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CHARACTERISTICS AND CLASSIFICATION OF THE SOILS OF GONDE MICRO-CATCHMENT, ARSI HIGHLANDS, ETHIOPIA

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ABSTRACT: Samples were collected from genetic horizons of representative soil profiles to study the morphological and physicochemical characteristics and to classify the soils of Gonde micro-catchment in Arsi highlands (Ethiopia) located at 70° 32′ 24″ to 70° 34′ 28″ N and 39° 13′ 15″ to 39° 19′ 02″ E. The study identified Humic Eutric Nitisols, Humic Epidystric Nitisols, Humic Orthidystric Nitisols, Humic Umbrisols and Grumic Mesotrophic Vertisols. Vertisols were found on flat slopes with imperfect drainage. Nitisols occupied the rolling and undulating slopes marked with reddish, very deep and well-drained soils. Umbrisols were distributed on the summit and shoulder positions of the landscape. Variability in soil characteristics largely depended on drainage, topography and land use patterns. Uncultivated Humic Umbrisols showed darker colour, soft consistence and lower bulk density values, whereas cultivated Nitisols had high bulk density values and reddish brown colours. The texture of surface horizons ranged from loam in Umbrisols to clay loam in Vertisols and Nitisols. Organic carbon was highest in Vertisols (6.35%) and ranged from 2.76–4.35% in Nitisols. Total nitrogen varied from 0.24–0.69% for the surface horizons. The highest CEC (49 Cmolc (+) / kg of soil) was recorded in A horizon of Umbrisols and the lowest (21 Cmolc (+) / kg of soil) in Humic-Epidystric Nitisols. The exchangeable K was in high range, while available P was low to medium ranging from 1.18–8.04 mg/kg for surface horizons. All studied soils were acidic (pH 5.1–5.6). In general, soils had low base saturation suggesting that the soils of the study area were more constrained by low fertility condition than physical properties alone.

Key words/phrases: **Arsi highlands, dystric, morphology, Nitisols, Umbrisols, Vertisols**

INTRODUCTION

The highlands of Arsi, with their favourable environmental conditions, are intensively cultivated and form one of the major cereal and pulse producing belts of Ethiopia. In these highlands, Murphy (1968) made an exploratory investigation on the soils' biochemical aspects. FAO/UNDP (1984) have also contributed to the knowledge of the soils of this area with a soil map at scale of 1:2 million. However these works can neither be easily correlated to local conditions nor have communication management value at farm/or micro-catchment level. As a result, decision makers and development workers usually give a blanket recommendation of agricultural technologies to increase crop productivity. This is irrespective of the presence of different types of soil-landscape relationships within micro-catchments that may require locally specific management methods. In fact, soil types and characteristics show great variation within a short distance in the Ethiopian highland micro-catchments (Ahmed Hussein, 2002; Mohammed Assen, *et al.*, 2005). Therefore, in increasing agricultural productivity and enhancing sustainable land management practices of Ethiopia differences in soil types must be considered.

Knowledge on the morphology, physical and chemical characteristics of the soils of the Gonde micro-catchment is vital to enhance sustainable crop productivity. Classification of soils is also useful to facilitate technology transfer and information exchange among soil scientists, decision makers, planners, researchers and agricultural extension advisors.

Thus, the present study was aimed at investigating the major morphological, physical and chemical characteristics and classifying the soils of Gonde micro-catchment, Arsi highlands of Ethiopia.

Description of the study area

Gonde micro-catchment is found at about 5 km north of Bekoji town on the Arsi highlands, southeast Ethiopia, just on top of the eastern margin of the Ethiopian rift valley, at about 255 km from Addis Ababa via Adama town. The macro-catchment is located between at 7° 32' 24'' – 7° 34' 28'' N and 39° 13' 15'' –39° 19' 02'' E. (Fig. 1)

The altitude ranges from 2600 to 3300 masl, with relative relief of 700 m. Gonde micro-catchment is a part of the Arsi-Bale plateau in general and the Chilalo–Galama massifs in particular. The study area occupies part of the western Galama mountain ridge. It shares certain common physical characteristics with Chilalo mountain range in the north and Kaka range in the south. Slope gradients range from 4 to over 50% and show an increasing pattern with rise in altitude. The mico-catchment exposes rocks of the Cenozoic era mostly formed during the Tertiary period as a result of the widespread volcanism induced by extensive fracturing and subsequent faulting (Mohr, 1971). Outpouring of lava along fissures covered a large part of Arsi highlands and created thick basaltic rocks of the trap series. The summit and shoulder slope segments of the volcanic mountains have also volcanic ash deposits of Quaternary period.

The area has a mean annual rainfall of about 1026 mm which increases with rise in altitude (Daniel Gemachu, 1977). The rainfall is distributed in bimodal pattern of which 72% occurs in June–October and 18% in March–May. The mean annual temperature is 14°C and lies in the cold thermal zone of Ethiopia (Engida Mersha, 2003) indicating that only cold growing crops can be cultivated in the area. The area is also categorized as moist *dega* zone as per traditional system.

The catchment forms part of the rift valley drainage system. Several intermittent and perennial streams join the main stream Gonde and these together flow westwards meeting the Katar further downstream. Katar ends up in the rift valley drainage basin of Lake Zeway.

The presence of old and remnant trees found in gullies and protected areas suggests that the area was once covered by intermediate and high altitude forest trees such as *Juniperus procera*, *Hagenia abyssinica,* and *Buddleja polystachya*. Nevertheless, a large part of the original natural vegetation has been cleared for expansion of agricultural lands, construction and fire wood purposes. On slopes above 3000 masl, natural vegetation containing plant species such as *Erica arborea* and *Hypericum revoltum* and various high altitude grasses predominates. No forest land use system has been observed in the study area except that farmers retained scattered trees along farm boundaries and planted *Eucalyptus globules* wood lots near homesteads as fences, and along road and stream sides.

The local economy is dominated by subsistence mixed agricultural activity. The major crops grown in the area are wheat (*Triticum spp.*), barley (H*ordeum vulgare*), horse bean (*Vicia faba*), field pea (*Pisium sativum*), rape seed (*Brassica spp.*) and linseed (*Linum usitatissinica)*. Mono cropping is the dominant practice and crop yields are low (< 1.3 t ha^{-1}). It is only when the land is exhausted that farmers rotate cropping such as from wheat to linseed. Farmers apply mainly Di-ammonium phosphate fertilizers for crops, except in linseed production. The homestead plots receive manure. Crop residues are used as livestock feed and fuel. Animals are allowed to graze free on the cultivated land during off season.

MATERIALS AND METHODS

Survey and soil sampling

With the help of 1:50000 topographic maps, a reconnaissance survey was performed to acquire general information on soils and environment of the study area. At this level, through the use of landscape and land use/vegetation relationships and surface soil characteristics (*e.g.,* colour, cracks, *etc.*) as field guide, tentative soil units and boundaries were identified and a tentative soil map was prepared. Following this, detailed free soil survey was conducted.

Soils were studied from auger holes, gully cuts and numerous visual observations. On the basis of auger observations, land use/cover and topographic patterns, representative pits were opened and described according to FAO (1990) guidelines for soil profile description. Accordingly, eight soil pits were opened from which six were sampled for laboratory analysis. A total of 39 disturbed (24) and undisturbed (15) samples were collected from genetic horizons. The FAO-

WRB (1998) classification legend was followed to classify the soils.

The tentative soil mapping units were adjusted in the field through manipulations of tentative soil boundaries. The final soil field boundaries were then delineated on the 1:50000 scale topographic map. This field soil map was digitized to produce the final soil map at a scale of 1:100000. In delineating boundaries, topographic factors (*e.g.*, slope breaks and types), vegetation characteristics, surface colour and land use patterns were used.

Soil analysis procedures

Dry bulk density and soil moisture contents at field capacity (FC) at -1/3 bar and permanent wilting point (PWP) at -15 bars were determined from undisturbed (core) soil samples (Baruah and Barthakur, 1997). The disturbed soil samples were air-dried, ground and sieved through a 2-mm sieve and analyzed for selected attributes at the National Soil Research Centre Laboratory (NSRCL), Addis Ababa. The soil samples were analysed adopting standard procedures for particle size (hydrometer method), pH (1:2.5 soil-water suspensions), organic carbon (Walkley and Black method, 1934), total N (Kjeldahl method) available phosphorus (Olsen and Dean, 1965); exchangeable bases (Ca, Mg, K and Na) and cation exchange capacity (CEC) were determined by ammonium acetate method at pH 7 (Jackson, 1970). Percentage base saturation (PBS) was found by dividing the sum of exchangeable bases by values of CEC kg^{-1} soil. Total porosity was obtained using the formula (1-bd/pd) 100 where bd is value of bulk density and pd is particle density, assumed to be 2.65g cm^{-3}.

RESULTS AND DISCUSSION

Major soil mapping units

The morphological and physicochemical characteristics were used in the identification of mapping units of the soils of Gonde micro-catchment. Specifically, the presence or absence of diagnostic horizons, properties and materials were used to distinguish soil units and subunits (FAO-WRB, 1998). Accordingly, Nitisols cover 82.3% (1234.5 ha), Vertisols 9.5% (142.5 ha) and Umbrisols 8.2% (123 ha) of the study area and their subunits are mapped (Fig. 1).

Site and morphological characteristics

Selected environmental and morphological characteristics of the soils are given in Tables 1 and 2, respectively. The surface soil colour patterns showed great variability in relation to position in the landscape, slope gradient and organic matter content. On slope gradients of 2% and less (profile 3), surface soil colour was very dark greyish brown (10 YR 3/2 moist). This surface colour in these soils changed to brown and dark grey (7.5 YR hues, moist) with depth of the profiles. The dry colours of these soils contained the same hues as the moist ones with one to two unit variations in values and/or chroma. As a result, the dry colour patterns varied from grey on the surface to dark grey or brownish yellow in subsoil horizons. The grey colour patterns could be due to imperfect drainage condition that caused iron removal from some of the horizons, whereas the brownish yellow patterns may be the result of release of free iron upon oxidation.

Soil colour patterns in profiles 1, 2, 4 and 5 become redder with depth. It changed from dark brown, with moist hues of 5 YR to 7.5 YR on surface, to red hues (5 YR or 2.5 YR, moist) in subsoil horizons. The dark brown surface soil colour could be attributed to a relatively high content of organic matter of the surface horizons. The red hues (5 YR or 2.5 YR, moist) in subsoil horizons indicated the well drainage conditions of the profiles (hence described as well drained class soils) as well as organic matter decreased in subsoil, suggesting the release of free iron to pigment the soils' reddish patterns.

Profile 6 exhibited soil colour patterns changing from black (10 YR 2/1) moist on surface to dark brown (7.5 YR 4/4) moist in subsurface. The topsoil dark colour of this profile reflected higher organic matter at high altitude of the catchment and its probable complexion with Al and Fe, which protected further mineralization of organic matter. As a result, light colour in subsoil horizons of profile 6 could be associated with a decline in organic matter. Therefore, in the study area, soil colour patterns showed variations both laterally on the surface among the profiles and vertically within a profile.

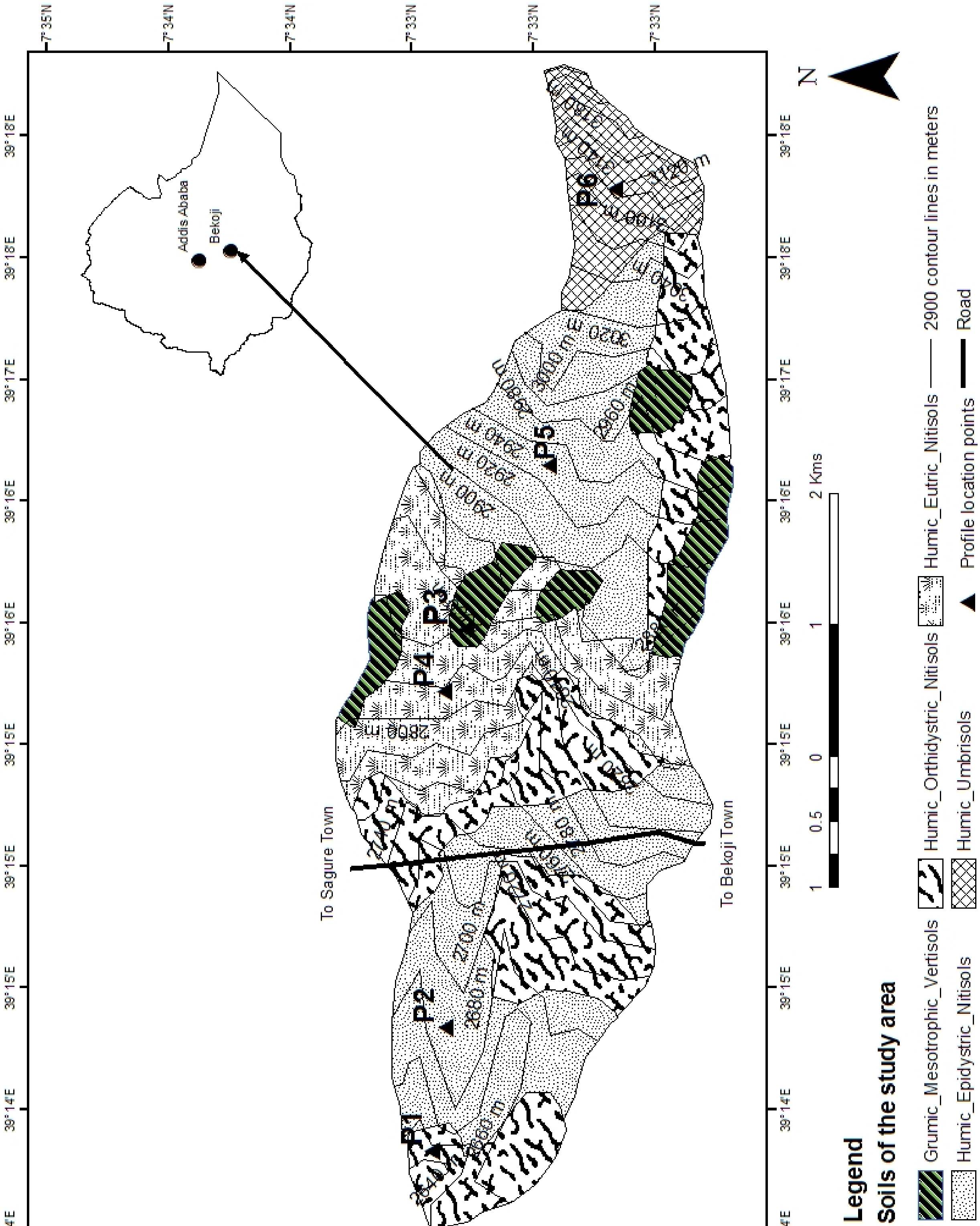

Fig. 1. Soil map of the study area. (Inset: Map of Ethiopia).

Table 1. Selected environmental information of representative profiles.

Profile No.	Location		Altitude (masl)	Slope (%)	Drainage class	Position	Micro topography	Surface		Erosion/ deposition	Parent material	Land use
	Latitude	Longitude						rock	stones			
P-1	7°33″25′N	39°13″50′E	2817	20	Well drained	shoulder	furrow	none	none	sheet and rill	basalt / colluvial	cultivated (wheat)
P-2	7°33″24′N	39°15″13′E	2740	23	Well drained	Back slope	Farm furrow, boundary	none	none	sheet erosion	basalt	cultivated (wheat)
P-3	7°31″21′N	39°29″50′E	2885	2	Imperfectly drained	foot slope	Farm furrow,	none	very few medium	deposition	colluvial	cultivated (linseed)
P-4	7°33″22′N	39°15″43′E	2820	11	Well drained	Middle slope summit	Farm boundary	none	none	sheet erosion	basalt	cultivated (barley)
P-5	7°33″22N	39°17″30′E	3020	5	Well drained	Middle slope summit	Farm furrow	none	none	Sheet erosion	basalt	cultivated (barley)
P-6	7°33″09′N	39°18″40′E	3340	38	Well drained	Middle back slope	none	none	few boulder	sheet and rill erosion	volcanic	fallow land

There are no considerable variations in soil structure characteristics among studied profiles. Slight variability in structure characteristics could be related to position of the profile in the landscape and organic matter content. The surface horizons have strong granular type with some variations in size of structures. In this horizon, the common size of structure is medium with coarse in very few topsoil. In the subsoil horizons, soil structure is blocky with either angular or sub angular variants with slight variation in grade and size. The development of blocky structure types could be related to the low level of organic matter, reduction in abundance of plant roots and higher clay in subsurface. On the other hand, predominantly intersecting shining slickenside was observed in profile 3. The other profiles including profiles 1, 2, 4, and 5 showed variable grades of shining faces throughout most of their subsoil horizons.

The dry soil consistence characteristics of the surface horizons (except profile 6) varies from slightly hard to soft with friable to very friable moist and slightly plastic and slightly sticky in wet consistency. The surface horizon of profile 6 has a soft dry and very friable moist and non-sticky and non-plastic wet consistency. These consistence characteristics in the latter profile could be related to high amounts of organic matter and low clay contents. In profile sections, consistence characteristics of each horizon increased by one or more grades from its respective overlying horizon. As a result, very hard, very firm, very sticky and very plastic consistence characteristics were common in the lower underlying horizons. The change in consistence characteristics from surface to subsoil horizons reflects high contents of clay and low contents of organic matter in subsoil horizons.

Horizon boundary characteristics show slight variations both among and within studied profiles. These differences seem to reflect variability in other soil characteristics such as weathering intensity, contents of organic matter and drainage conditions. For most of their horizons, most profiles on gentle to rolling slope lands (*e.g.,* profiles 1, 2, 4 and 5) have clear smooth boundaries on the surface that changed to gradual and/or diffuse smooth boundary in their subsoil horizons. These situations may reflect the presence of similar characteristics of subsoil horizons within a profile and slight differences between topsoil and subsoil horizons. The existence of similar subsoil horizons within a profile could be related to high and uniform contents of clay in the horizons, probably suggesting presence of intense weathering rates in most profiles of the micro-catchment. This is a typical characteristics of most tropical soils (Young, 1976). The existing differences in boundary characteristics between topsoil and subsoil horizons of these profiles could reflect effects of ploughing, relatively high contents of organic matter and low contents of clay of the topsoil horizons.

On the other hand, foot slope soils (profile 3) show abrupt wavy boundaries in the upper few horizons grading to clear to gradual wavy boundaries in the underlying horizons. These features are basically related to fluctuating water tables in the horizons, as verified through the presence of various grades of mottles. Therefore, the profile indicates the presence of different soil moisture regimes between its recognized genetic horizons and consequently the profile was described as imperfectly drained.

Table 2. Selected morphological characteristics and classification [1].

Depth (cm)	Hor-izon	Colour Munsel value		Structure Type/size/ grade	Consistence Dry/moist/wet	Cutanic feature	Roots Abun-dance/ size	Boundary Distinctne/ topography
		Moist	Dry					
Profile 1: Humic-Orthidystric Nitisols								
0–15	Ap	5YR3/2	5YR3/4	GR,ME,ST	SHA,VFR,SST,SPL	None	M,f-c	C,S
15–55	Bt_1	5YR3/4	5YR4/6	PR,CO,VST	HA,FI,ST,PL	None	F,Vf	G,S
55–110	Bt_2	5YR3/4	5YR4/6	SAB,ME,MO	VHA,FI,ST,PL	Nitic	Vf,Vf	G,S
110–200	Bt_3	2.5YR3/4	2.5YR3/6	SAB,ME,ST	VHA,VFI,ST,PL	Nitic	None	---
Profile 2: Humic-Epidystric Nitisols								
0–18	Ap	7.5YR3/2	5YR4/6	GR,CO,ST	SHA,VFR,SST,SPL	None	M,Mc	C,S
18–66	Bt_1	5YR3/4	5YR4/8	SB,ME,ST	HA,FR,SST,SPL	None	F,F	G,S
66–90	Bt_2	2.5YR3/4	2.5YR3/6	SB,ME,MO	HA,FI,ST,PL	Nitic	V,Vf	G,S
90–135	Bt_3	2.5YR3/4	2.5YR3/6	SB,ME,MO	HA,FI,ST,PL	Nitic	V,Vf	G,S
135–200	Bt_4	2.5YR3/4	2.5YR3/6	SB,ME,MO	HA,VFI,VST,VPL	Nitic	None	---
Profile 3: Grumic-Mesotrophic Vertisols								
0–14/22	Ap	10YR3/2	10YR4/3	GR,ME,ST	SHA,FR,SST,SPL	None	M,Me-Co	A,W
14/22–78	A_1	7.5YR4/4	7.5YR6/6	SB,FI-ME,ST	SHA,FR,VST,VPL	Partly intersect	F,F	A,W
78–110	A_2	10YR4/1	10YR5/4	AB,VCO,VST	EHA,EFI,EST, PL	Intersecting	Vf,Vf	G,W
110–137	A_3	7.5YR5/2	7.5YR5/4	AB,VCO,VST	EHA,EFI,EST,EPL	Intersecting	None	C,W
>137	R	Hard rock						--
Profile 4: Humic-Eutric Nitisols								
0–20	Ap	7.5YR3/2	5YR5/6	GR,ME,ST	SO, FR,SST,SPL	None	Me,M	C,S
20–76	Bt_1	5YR3/3	5YR4/4	SB,FI-ME,ST	HA,FI,ST,PL	None	F,F	D,S
76–142	Bt_2	2.5YR3/4	2.5YR4/6	SB-AB,ME-CO,ST	HA,VFI,VST,VPL	Nitic	Vf,Vf	G,S
142–200	Bt_3	2.5YR3/4	2.5YR4/6	SB,ME-CO,ST	VHA,VFI,VST,VPL	Nitic	None	---
Profile 5: Humic-Epidystric Nitisols								
0–20	Ap	7.5YR3/2	7.5YR 5/4	GR,ME,ST	SHA, FR,SST,SPL	None	C,M	G,S
20–55	Bt_1	5YR3/2	5YR4/6	SB,FI-ME,VST	SHA,FR,ST,PL	None	F,F	G,S
55–122	Bt_2	5YR3/4	5YR4/6	SB-AB,ME-CO,ST	HA,FI,VST,VPL	Nitic	Vf,Vf	C,S
122–200	Bt_3	2.5YR3/4	2.5YR4/6	SB,ME-CO,ST	HA,FI,ST,VPL	Nitic	Vf,Vf	--
Profile 6: Humic Umbrisols								
0–30	Ap	10YR2/1	10YR3/2	GR,M,ST	SO,VFR,NST,NPL	None	C,M	G,S
30–74	AB	7.5YR2/2	7.5YR3/4	SB,M-C,ST	SO,FI,SST,SPL	None	C,M	A,S
74–138	Bw	7.5YR ¾	7.5YR5/4	SB, C, ST	SHA,FI,ST,PL	None	F,F	A,W
>138	C	unconsolidated gravel fragments						

[1] Abbreviations are as per FAO (1990).

Physical characteristics

The texture class of the studied soils varies from silty clay loam on the surface to clayey in subsoil horizons (Table 3). The content of clay varies from 9% in topsoil horizon of profile 6 to 81% in subsoil horizon of profile 2. This revealed an increasing pattern of clay content and a decreasing pattern in sand and silt contents with depth of profiles, identifying most subsoil horizons as argillic (Bt) (FAO-WRB, 1998). In most of the profiles, subsoil horizons have more or less uniform clay distributions (*e.g.*, profiles 1, 2, 3, 4 and 5). This feature of subsoil horizons indicates the presence of uniform weathering intensities and/or lithological characteristics. On the other hand, profile 6 has a large difference in clay content between its recognized horizons, revealing the presence of differences in lithological and/or rates of weathering between horizons (Table 3). The differences in topsoil particle size classes could further be attributed to differences in erosion-deposition intensities. For instance, profiles 1 and 2, located in the shoulder and back slope positions, respectively, and with steep slopes, were exposed to erosion where finer particles could be removed from the surface, hence resulting in lower contents of surface clay. Also, profile 3, located in foot slope position with nearly flat gradients, could receive finer size materials onto its topsoil horizon. The silt/clay ratios show a similar pattern of variation as the clay size particles. The ratio generally decreases with depth of profiles, revealing the increasing trend in contents of clay in that same pattern for reasons discussed earlier.

The bulk densities of the soils show great variability with respect to contents of organic matter, structural characteristics, approximated parent material and position of horizons in a profile (Table 3). In most of the profiles, the bulk density increases irregularly with depth. Surface horizon bulk density ranges from 0.75 g cm^{-3} to 1.19 g cm^{-3}; being minimum in profile 6 and maximum in profile 4. This revealed that the high amount of organic matter and well structure characteristics of profile 6 resulted in reduced bulk density. Hence, the non-systematic increasing pattern in bulk densities with depth of profiles could be related to a decrease in contents of organic matter and presence of blocky types of structure. Consequently, in the underlying horizons, bulk density varies from 0.9 g cm^{-3} to 1.5 g cm^{-3}. The increase in clay content with depth did not have any influence on bulk densities of subsoil horizons. Total porosity values were derived by manipulating the values of bulk density; hence these characteristics show the same pattern of variability as bulk densities.

In most of the cases, patterns in field capacity (FC), permanent wilting point (PWP) and available water were noticed among the soils of the catchment, showing unsystematic variation with depth of most profiles. The FC ranged from 30 to 43% for the surface horizons (Table 3); being higher in a horizon containing more organic matter and vice versa. In the subsoil horizons it varied between 3 and 64%, the lowest being in profiles 1 and 3 and the highest in profile 6, revealing no relationship either to contents of clay, organic matter or soil structure characteristics.

There were slight differences in available water capacity among the studied profiles and identified horizons of the soils. Soil available water varied from 2% (profile 3) to 11% (profile 4) for the surface horizons. In the subsoil horizons it ranged between 2% (profile 3) and 17% (profile 1), showing a relatively wide difference for underlying horizons. Hence, the available water holding capacity was found to be high for most of the lowest underlying horizons of the profiles, and low in some of the surface horizons.

Chemical characteristics

Values of soil pH generally show a slight increasing trend with depth. However, for both surface and subsoil horizons soil pH values are < 7. In the surface horizons, it ranges from 5.1 to 5.6 (Table 4). The low pH could be due to the effect of leaching as a result of the high rainfall in the study area. In subsoil horizons, pH ranges from 5.3 to 6.3 and does not show any clear pattern. Soil pH of < 5.5 indicates the presence of Al and removal of exchangeable cations, revealing low phosphorus availability due to binding effects of Al and Fe.

Table 3. Selected soil physical characteristics.

Depth (cm)	Particle size analysis (%)				Si/C	BD (g cm^{-3})	FC	PWP	AWC	Porosity (%)
	Sa	Si	C	class						
					Profile 1					
0–15	33	36	31	Clay loam	1.2	1.16	39	36	3	56
15–55	3	20	77	Clay	0.3	1.12	32	28	4	57
55–110	5	18	77	Clay	0.2	1.04	31	28	3	61
110–200	5	18	77	Clay	0.2	1.10	49	32	17	59
					Profile 2					
0–18	29	34	37	Clay loam	0.92	-	-	-	-	-
18–66	17	12	71	Clay	0.17	-	-	-	-	-
66–90	7	20	73	Clay	0.27	-	-	-	-	-
90–135	3	20	77	Clay	0.26	-	-	-	-	-
135–200	5	14	81	Clay	0.17	-	-	-	-	-
					Profile 3					
0–22	43	20	37	Clay loam	0.54	0.87	30	28	2	67
22/48–70	9	34	57	Clay	0.60	1.31	31	23	8	50
48/70–95	9	14	77	Clay	0.18	1.27	36	29	7	52
95–137	9	14	77	Clay	0.18	1.40	34	32	2	47
					Profile 4					
0–20	29	44	27	Loam	1.63	1.19	35	24	11	55
20–76	11	32	57	Clay	0.56	1.29	33	25	8	51
76–142	11	20	69	Clay	0.29	1.32	25	21	4	50
142–200	11	18	71	Clay	0.25	1.42	64	27	37	46
					Profile 5					
0–20	17	52	31	Silt clay loam	1.68	-	-	-	-	-
20–55	13	36	51	Clay	0.71	-	-	-	-	-
55–122	5	25	70	Clay	0.36	-	-	-	-	-
122–200	5	22	73	Clay	0.30	-	-	-	-	-
					Profile 6					
0–30	49	42	9	Loam	4.67	0.75	43	34	9	72
30–74	42	42	19	Loam	2.21	0.91	25	20	5	66
74–138	34	34	47	Clay	0.72	1.51	38	20	18	43

-=Not determined, sa= sand, si= silt, C = clay, BD= bulk density, FC= field capacity, PWP= permanent wilting point, AWC= available water capacity.

Variability in the spatial distribution of organic matter is ascribed to effects of land use history, drainage conditions, positions in the landscape and altitude. The study indicates that the level of soil organic matter is high for fallowed soils and increases with rise in altitude. The organic matter of the topsoil ranges from 4.76% in long period cultivated profile 2 to 10.95% in the recently cultivated profile 3 (Table 4). The high level of organic matter in the surface horizon of profile 3 could also be related to its foot slope position. This position could allow the profile to receive organic matter from upper slope areas via processes of erosion-deposition. Also, profile 3 exhibits imperfect drainage pattern creating anaerobic condition, retarding rate of mineralization and preserving the organic matter relative to the better-drained soils of the study area. Besides, the profile was under fallow for two years contributing to high organic matter in profile 3.

The organic matter in fallow high altitude profile 6 was 9.65%, which attains the second highest level among the studied profiles. The increase in organic matter with altitude suggests its poor decomposition caused by low temperatures at higher altitudes. It could also be associated with the presence of vegetation cover, adding organic materials to be incorporated into the soils. The relative low organic matter in the other surface soil horizons could be related to continuous cropping. These facts confirm that long term cultivation in the catchment caused soil organic matter deterioration. Hence, soil organic matter improvements can be achieved through fallowing systems of cultivated soils. Variations in amount of organic matter could also be related to slope forms and gradients. Accordingly, profile 2, being located on a steep gradient *i.e.*, 23% and convex slope form, would lead to severe erosion as compared to other profiles, thus lowering its organic matter.

Organic matter shows declining trend with depth in all studied profiles, suggesting relatively greater addition of decomposable organic materials on the surface horizons. Although cultivation has a negative influence on organic matter, it has contributed to relative high levels of surface organic matter through decomposition of roots of annual crops. In the subsoil horizons, levels of organic matter ranges from 1.69% in profile 3 to 5.69% in profile 6.

The amount of total nitrogen (TN) differs in relation to variation in levels of organic matter and drainage conditions. It is relatively high in the surface horizons and systematically decreases with depth. On the surface horizons, it ranges from 0.24% (profile 2) to 0.69% (profile 6) revealing high ratings for soils of Ethiopia (Weigel, 1986). The high level of total nitrogen does not correlate with the high level of organic matter of profile 3, which could be attributed to the imperfect drainage condition of this profile, which might have retarded mineralization. The relatively high level of total nitrogen corresponds to profile 6, reflecting that well drained profile might have promoted mineralization.

The carbon-to-nitrogen ratio (C:N) shows an irregular variation with depth in all studied profiles, probably suggesting existence of different conditions of mineralization in the recognized horizons. The high C:N ratio (16) was observed for the surface horizons of profile 3, which has imperfect drainage, revealing that the variation in C:N ratio could be related to soil drainage condition. The C:N ratio for most of the horizons was > 10, indicating a slightly low level of mineralization (Thompson and Troeh, 1993). In general, a C:N ratio of about 10:1 suggests relatively better decomposition rate, serving as index of improved nitrogen availability to plants and possibilities to incorporate crop residues to the soil without having any adverse effect of nitrogen immobilization.

Table 4. Selected soil chemical characteristics.

Depth (cm)	pH (H_2O)	Av.P mg kg^{-1}	Exchangeable bases and CEC Cmol$_c$ kg^{-1} soil					CEC/Clay Cmol$_c$ kg^{-1}	BS (%)	OC (%)	TN (%)	C/N
			Ca	Mg	K	Na	CEC					
					Profile-1							
0-1	5.2	2.78	5.54	1.64	0.77	0.10	27	90	30	4.35	0.300	15
15-55	5.3	0.32	8.38	3.29	0.32	0.24	25	30	48	2.68	0.190	14
55-110	5.6	0.84	7.09	2.47	0.26	0.09	24	30	41	1.57	0.100	15
110-200	6	1.56	7.78	4.11	0.25	0.46	22	30	57	1.05	0.070	14
					Profile-2							
0-18	5.5	1.86	7.44	1.07	1.1	0.09	27	72	36	2.76	0.244	11
18-66	5.7	1.11	7.88	1.97	0.50	0.14	24	34	44	2.45	0.146	17
66-90	5.8	1.76	8.73	1.97	0.74	0.33	24	33	48	2.05	0.136	15
90-135	6.0	2.56	8.28	2.88	0.79	0.33	24	31	51	1.65	0.129	13
135-200	6.0	3.6	5.09	1.97	0.82	0.18	21	26	38	1.30	0.126	10
					Profile-3							
0-22	5.2	1.18	8.03	1.7	0.38	0.10	31	84	33	6.35	0.392	16
22-48/70	5.3	1.76	8.63	2.3	0.28	0.33	23	40	50	2.25	0.125	18
48/70-95	6.1	0.68	23.35	4.8	0.72	0.50	40	51	74	1.55	0.101	15
95-137	6.3	0.18	26.85	4.6	0.72	0.52	41	54	79	0.98	0.075	13
					Profile- 4							
0-20	5.1	4.78	12.33	0.82	1.31	0.23	28	105	52	3.05	0.311	10
20-76	5.9	1.38	12.57	2.30	0.83	0.18	28	49	57	2.55	0.226	11
76-142	6.1	5.50	5.29	2.96	1.21	0.07	24	34	40	1.50	0.130	12
142-200	6.0	3.52	7.83	3.04	0.61	0.35	27	38	44	1.00	0.095	11
					Profile-5							
0-20	5.1	8.04	9.43	0.99	2.14	0.09	29	95	43	3.25	0.380	9
20-55	5.5	2.10	6.89	1.40	2.07	0.15	27	52	39	2.05	0.190	11
55-122	5.9	13.76	6.94	1.81	1.79	0.15	18	29	58	1.25	0.100	13
122-200	5.9	13.12	8.88	3.04	0.78	0.22	21	29	61	1.05	0.080	13
					Profile-6							
0-30	5.6	4.3	18.26	2.21	1.45	0.12	49	544	45	5.60	0.692	8
30-74	5.8	1.34	12.23	2.14	1.09	0.11	39	206	40	3.30	0.328	10
74-138	5.9	2.92	10.88	2.30	0.80	0.08	28	59	51	1.68	0.171	10

Av.P = available phosphorus, Ca = calcium, Mg = magnesium, K = potassium, Na = sodium, CEC = cation exchange capacity, BS = base saturation, OC = organic carbon, TN = total nitrogen, C/N= carbon-nitrogen ratio.

Exchangeable calcium (Ca) followed by exchangeable magnesium (Mg) form the dominant cations in all of the horizons and profiles of the study area. The exchangeable Ca alone contains 20 to 37% of the total exchange site of the surface horizon of the soils. In the surface horizons, exchangeable Ca varies from 5.54 $cmol_c$ kg^{-1} soil (profile 1) to 18.26 $cmol_c$ kg^{-1} soil (profile 6). The high contents of exchangeable Ca in the surface horizon of profile 6 revealed low rates of removal of cations as well as young soil formation stage of the soils. This reflects the existence of variability in soil formation and characteristics within the micro-catchment. Accordingly, low exchangeable Ca in the other profiles suggests relatively more developed soils. In the subsoil horizons, contents of exchangeable Ca show an increasing trend in profiles 3 and overall decreasing trend in the other profiles, and vary from 5.29 $cmol_c$ kg^{-1} soil to 26.85 $cmol_c$ kg^{-1} soil. The high levels of exchangeable Ca in subsoil horizons of profile 3 could be related to its imperfect drainage pattern, which restricted the downward movement of solutes, as well as to the young alluvial parent material. In these subsoil horizons, exchangeable Ca contributed 58 to 65% of the exchange site of the soils. These values are lower than those in the soils of the other parts of Ethiopian south-eastern highlands (Eylachew Zewdie, 1999; Mohammed Assen *et al.,* 2005), which are considered to be relatively young soils. Therefore, variation in the contents of exchangeable Ca in the Gonde micro-catchment could be related to position in the landscape, slope gradient, parent material, clay type and weathering stage of the soils.

The exchangeable Mg occupies 3.4 to 18.7% of the exchange site of the soils. In any of the horizons where exchangeable Ca is low, the content of exchangeable Mg increases. This suggests the dominance of bivalent over monovalent cations in the soils of the study area. Exchangeable Mg varies from 0.82 to 2.22 $cmol_c$ kg^{-1} in the surface horizons and from 1.4 to 4.77 $cmol_c$ kg^{-1} in the subsoil horizons. It shows an increasing pattern with depth of the profiles. This is an indication of the presence of relatively weathered B- horizons; the content of Mg may exceed Ca in more matured soils (Black, 1968).

The contents of exchangeable K and Na are very low, which together were < 1% of the exchange site of the soils. The exchangeable K shows a decreasing pattern with depth in most of the studied profiles. Exchangeable K may be sufficient in the surface horizons and medium to low in most of the subsoil horizons for crop cultivation (Landon, 1991). Therefore, whereas K deficiency may not be expected in the surface horizons, this could be so in all subsoil horizons. From this, it can be stated that deep rooting plants may suffer from K deficiency. Correction of this element may be required for economical crop production in the study area and elsewhere in the Arsi highlands with similar environments.

Exchangeable sodium is low throughout the profiles of the studied soils (Table 4). It shows an irregular pattern of variation with depth of the profiles. In fact, high Na would not be expected in the high rainfall areas as in the study area. As a result, adverse effects of Na would not be expected in the study area and in similar environments of the Arsi highlands in general.

In all sections except profile 6, the magnitude of exchangeable Na shows a general increasing trend with depth. Amount of exchangeable Na varied from 0.09 $cmol_c$ kg^{-1} soil to 0.23 $cmol_c$ kg^{-1} soil in the surface and 0.07 $cmol_c$ kg^{-1} to 0.52 $cmol_c$ kg^{-1} soil in the subsoil horizons. The highest amount of exchangeable Na for surface horizons is recorded in profile 3. This could be due to the location of the soil in the foot slope position where the slope is level and has poor internal drainage with restricted downward mobility of elements. In general, in the study area, magnitude of exchangeable cations was in the order of Ca> Mg> K> Na.

In most of the cases, CEC of surface horizons is higher than that of subsoil horizons. In the surface horizons, CEC varies from 27 $cmol_c$ kg^{-1} soil (profiles 1 and 2) to 49 $cmol_c$ kg^{-1} soil (profile 6). CEC values generally show a systematic variation with depth in some profiles (*e.g.,* Profiles 1, 2, and 6) and non-systematic variation with depth in other profiles. In the subsoil horizons, CEC varies between 18 $cmol_c$ kg^{-1} soil (profile 5) and 41 $cmol_c$ kg^{-1} soil (profile 3). Accordingly, the increase in clay contents with depth of the profiles does not match with increase in CEC.

The CEC/clay ratios are also greater for the surface than the subsoil horizons of the studied profiles. Except for some profiles (*e.g.,* profiles 3 and 4), CEC/clay shows a systematic decrease with depth of the profiles. This suggests that CEC variations could not be explained by amount of clay. The CEC/ clay ratio is also high for profile 6, which is located in high altitude parts of the study area. These facts indicate that CEC could be explained by type of clay mineralogy and stages of soil development. That is, the high CEC values in high altitude profile 6 could indicate low stage of soil development of the profile, supporting earlier statements. Accordingly, the decline in total CEC or CEC/clay with depth of profiles could be an indication of the presence of mixed clay mineralogy. The CEC of the surface horizons of all profiles and subsoil horizons of profile 6, and to some extent that of profile 3, may reveal the presence of smectitic mineral.

The percentage base saturation (PBS) is generally < 50% in most of the horizons and profiles. Accordingly, most of the profiles can be labelled as dystrophic soils for their low base status (FAO-WRB, 1998). Although it still remains low, PBS shows a slight increase with depth of all the profiles, suggesting downward movement of bases. The low PBS of the soils is an indication of effective leaching processes of bases as a result of the high rainfall in the study area. These situations may result in low and unbalanced availability of exchangeable bases for plants to be taken up. As a result liming may be required in the cultivation of soils of the study area and elsewhere in similar environments of the Arsi highlands. The low PBS may also indicate the existence of appreciable amounts of Al and Fe at toxic levels. This again suggests that exploitation of the soils for agricultural purposes would not be possible unless corrections are made for some of these elements. This holds true particularly in the commercial farms of the Arsi highlands. The high PBS in subsoil horizons of profile 3 indicates low leaching in these horizons probably due to the existence of vertic properties, as described elsewhere in this paper.

Compared to the ratings for some tropical soils (Landon, 1991), the contents of available P are generally low throughout the studied soils and horizons. In the topsoil horizons available P ranges from 1.18 mg kg^{-1} soil (profile 3) to 8.04 mg kg^{-1} soil (profile 5). In the subsoil horizons, it varies from 0.32 mg kg^{-1} soil (profile 1) to 13.76 mg kg^{-1} soil (profile 5). Available P shows non-systematic patterns of distribution with depth of the studied profiles, and does not show any clear pattern of variability among studied profiles of the soils. The low P content of the soils could be related to P fixation by Al and Fe (Eylachew Zewdie, 1999). This situation could be confirmed owing to low pH of soils. In fact, low P is a common feature of soils characterized by tropical humid climates as in the present study area (Young, 1976). Consequently, low P in the soils could form one of the major soil fertility limiting factors in the study area as well as in the other similar environments of the Arsi highlands in general. Therefore, any economical agricultural production would require raising of available P through various P management methods, such as fertilization and/or organic manure application.

Subunit mapping units

The subsoil horizons of profile 3 exhibit predominantly intersecting slickensides and high clay contents (> 30%) up to 25 cm. Observations of the profile in dry spells show the existence of periodic cracks. These morphological characteristics meet requirements for vertic properties, which are considered to be diagnostic of a vertic horizon. The CEC/clay values of the vertic horizons also indicate the existence of appreciable amounts of expanding clay minerals such as smectite. These conditions are typical characteristics of vertisol mapping units (FAO-WRB, 1998; Soil Survey Staff, 1999). These soils show a base saturation (by 1M NH_4OAc) of less than 75% between 20 cm and 100 cm from the soil surface, and meet requirements for a mesotrophic qualifier. Profile 3 also has grumic soil structure characterized by a surface layer with a thickness of 3 cm or more and with a strong structure finer than very coarse granular Vertisols. Therefore, these soils are recognized and classified as Grumic- Mesotrophic Vertisols at the subunit level (Fig. 1). Grumic Mesotrophic Vertisols occupy 9.5% (142.5 ha) of the micro-catchment.

Profile 6 has high organic matter with dark colour and low base saturation on the surface horizons thus qualifying as umbric A horizon (FAO-WRB, 1998). Its subsoil horizon qualifies for a cambic horizon as set out in FAO-WRB (1998). Therefore, soils represented by profile 6 are classified as Umbrisols at reference unit level. Furthermore, these soils have humic properties that show organic carbon content of > 1.4% as weighted average over a depth of 100 cm from the soil surface and qualify as humic at subunit level. Thus soils represented by profile 6 are identified as Humic Umbrisols at second level. These soils cover 8.2% (123 ha) of the study area and are found on the steep mountain slopes at altitudes ranging from 3100 to 3300 masl.

The subsoil horizons of profiles 1, 2, 4 and 5 exhibit shiny properties at their pedsurfaces which, together with other diagnostic properties, can satisfy requirements for nitic horizon (FAO-WRB, 1998). The surface horizons of these soils uniformly meet the requirements for an ochric A horizon (FAO-WRB, 1998). These soils are mapped as Nitisols at the group level. The Nitisols of the studied profiles are further mapped into second and third level units on the basis of recognized unique qualifiers depending on their specific morphological and physicochemical properties.

Accordingly, profile 1 has low base saturation status (< 50%) in all of its parts between 20 cm and 100 cm from the soil surface and qualifies for orthidystric concept at the subunit level. It also has a humic soil property as defined above and recognized meets requirements as a humic qualifier at third unit level. Therefore, soils represented by profile 1 are identified as Humic-Orthidystric Nitisols (Fig. 1). They cover 24.6% (369 ha) of the total area.

Profiles 2 and 5, having low base saturation (<50%) between 20 and 50 cm from the soil surface, qualify for epidystric qualifier at the subunit level. They also show a humic soil property and meets requirements for a humic qualifier at third level. Accordingly, soils represented by profiles 2 and 5 are mapped as Humic- Epidystric Nitisols (FAO-WRB, 1998). These soils cover about 34.5% (517 ha) of the total area of the micro-catchment.

Profile 4 shows high base saturation (> 50% in 1M NH_4OAc at pH 7) between 20 cm and 100 cm from the soil surface and meets requirements for eutric qualifier at second unit level. It also meets requirements for a humic qualifier as used earlier at third level of classification. Accordingly, soils represented by profile 4 are separately mapped as Humic-Eutric Nitisols (FAO-WRB, 1998). The area of these soils in the catchment is 348.5 ha hectares contributing 23.2% of the total area.

CONCLUSIONS

This study revealed that soil types and characteristics vary locally within the micro-catchment affected by certain micro-level factors. The soil types are highly influenced by differences in land use, topographic, drainage, climatic and geological conditions. The colour of surface soil varies from black in fallowed Umbrisols through dark brown and grey in poorly drained Vertisols to reddish in well-drained Nitisols. Also, lower bulk densities are observed under fallowed and vegetation soils. The texture of the soil varies with soil development stage, relative position of the profile in the landscape and horizon in the profile. Consequently, soils on low-slope position have high contents of clay, whereas soils on steeper and upper slope positions are relatively rich in sand and silt contents.

Higher organic carbon and total nitrogen are observed on fallow than on continuously cultivated soils. This indicates that soil organic carbon and nitrogen contents can be replenished through a fallow farming system; the latter can serve as one of the sustainable farming systems. It is shown that inappropriate cultivation system (*e.g.*, continuous cultivation) forms the main cause in the degradation of soils, and other natural resources of the study area in general.

Soil pH, exchangeable bases, percentage base saturation and available phosphorus are low in most of the soil types. Therefore, nutrient imbalances, induced by high Ca/Mg ratios, low pH and low to medium available P are the major chemical and fertility problems in the soil units. On the other hand, steep slope and cold climate associated with Umbrisols, and poor drainage conditions of Vertisols, are among the physical constraints in these soil units for crop production. Furthermore, severe water erosion is detrimental to sustainable crop production in the catchment as evidenced by the development of deep and wide gullies within farmlands. This implies cultivation practices without conservation-based development activities. Thus, designing and implementing appropriate soil conservation measures, to prevent loss of soil and soil nutrients, would be indispensable in maintaining sustainable crop production and environmental management in general.

The short-distance variability in the characteristics of the soils of Gonde micro-catchment calls for the use of appropriate farming technologies. In this study, a soil survey at 1:50000 scale (semi-detailed) helped to identify different soil phases. Therefore, in a country like Ethiopia, where there is an urgent need on soil information for agricultural and environmental planning, it is recommended to undertake surveys at this intermediate scale.

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