurface which is probably due to the impact of the buried soil. The silt-clay ratio of the soil varies from 1.37 to 0.73. The low silt-clay ratio in general justifies the high rate of weathering of the soil.

Table 7.* Selected morphological and physical characteristics of Mollic Gleysol.

Depth (cm)	Horizon	Colour (moist)	Mottle	Texture class	Structure	Consistence	Boundary	Plant roots
Profile TIII-1; Slope <1%								
0- 35	Ahg	10YR3/2	5YR5/6	sicl	3-csbk	ws,wp	cs	cmf
15- 67	Bg1	10YR3/1	5YR4/4	sicl	3-csbk	wss,wsp	cs	fwf&md
67- 116	Bg2	10YR3/1	2.5YR3/6	sicl	3-csbk	wss,wsp	cs	vff,fwmd
116- 150	Bb1	10YR2/1	10YR2/1	c	3-msbk	ws,wp	-	-
>150 Bb1 horizon continues below 150 cm								

Source: AOK (1996).
* Abbreviations for profile and root descriptions are as for Table 1.

Chemical and biochemical characteristics

The chemical and biochemical characteristics are presented in Tables 8 and 9. The pH of the soil ranges from 6.45 to 6.89 and the organic carbon of the soil ranges from 0.76 to 1.64. As expected organic carbon generally decreases with depth.

A good chemical condition of a soil is manifested in the available phosphorus, cation exchangeable capacity, and base saturation. The available P of the soil ranges from 16-6.4 $mg(kg)^{-1}$. The CEC of surface soil is 55.00 cmol (+)/kg soil and CEC of clay is 141 cmol (+)/kg soil. The percentage base saturation of surface soil is 121 per cent, with slight non-uniformity trend in depth.

Exchangeable Ca is the dominant cation constituting the largest share of the bases, which account for 69.7 %, followed by Mg, 27.6%. The ratio of Ca and Mg of the soil is 2.85-2.19. The exchangeable potassium percent of the soil varies from 0.67-1.32, which suggests very severe deficiency of potassium in the soil (Landon, 1991:126).

Table 8. Particle size distribution, pH, organic matter, total nitrogen and available phosphorus for Mollic Gleysol.

Depth (cm)	Texture (%)			Sand:clay ratio	Silt:clay ratio	pH H_2O 1:2.5	Org. Mat (%)	Organic C (%)	Total N (%)	C/N	Avail P mg $(kg)^{-1}$
	Clay	Sand	Silt								
ProfileTIII-1											
0- 35	17	48	35	0.350	1.37	6.45	2.82	1.64	0.18	9	16.04
35- 65	13	54	33	0.240	1.64	6.68	2.06	1.20	0.14	9	14.96
67–116	15	40	45	0.375	0.89	6.82	1.82	1.06	0.10	7	23.7
116- 150	15	36	49	0.417	0.73	6.89	1.31	0.76	0.11	7	18.16

Table 9*. Cation exchange capacity, exchangeable basic cation and percentage base saturation for Mollic Gleysol.

Depth (cm)	CEC cmol(+) kg^{-1}		Exchangeable Cations cmol(+)/kg soil				BS (%)	EPP	Ca:Mg ratio
	Soil	Clay	Na	K	Ca	Mg			
Profile TIII-1									
0- 35	55.0	141	0.70	0.37	47.9	17.74	121	0.67	2.70
35- 65	54.6	153	0.70	0.35	53.39	18.74	134	0.64	2.85
67- 116	52.4	108	0.77	0.52	37.43	17.08	106	0.99	2.19
116- 150	46.8	90	0.70	0.62	34.43	15.16	109	1.32	2.27

*Abbreviation are as for Table 3.

Basis of classification

The gleyic and stagnic properties of the soil, which prevail within 50 cm, are manifested in the distinct prominent mottles and the saturation of most of the subsurface soils. Furthermore, the soil has developed neither on stratified materials nor on course texture (fluvic deposition) since no lithological discontinuities were observed as shown by sand and silt ratio value. The difference of 0.2 or more in the values of sand and silt ratio between two adjacent horizons is an index of the lithological discontinuities (Sidhy *et al.*, 1976 cited in Kaistha and Gupta, 1993). Moreover, the soil is marked by mollic A horizon. Thus the soil is in line with the FAO/UNESCO (1990) qualifying criteria of Mollic Gleysol.

Potential and constraints

The high nutrient availability and the nutrient retention capacity of the soil show the good agricultural productivity of Gleysols. Moreover, the flat position in which the soil mantled would promote the application of mechanized agriculture. However, the crop productivity of the soil is limited by the high water table condition, which hinders the growth of roots. Generally, owing to the above problem, the area is largely left for grazing. Especially in drought situations, these lands are very important grounds of grazing.

Mollic Fluvisols

Fluvisols in Werkaryia area occur on slopes ranging from very gentle to gently sloping. The parent material of the soil is alluvial deposit. Fluvisols have thus their origin in alluvial rather than in pedogenic processes. The soils are marked by deep solum but due to flooding and drainage problems they are used for grazing.

Morphological and physical characteristics

The morphological and physical properties are presented in Tables 10 and 11. The value of the difference of the ratio of sand and silt of the adjacent horizons of the Fluvisol is above 0.2, which suggests the development of soils on stratified parent materials. As a result of lithological breaks, the morphological, physical, biochemical and chemical characteristics of soils have not shown definite trends in depth of the profile (Tables 10, 11 and 12).

The commonest feature of the soils is dark colour with hues of 10YR and chromas of equal to or below 3. The soils are also marked by the presence of mottles, which indicate the characteristics associated with high water table (gleyic and stagnic conditions of the soils). The soils exhibit moderately to strong, medium to course blocky structure and slightly sticky to slightly plastic consistence. In general the texture of the soil is loam at the surface and clay content increases at the sub-surface.

Table 10*. Selected morphological and physical characteristics.

Depth (cm)	Horizon	Colour (moist)	Mottle	Texture class	Structure	Consistence	Boundary	Plant roots
Profile TI-1; Mollic Fluvisols; Slope 2%								
0-12	Ah	10YR3/2	5YR5/6	l	2-msbk	wss,wsp	cs	vfqf,fwmd
12-40	1Bg	10YR3/1	2.5YR4/8	c	3-csbk	wss,wsp	cs	cmf
40-160	2Bg	10YR2/1	-	cl	2m&csbk	wss,wsp.	-	
>160	2Bg horizon continues below 160 cm							
Profile T2-1; Mollic Fluvisol; Slope 10%								
0-13	Ah	10YR3/2	2.5YR3/6	l	2-msbk	wss,wsp	cs	vfqf
13-50	1Bg	10YR3/2	-	sil	2-msbk	wso,wpo	cs	cmfi
50-100	2Bg	10YR2/1	-	c	2-msbk	ws,wp	-	
>100	2Bg horizon continues below 100 cm							

Source: AOK (1996).
* Abbreviation for profile and root descriptions are as for Table 1.

Table 11. Particle size distribution, pH, organic matter, total nitrogen and available phosphorus for Mollic Fluvisol.

Horizon	Depth (cm)	Texture (%) Sand	Silt	Clay	Sand:Silt ratio	Silt: Clay ratio	pH H_2O 1:.2.5	Org C (%)	Org.Mat (%)	Tot N (%)	C/N	Avail P mg(kg)$^{-1}$
Profile TI-1												
TI-1	0-12	37	40	23	0.925	1.74	5.09	11.56	6.70	0.53	13	8.76
TI-1	12-40	23	36	41	0.639	0.88	6.18	5.54	3.21	0.46	7	5.38
TI-1	40-60	41	30	29	1.360	1.03	4.97	10.11	5.87	0.56	10	17.56
Profile TII-1												
TII-1	0-13	35	38	27	0.920	1.41	5.09	9.56	5.55	0.45	12	14.04
TII-1	13-50	57	24	19	2.370	1.26	6.18	21.19	12.29	1.21	10	12.20
TII-1	50-100	35	34	31	1.030	1.10	4.97	6.43	1.64	0.50	7	10.60

Chemical and biochemical characteristics

The chemical and biochemical characteristics of Fluvisols are presented in Tables 11 and 12. Likewise the morphological and physical properties; the characteristics of the chemical and biochemical also hardly show definite trends in depth. In general, the soil is marked by a good chemical condition as reflected in the high values of organic matter, available phosphorus, cation exchange capacity and base saturation. On the other hand, the pH of the surface and the lower part of the subsurface of the soil are characterized by strongly acid reactions (pH <5.5). The exchangeable potassium percent of the soil is also ranges from 0.72–0.3, which suggests the deficiency of this element. The range of the ratio of Ca to Mg is wider (3.58–6.78). The lower value of Mg is the common feature of those soils receiving drainage, for Mg is released by hydrolysis and transported in solution (Fitzpatrick, 1978).

Table 12*. Cation exchange capacity, exchangeable basic cations and percentage base saturation for Mollic Fluvisol.

Horizon	Depth (cm)	CEC cmol (+) kg		Exchangeable cations cmol(+)kg soil				BS (%)	EPP	Ca:Mg ratio
		Soil	Clay	Na	K	Ca	Mg			
Profile TI-1										
	0–12	67.28	193	0.74	0.24	25.95	3.83	46	0.36	6.78
	12–40	60.68	122	0.50	0.25	23.94	4.83	52	0.41	6.78
	40–60	61.88	144	0.58	0.32	20.96	4.50	43	0.52	4.07
Profile TII-1										
	0–13	62.08	159	1.20	0.45	30.94	9.16	67	0.72	3.40
	13–50	71.96	156	0.58	0.22	32.44	4.06	52	0.31	8.00
	50–100	60.48	154	0.50	0.25	27.94	4.00	52	0.31	8.00

Abbreviations are as for Table 3.

Basis of classification

The soils are marked by irregular trends in the characteristics of texture, organic matter, total nitrogen, cation exchange capacity and base saturation with depth. This is due to stratification of the soil as indicated by the ratio of sand:silt, which suggests fluvic properties. Moreover, all the soils are marked by mollic A horizon. These characteristics of the soil thus satisfy the criteria set by FAO/UNESCO (1990) for Mollic Fluvisol.

Potential and constraints

The deep solum, the high organic matter, cation exchangeable capacity, base saturation and available phosphorus could be very conducive for plant growth, if the soil is cultivated. However, the problem of flood and imperfect drainage due to the flat land position and the high water table, impede cultivation of crops.

Eutric, Lithic and Mollic Leptosols

In the study area Leptosols comprise about 47.8% of the total area. Leptosols mantle the ridge crests and upper and lower backslope. In most cases, except the very steep backslope slope in which the soils have formed naturally, Leptosols are the result of accelerated erosion caused by deforestation, overgrazing, cattle tracks and unwise cultivation (ploughing up and down slope, intensive tillage practices, absence of soil conservation measures). The parent materials of these soil units were of residual and colluvial materials on slopes that range from gently sloping to steep. The uses of these soils widely vary and include forestry, grazing and cultivation. The special features of the soils are the shallow depth and the C, Cr, R horizons sequences. In some upper backslope positions Leptosols occur in association with Phaeozems.

Morphological and physical characteristics

The morphological, physical and chemical properties of Leptosols vary significantly (Tables 13, 14 and 15). The depth of the fine earth fraction of Leptosols is equal to or below 30 cm. In some part, the depth is limited to 10 cm. In all cases the Ap/Ah horizons are underlain by the C, Cr, R. Mostly, these horizons are separated by wavy boundary.

The colour of the soils varies significantly. The soils are marked by very dark grey (10YR 3/1), dark greyish brown (10 YR 3/2), and dark brown (10YR 3/3), 7.5 YR 3/2, and 7.5 YR 3/3) colours. The structures are strong and moderate fine and medium sub-angular blocky. The soils are non- sticky, non-plastic to slightly sticky and slightly plastic.

The texture of the soils is gravelly loam, the gravel content in some case reaches 30%. The average clay content in the AP/Ah horizons of the soils is 22.5. The silt/ clay ratio, which ranges from 1.03 to 2.00 and the considerable gravel content of the soil are indicative of the less weathered state of the soil. This may be because the present soil is dominantly composed of the AC horizons of previous soils that have been severely eroded.

Chemical and biochemical characteristics

The soils have a pH of 7.43 to 5.79 with a mean of 6.7. The mean value of the organic carbon of the Leptosol is 2.1 with the range of 0.78–6.3%. The average ratio of C to N is 10, which shows the high humification of the organic matter. The organic matter content of the soil (range of 10.9–1.3) is consistent with those observed in the Wurgo catchment (Belay Tegene, 1995). The high organic matter of the soil is ascribed to the vegetation cover, the addition of manure to the soil by people on the crest and also the dung of the livestock in the grazing area.

Available P is marked by the very wide range, 0.66–61.26 $mg(kg)^{-1}$ in the soil. The cation exchangeable capacity of the soil is 50.8– 66.2 cmol (+)kg soil and the base saturation is from 54 to 114%. The high value of the cation exchangeable capacity is in accordance with the trachyte parent materials. It is also in consistency with the Andosols of the Tib mountains, which has developed on the trachyte tuff (Belay Tegene, 1995).

Calcium is the dominant exchangeable cation (73.2% of the total) followed by Mg (24.4%). Unlike the other soil units, serious imbalances are not observed among exchangeable cations.

Table 13 * Selected morphological and physical characteristics of Mollic, Lithic and Eutric Leptosols.

Depth (cm)	Horizon	Colour (moist)	Texture	Structure	Consistence	Boundary	Plant roots
Profile TI-4; Mollic Leptosol; Slope 21%							
0- 11	Ah	10YR3/2	cl(vg)	2-msbk	wso,wsp	Cs	fwf
>11	C						
Profile TII-4; Lithic Leptosol; Slope 50%							
0- 5/12	Ah	7.5YR3/2	l(vg)	2-fsbk	wss,wpo	Cs	fwf
>5/12	C						
Profile TII-5; Mollic Leptosol; Slope 18%							
0- 25	Ah	10YR3/2	l(g)	2-fsbk	wss,wpo	Cs	fwf
>25	R						
Profile TIII-4; Mollic Leptosol; Slope 35%							
0- 24	Ah	10YR3/2	l(g)	3-msbk	ws,wp	Cs	fwm
>24	R						
Profile TIII-5; Eutric Leptosol; Slope 11%							
0- 15	Ap	10YR3/3	cl(g)	3-msbk	wss,wsp	Cs	Fwf
>15	C						
Profile TIV-3; Mollic Leptosol; Slope 15%							
0- 20	Ah	10YR3/1	s(vg)	2-fsbk	wss,wsp	Cw	Cmf
>20	C						
Profile TV-1; Mollic Leptosol; Slope 10%							
0- 20	Ah	10YR3/2	sl(g)	2-msbk	wso,wpo	Cs	Cmf
>20	C						
Profile TV-2a; Mollic Leptosol; Slope 70%							
0- 20/30	Ah	7.5YR3/3	cl(g)	3-msbk	wss,wsp	Cw	Fqf
>20/30	CR						
Profile TVI-2; Mollic Leptosol; Slope 62%							
0- 13	Ah	7.5YR3/2	sl(vg)	2-fsbk	wso,wpo	Cs	Cmf
13- 43	CA1	7.5YR3/2	sl(vg)	2-fsbk	wso,wpo	Cs	Cmf
43- 97	CA2	2.5YR3/2	l	-	-	Cs	-
97- 120	Bb	10YR3/2	l(g)	2-msbk	wss,wsp		Fwf

Source: AOK (1996).
* Abbreviations for profile and roots descriptions as of Table 1.

Basis of classification

The described soils are characterized by depths limited by hard rock within 30 cm. The soils are less developed, as these have no horizons other than a mollic or ochric A horizon and therefore key out as Leptosol of the FAO/UNESCO (1990) classification system.

Furthermore, three subunits of Leptosols are distinguished based on depth and colour. Those soils with depths limited to 10 cm are grouped in Lithic Leptosols. The soils with depths of above 10 cm and that show ochric A horizon are classified as Eutric Leptosol and while those that show mollic A, qualify for Mollic Leptosol.

Table 14. Particle size distribution, pH, Organic matter, total nitrogen and available phosphorus for Leptosols.

Horizon	Depth (cm)	Texture(%) Sand	Silt	Clay	Silt: Clay ratio	pH (H_2O) 1:2.5	Org Mat (%)	Org. C (%)	Tot N (%)	C/N	Avail. P mg(kg)-1
Profile TI-4	0–11	35	34	31	1.10	6.51	5.74	3.33	0.32	10	3.84
Profile TII-4	0–5/12	37	40	23	1.74	6.51	3.99	2.31	0.18	13	3.18
Profile TII-5	0–25	39	40	21	1.90	7.06	2.34	1.36	0.13	11	6.36
Profile TIII-4	0–24	45	30	25	1.20	6.91	5.33	1.36	0.22	14	61.26
Profile TIII-5	0–15	29	36	35	1.03	6.56	2.48	1.44	0.16	9	3.56
Profile TIV-3	0–12/20	55	28	17	1.65	5.79	10.93	6.34	0.36	17	7.80
Profile TV-1	0–20	55	30	15	2.00	5.96	2.61	1.52	0.13	8	3.74
Profile TV-2a	0–30	29	42	29	1.45	6.72	4.33	2.51	0.25	10	1.22
Profile TVI-2	0–13	63	22	15	1.47	7.33	1.89	1.10	0.11	10	3.60
	13–43	67	18	15	1.20	6.99	1.34	0.78	0.108	7	0.66
	97–120	49	30	21	1.43	7.43	1.41	0.82	0.11	7	1.22

Table 15*. Cation exchange capacity, exchangeable basic cations and percentage base saturation for Leptosols.

Horizon	Depth (cm)	CEC cmol(+)/kg Soil	Clay	Exchangeable cations cmol(+)/kg soil Na	K	Ca	Mg	BS (%)	EPP	Ca:Mg ratio
Profile TI-4	0–11	50.8	127	0.35	0.86	22.46	3.58	54	1.69	6.27
Profile TII-4	0–5/12	54.6	203	0.16	0.33	32.44	16.99	91	0.60	3.52
Profile TII-5	0–25	65.8	291	0.16	0.33	38.42	16.58	84	0.51	4.19
Profile TIII-4	0–14/24	66.3	222	1.09	3.62	27.94	10.41	65	5.47	5.99
Profile TIII-5	0–15	54.8	142	0.55	0.61	23.45	5.83	56	1.11	4.02
Profile TIV-3	0–12/20	54.2	190	0.55	0.55	33.93	11.16	85	1.01	5.62
Profile TV-1	0–20	61.4	374	0.55	0.33	51.90	17.49	114	0.54	4.46
Profile TV-2a	0–20/30	62.4	185	0.47	0.30	48.90	13.66	101	0.48	6.39
Profile TVIT-2	0–13	58.2	363	0.46	0.33	46.91	13.83	106	0.57	3.38
	13–43	58.8	374	0.54	0.30	48.40	14.41	108	0.51	3.46
	97–120	57.4	260	0.69	0.25	45.41	15.74	108	0.44	3.10

* Abbreviation are as for Table 3.

Potential and constraints

Leptsols are marked by high cation exchangeable capacity and base saturation. This suggests the fertility of the soils and also indicates the capacity of the soils to retain the released as well as the added soil nutrients. Moreover, the high organic matter content supplies different nutrients and maintains the structure stability of the soils. The loam texture and the pH are also suitable for plant growth.

However, the steep slope and the shallow soil profile are generally detrimental to crop cultivation. The steep slope causes more run-off which erodes the soil. Oxen-ploughing on the steep slopes is also difficult and, thus people plough these soils by hand using hoe, which is time and labour consuming.

In addition, the shallowness of the soil causes loss of their relatively good chemical condition due to nutrient removal by crop and erosion within a few years of cultivation (Weigel, 1986). Furthermore, the very steep slope encourages erosion, and if cultivation continues, the soils would soon be reduced to barren rock outcrops. The capacity of water reserves of the soil is inhibited by the shallow soil depth. Thus, the little variation in amounts and patterns of rainfall affects the yields very significantly (Belay Tegene, 1995).

ACKNOWLEDGEMENTS

I am very grateful to Professor Belay Tegene, who inspired me to engage in this area of research and who gave me substantive advice and comments. I would also like to thank the anonymous reviewers of *SINET* for their constructive suggestions to the improvement of the manuscript. I am gratefully indebted to the Peasant Production and Development in Ethiopia, PPDE, for the financial assistance. Thanks are also due to Ato Dereje Tilahun for facilitating the soil lab analysis and Ato Birhanu Tefera for reading the manuscript.

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