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Topographic positions and land use impacted soil properties along Humbo Larena-Ofa Sere toposequence, Southern Ethiopia

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Understanding the dynamics and distribution of soil characteristics as influenced by landscape features and land use is critical for making decisions with regards to crop production and other types of proper land use. A field study was conducted to evaluate the relationship between topography position, land use and soil properties along the toposequence of Humbo Larena - Ofa Sere in Wolayita zone, Southern Ethiopia. Five slope classes were considered and a total of five pedons, one on each slope class, were opened and described at the study area. Soil samples collected from identified horizons of each pedon were analyzed for physicochemical properties. Additionally, random surface soil samples (0-20 cm) were collected from adjacent cultivated and grassland soils within a 100 m radius of each pedon; and three composites were made for each slope class. The pedons showed variability in physical, chemical and morphological characteristics of the soils. Field as well as laboratory determinations revealed the dominance of clay fraction in the soils. The existence of buried horizons with abrupt textural and sharp color changes showed the occurrence of lithological discontinuity in the pedon opened at depression. The available P content was higher in cultivated soils, whereas grassland soils had more organic carbon (OC), exchangeable bases and cation exchange capacity (CEC). Two soil types; Rhodic Alisols (Clayic) and Pellic Vertisols (Grumic) were identified in the area. Generally, slope and land use influenced soil properties, suggesting the need for different management practices for varying slope gradients and land uses for sustainable agricultural production.

Key words: Toposequence, physicochemical properties, land use, pedon, slope gradient, landscape position, soil classification.

INTRODUCTION

Information on soil characteristics and distribution of soil types is necessary for planning and implementing sustainable land use, rehabilitation of degraded lands and implementing sound researches on soil fertility (Ali et al., 2010; Dinku et al., 2014). In order to evaluate the quality of our natural resources and their potential for

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sustainable use, detailed information on soil properties are required (Teshome et al., 2016). It is therefore, very useful to study and understand the properties of soils and their distribution over an area in order to develop management plans for an efficient utilization of soil resources (Abay et al., 2015). All soils are naturally variable with their properties changing across landscape and vertically down the soil profile (Brady and Weil, 2002; Sheleme, 2011). Knowledge about the properties of soils can be generated directly through field observation, though soil properties are extremely variable in space and time (Korres et al., 2013). A better mechanism for predicting adequate soil information is by using biophysical and climatic characteristics that have established strong relationships with soil properties (Fantaw et al., 2006; Dinku et al., 2014).

Several studies have been conducted to determine dominant controlling factors on soil properties within landscape (Fantaw et al., 2006; Mulugeta and Sheleme, 2010; Dinku et al., 2014). Dinku et al. (2014) regarded topography as the dominant factor influencing soil property variation along a toposequence due to its influence on runoff, drainage and soil erosion, and consequently on soil development along a toposequence of Ele watershed, Southern Ethiopia. Similarly, Mulugeta and Sheleme (2010) indicated that most of the important soil quality indicators were affected by different landscape positions, particularly at surface horizons. Many soil properties including particle-size distribution, pH, organic carbon, total nitrogen, available phosphorus, exchangeable cations and cation exchange capacity vary with slope position (Mulugeta and Sheleme, 2010; Dinku et al., 2014; Teshome et al., 2016). All these studies demonstrated a strong relationship among topographic positions and soil properties, such that the distribution of a particular soil property may vary with topographic attributes.

Different soil properties encountered along landscapes will affect the patterns of plant production, litter production and decomposition, which have effects on carbon and nitrogen contents of soils (Mulugeta et al., 2012). Soil properties such as clay content and its distribution with depth, sand content and pH have been shown to be highly correlated with landscape position (Wang et al., 2000; Mulugeta and Sheleme, 2010) while organic matter varied with slope position (Miller et al., 1998). The depth of A-horizon decreased with increasing slope gradient, whereby the soils at shoulder are shallow due to erosion while those on foot slopes are thicker due to deposition (Mulugeta and Sheleme, 2010).

Soil properties can also vary with land use and management system (Alemayehu and Sheleme, 2013). Land management and its various uses for crop production in mountain areas influence runoff and erosion, which in turn results in varying physicochemical properties of the soils under cultivation and grazing lands (Belayneh, 2009). Soil classification is important in identifying the most appropriate use of soil, estimating production, extrapolating knowledge gained at one location to other and providing a basis for future research needs (Teshome et al., 2016).

The Humbo Larena area in Southern Ethiopia is densely populated with small farm size. Intensive cultivation in this area, with subsequent removal of plant residues, resulted in severe degradation of soil fertility. Subdivision of the fields into several plots; field and root crops production, enset (*Ensete ventricosum*) and coffee plantations; and for tethering, animals has led to different fertility gradients and has complicated the management. The decline in soil fertility is exacerbated by soil erosion, which is aggravated by steep slopes, poor vegetation cover and continuous cropping. Thus, different positions along the toposequence require different management practices. The present study was therefore carried out to assess the morphological, physical and chemical properties of the soils under different land use systems along the toposequence, and generate data for management options.

MATERIALS AND METHODS

Description of the study area and soil sampling

The study was conducted along the toposequence of Humbo Larena and Ofa Sere villages in Southern Ethiopia that lies within 06° 46’ to 06° 47’ N and 37° 45’ E. The study site receives about 1,272 mm of rainfall per year with mean annual temperature of 19.9°C (Table 1). The toposequence covers about 4 km with altitude ranging between 1794 and 1860 masl and having different land forms (Figure 1 and Table 2). The toposequence was divided into four slope categories: Flat/level (<1%), nearly flat (1-2%), gently sloping (2-5%) and sloping (5-15%). Five representative pedons; one each on the flat, nearly flat and gentle sloping, and two on sloping positions, were excavated on the toposequence, and soil samples were collected from all identified horizons of each pedon. The morphological, physical and chemical properties of the soils were studied through field observation and laboratory analyses.

Representative pedons were selected based on site and soil profile characterization following the Guidelines for Field Soil Descriptions (FAO, 2006). The land units were identified on the basis of topographic features and land/soil characteristics using field observations and topographic maps. Soil auger observations were implemented using ‘Edelman auger’ to identify variation in soil depth and texture characteristics along the slope gradient. Points with the same soil depth and texture classes in a given slope category were considered as a pedon. Pedon-CR was located on concave crest, -US on upper slope, -MS on middle slope, -LS on lower slope and -DE on the depression at the bottom (Figure 1 and Table 2). The soil profiles of all pedons were described *in situ* following the Guidelines for Field Soil Descriptions (FAO, 2006) and using the Munsell Chart to identify soil colors. There were a total of 18 soil descriptions, on average 4 per pedon, corresponding to respective diagnostic horizons.

To identify the influence of land use types on the chemical properties as well as fertility of the soils along the toposequence, twelve random surface soil samples (0-20 cm) within 100 m radius of each pedon were collected from cultivated and grasslands and three composites of each land use systems per pedon were made. The grasslands were put under fallow for two consecutive years, except for the US and DE pedons, which were used for cattle

Table 1. Mean monthly and annual rainfall (mm) and average temperature of the study area, 1986-2014

Year	RF/Tº	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean annual RF (mm)	Mean Tº (ºC)
1986-1995	mm	29.4	57.5	70.1	137.0	173.7	102.5	161.9	145.6	90.4	64.3	35.1	44.0	1,112	
	ºC	20.4	21.0	21.3	20.4	19.6	18.6	17.6	18.0	18.8	19.3	20.6	20.6		19.7
1996-2005	mm	39.1	24.1	78.0	159.4	188.4	156.0	183.7	195.6	95.2	127.6	56.0	32.0	1,335	
	ºC	20.5	22.1	21.9	20.8	19.8	18.7	17.7	18.2	19.0	19.5	20.3	20.7		19.9
2006-2014	mm	22.4	32.6	72.8	168.3	163.8	140.2	193.9	208.3	155.8	109.0	62.9	37.9	1,368	
	ºC	21.0	22.0	22.2	21.0	20.0	19.2	18.3	18.5	19.2	19.9	20.4	20.2		20.2
Mean	mm	30.0	38.1	73.5	154.9	175.3	132.9	179.8	183.2	113.8	100.3	51.3	38.0	1,272	
	ºC	20.6	21.7	21.8	20.7	19.8	18.8	17.9	18.2	19.0	19.6	20.4	20.5		19.9

RF = Rainfall.

tethering and fallow for more than five years, respectively.

Laboratory and statistical analyses

The soil samples collected from every identified horizon and the composite surface samples of the two land uses from the different landscapes were air-dried and ground to pass 2 mm sieve. For the determinations of total nitrogen (TN) and organic carbon (OC), a 0.5 mm sieve was used. Analyses of physicochemical properties were carried out following standard laboratory procedures.

Particle-size distribution was determined by modified hydrometer analysis (Xiao, 2009). Soil pH was measured using 1:2.5 soil to water ratio following the procedure outlined by Sahlemedhin and Taye (2000) while OC was determined by wet digestion (Walkely and Black, 1934). Total N was determined by Kjeldahl wet digestion and distillation method (Bremner and Mulveny, 1982), and available P by modified Olsen method (Olsen and Sommers, 1982). Cation exchange capacity and exchangeable bases were extracted by 1 M ammonium acetate (pH 7) method (Van Reeuwijk, 1993). In the extract, Ca and Mg were determined by atomic absorption spectrophotometer (AAS) and exchangeable K and Na by flame photometer. The Si content in the soil samples were extracted by Mehlich-3 Method (Mehlich, 1984) and determined using AAS.

Data from surface soil samples of different land uses and landscape positions along the toposequence were analyzed using General Linear Model of SAS software version 9.0 (SAS Institute, 2009). Analysis of variance (ANOVA) was conducted and least significant difference (LSD) was employed to compare the means.

RESULTS AND DISCUSSION

Site characterization

The site characteristics of the pedons indicated differences in slope, permeability and extent of water erosion (Table 2). Pedons CR, US, MS, LS and DE were on landscapes, which are having slopes of <2, 8, 6, 4 and <0.5%, respectively; and are located on slope classes of convex crest, upper slope, middle slope, lower slope and depression, respectively. The pedons on the convex crest, upper, middle and lower slope classes were well drained, whereas the pedon on depression was poorly drained. Evidences of slight to accelerated water erosion were observed at the sites and surrounding all pedons, except the pedon on depression, showing the susceptibility of soils to water erosion. The US and MS pedons showed signs of accelerated water erosion as evidenced by gullies on the surrounding landscape, while CR and LS experiencing slight water erosion and DE continuous deposition of materials from the nearby Sodo town and the mountains. Consequently, the soils of pedon DE were developed from continuous deposition of material originating from the surrounding hilly slopes including the studied toposequence on which the other pedons are located. On the other hand, the soils of pedons CR, UP, MS, and LS were developed from *in situ* weathering of basaltic parent material, although influence of material deposition was noted on the surface layer of LS pedon.

The slope and parent materials are the major contributing factors for the differences in the site characteristics, that is, erosion, deposition and

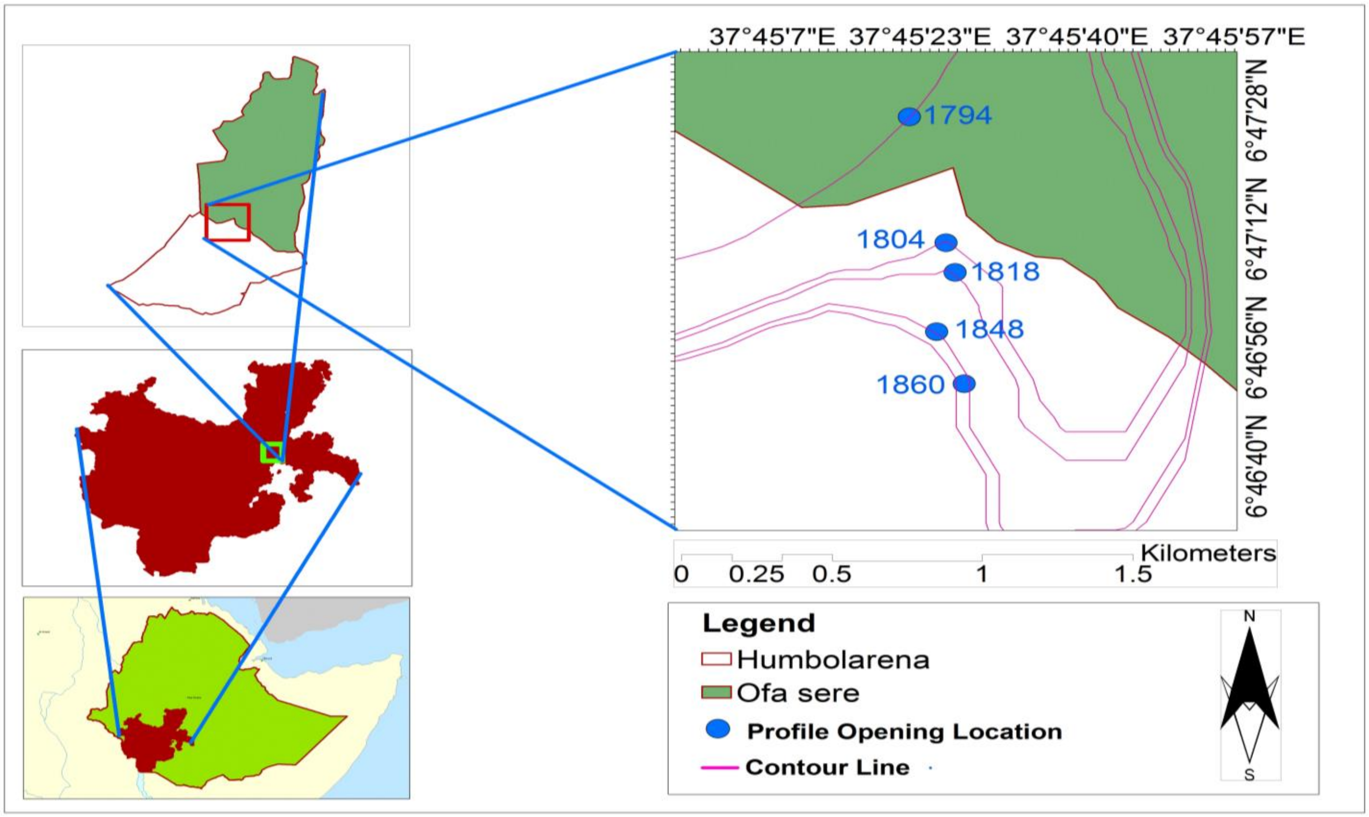

Figure 1. Map of the study site, southern Ethiopia.

drainage. The parent materials determine certain soil properties and drainage condition such as clay mineralogy, which is among other factors to determine the type of soil (Dinku et al., 2014). For instance, the parent material of pedon DE and saturation of the landscape during the wet seasons give rise to the formation of swell and shrinking type clay at the poorly drained depression site. The observed well-drained condition and water erosion on US and MS pedons could be attributed to relatively steep slope gradients and subsequent downslope movement of water. Farmers apply contour plowing and terracing to reduce removal of surface soils on these landscapes. The CR and LS pedons are also well drained with only slight erosion owing to the gentle and nearly flat slopping conditions at these positions. The results are coherent with topographic impact on soil quality through direct soil and water movement and indirect profile development as documented earlier (Thompson and Troeh, 1993).

Morphological properties of the soils

The morphological properties of soils; depth, horizon, color, structure, consistency and horizon boundary varied along the toposequence at the study site. All the pedons had a very deep profile (>200 cm) except the upper slope pedon (Table 3). The CR, MS and LS pedons were characterized by A and B sequence of horizons, while the US pedon consisted of 3 horizons and a rock layer (A-B-BC-R). The pedon at the depression had an A-C-2B-2Bi sequence of horizons showing deposition of materials from the topographically higher pedons and surrounding hilly slopes resulting in lithological discontinuity. The A horizons were formed as a consequence of incorporation of humified organic materials from agricultural crops in the upland toposequence. The B horizons on higher slope positions along the toposequence are the result of *in situ* weathering of the parent material, whereas those at the depression are formed by wetting and drying cycles that aggregated the clay-textured into wedge-shaped angular blocks with pressure faces.

The thickness of the surface horizons (A1 and A2) varied along the toposequence, where the pedon at the LS had relatively the thickest (86 cm) surface horizon followed by the CR, MS and US pedons in decreasing order (Table 3). The relatively shallow thickness of the surface layers of US and MS pedons as compared to that of LS pedon could be attributed to the influence of runoff, which might have removed soil particles from the upper and middle slope positions and partly deposited on the lower slope landscape. Dinku et al. (2014) indicated that

Table 2. Location and site characteristics of the pedons.

Pedon[†]	Geographic position		Altitude (masl)	Slope (%)	Drainage	Erosion		Land use	PM
	Latitude	Longitude				At site	Surrounding		
CR	06° 46’ N	37° 45’ E	1860	1.5	WD	S	S	Cultivated	Basalt
US	06° 46’ N	37° 45’ E	1848	6	WD	M	AG	Cultivated	Basalt
MS	06° 47’ N	37° 45’ E	1818	8	WD	M	AG	Cultivated	Basalt
LS	06° 47’ N	37° 45’ E	1804	4	WD	S	S	Cultivated	Basalt
DE	06° 47’ N	37° 45’ E	1794	<0.5	PD	None	None	Grassland	Pyroclastic deposit

[†]CR, US, MS, LS and DE refer to pedons on crest, upper slope, middle slope, lower slope and depression, respectively; WD = Well-drained; PD = Poorly drained; S = Slight; AG = Accelerated gulley; PM = Parent material.

steepness, shape and length of slope are important in influencing the rate at which water enters into or runoff the soil. The running water, if the site is unprotected, may erode soils on slopes and form thinner surface layer because the surface soil is consistently removed by erosion. On the other hand, the increment in the thickness of surface layers at LS can be attributed to soil deposition at lower landscape position corroborating the previous findings (Mulugeta and Sheleme, 2010; Sheleme, 2011; Dinku et al., 2014). The gentle slope situation at LS could be the result of accumulation of the soil deposits eroded from the upper and middle slope positions. Furthermore, the continuous deposit of materials from the present toposequence and the surrounding hilly slopes on the pedon at depression might have resulted in development of soils from different geological origin causing lithological discontinuities in the soils.

The shallow thickness of the surface layers of the pedons on upper and middle slopes is an indication of soil instability due to active process of soil erosion, whereas the relatively thick surface layers in the other landscapes (CR and LS) could be an indication of the relative stability of the soils. The horizons in these pedons are characterized by clear smooth and gradual smooth boundaries at the surface and subsurface, respectively (Table 3), whereas pedon DE had abrupt wavy boundary between the two geologic materials from which the soils develop (Figure 2).

The pedons have shown a great variability in relation to soil color patterns. Surface soil color ranged from very dusky red (2.5YR 2.5/2) to very dark brown (7.5YR 2.5/2) moist, whereas the color of the subsurface horizons varied from dusky red (7.5R 3/3) to black (G1 2.5/N) moist (Table 3). Most of the pedons (CR, US, MS and LS) had darker color in the surface as compared to subsurface horizons owing to the relatively higher organic matter contents in the surface horizons. The results show that soil color is highly influenced by organic matter content whereby the color is getting darker with increase in organic matter content (Haviln et al., 1999; Teshome et al., 2016). In general, hue is redder and the value and chroma increased with soil depth (Table 3). Soils on slopes that were never saturated with water had reddish and brownish subsoil colors, which are indicatives of well-drained and aerated conditions. This might be due to an accumulation of sesquioxides in subsurface layer, which are often responsible for the apparent reddish soil color. Red color in surface and subsurface horizons suggest the presence of iron compounds in the different states of oxidation and hydration as was also suggested by Foth (1990) and Alemayehu et al. (2016). Abayneh (2005) have also reported soil profiles with darker B horizons as compared to their surface counterparts.

The moist soil color of the horizons in the pedon at the depression (DE) varied from reddish brown (2.5YR 3/2) to black (G1 2.5/N). The horizons in this pedon varied from that of others with respect to soil color due to reduction reaction caused by seasonal water saturation. The gley color in subsurface layer of this pedon is attributed to imperfect drainage condition, as the pedon was located on poorly drained area. Soils formed under water saturation condition for certain period of time during the year will tend to have gray-colored horizons due to reduction reactions (Foth, 1990; Mulugeta and Sheleme, 2010; Dinku et al., 2014). The sharp changes in color both in moist and dry as well as the existence of buried horizons (2B, 2Bi) with abrupt textural changes in the pedon at depression (DE) show the occurrence

Table 3. Morphological characteristics of the soils in the Pedons.

Pedon†	Depth (cm)	Horizon	Color		Structure*	Consistency*		Boundary@
			Moist	Dry		Moist	Wet	
CR	0-33	Ap1	2.5YR 2.5/2	2.5YR 4/3	WE, VM, GR	VFR	SST, SPL	C, S
	33-55	Ap2	2.5YR 3/2	2.5YR 4/3	MO, FM, SB	FR	ST, SPL	C, S
	55-123	B1	10R 3/4	10R 3,6	MO, FM, AB	FI	ST, PL	G, S
	123-200+	B2	7.5R 3/4	10R 4/6	MO, FC, AB	FI	ST, PL	-
US	0-18	Ap1	5YR 2.5/2	2.5YR 3/3	WE, VM, GR	VFR	SST, SPL	C, S
	18-41	Ap2	2.5YR 3/2	10YR 4/4	MO, FM, SB	FR	ST, PL	G, S
	41-90	B	2.5YR 3/3	2.5YR 4/6	MO, FM, AB	FR	ST, PL	G, S
	90-150	BC	2.5YR 3/4	10R 4/6	MO, FM, AB	FR	ST, PL	C, W
	-	R	-	-	-	-	-	-
MS	0-25	Ap1	2.5YR 2.5/2	5YR 4/3	WE, VM, SB	VFR	SST, SPL	C, S
	25-52	Ap2	5YR 3/3	5YR 4/4	MO, FM, SB	FR	SST, SPL	C, S
	52-200+	B	10R 4/3	10R 4/6	MO, FC, AB	FI	ST, PL	-
LS	0-25	Ap1	7.5YR 2.5/2	5YR 3/4	WE, FM, GR	VFR	SST, SPL	C, S
	25-86	Ap2	5YR 2.5/2	2.5YR 3/3	MO, FM, SB	FR	SST, SPL	G, S
	86-200+	B	7.5R 3/3	10R 4/6	MO, FC, AB	FI	ST, PL	-
DE	0-14	A	2.5YR 3/2	5YR 3/2	MO, F, GR	FR	ST, PL	A, S
	14-50	C	10YR 3/1	7.5YR 5/1	MA	FR	SST, SPL	A, W
	50-100	2B	G1 2.5/N	G1 3/1	MO, F, AB	VFI	VST, VPL	D, W
	100-200+	2Bi	G1 2.5/N	G1 3/1	ST, C, AB	VFI	VST, VPL	D, W

†CR, US, MS, LS and DE refer to pedons on crest, upper slope, middle slope, lower slope and depression, respectively; *WE = Weak; F = Fine; FM = Fine to medium; FC = Fine to coarse; VM = Very fine to medium; C = Coarse; GR = Granular; SB = Sub-angular blocky; AB = Angular blocky; VFR = Very friable; FR = Friable; FI = Firm; VFI = Very firm; SST = Slightly sticky; ST = Sticky; SPL = slightly plastic; PL = Plastic; VST = Very sticky; VPL = Very plastic; @ C = Clear; S = Smooth; G = Gradual; W = Wavy; A = Abrupt; D = Diffuse.

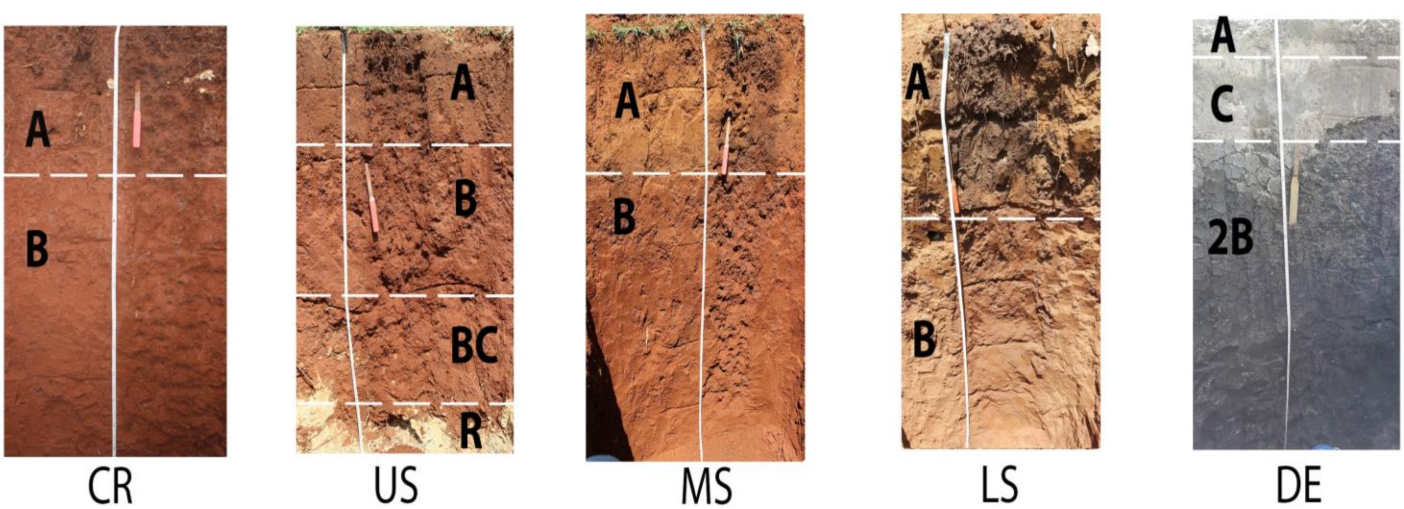

Figure 2. Profiles of the representative pedons.

of lithological discontinuity in the location.

The soil structure in the pedons on the slope positions (CR, US, MS and LS) varied from weak, fine to medium granular and sub-angular blocky at the surface to moderate, fine to coarse angular blocky in the subsurface layers, whereas pedon DE had moderate, fine granular in the surface and strong, coarse angular blocky in its subsurface horizons (Table 3). In general, a better structural development down the profile was observed in all pedons due to the relatively higher clay content of the subsurface horizons than their respective surface horizons (Ashenafi et al., 2010; Alemayehu and Sheleme, 2013).

Very friable consistence was observed in the surface layers of the profiles, except for DE pedon where friable consistence was noted, whereas the wet consistence ranged from slightly sticky/slightly plastic to very sticky/very plastic (Table 3). The very friable and friable consistence observed in the surface layers could be attributed to the relatively higher organic matter contents of the layers and indicates that the soils are workable at appropriate moisture content. Although consistence is an inherent soil characteristic, the presence of high organic matter in the surface horizon changes its consistence (Wakene and Heluf, 2006). The very sticky/very plastic consistence observed in the pedon at depression could be attributed to the dominance of the smectite clay minerals in the layers. Smectite clay minerals mainly control the plasticity in soils and form smooth gels when mixed with sufficient water. These are main constituent of highly plastic soils, which experience periodic swelling and shrinkage during alternate wet and dry periods (Dinku et al., 2014).

Physical properties of the soils along the toposequence

The field as well as laboratory textural class determinations revealed that the soils are dominated by clay fraction and accordingly, the textural class of the soils in all pedons was clay (Table 4). This could be attributed to the basaltic parent material, which weathers into fine-textured soils (Buol et al., 2003). The textural class of the soils did not also vary under different land use systems, indicating the mineral particles in a soil are not readily subject to change by management practices (Sheleme, 2011). However, the soils at all slope positions showed discernible increase in clay content with depth indicating high rates of clay formation in subsoil horizons.Change in clay percentage down the profile suggests pedogenic eluviation-illuviation processes (Mulugeta and Sheleme, 2010). But, vertical migration of clay down the profile was not evident in the present study, as clay cutans or clay skins were not observed in the B-horizons during description of the profiles in the field. Thus, the accumulation of clay in the subsoil horizons of the pedons could have been due to predominant *in situ* synthesis of clay from the weathering of primary minerals in B horizons.

As a result of higher clay contents in B horizons compared to their respective surface layers, the silt:clay decreased with increasing depth within the profiles, and from the crest to the middle slope position along the toposequence (Table 4). However, the silt content and silt:clay ratio increased at LS position due to the higher silt fraction content of this pedon compared to those on the upper slopes indicating the susceptibility of silt separates to water erosion. In accordance with Mulugeta and Sheleme (2010), when erosion occurs on hill-slope, the silt content often is higher in bottom soils compared to the soils on hill-slope. In general, the silt:clay ratio of the soils along the slope (CR, US, MS and LS) is below a unity showing that the soils are at the advanced stage of weathering (Abayneh, 2005). On the other hand, inconsistent silt:clay ratio was observed in the DE pedon due to the contrasting materialsforming the soil, whereby it was more than a unity in the C and lower than unity in clayey horizons.

Chemical properties of the soils along the toposequence

The soil pH in the surface layers (A horizons) of the pedons varied from moderately acidic to neutral (EthioSIS, 2016), except for that of the depression pedon (Table 5), and was within the preferred range for most crops. The pH decreased with soil depth at the crest, increased at upper slope and depression, and remained unchanged at the other two slope positions (MS and LS). Lower pH value was recorded in steep slope position as compared to the gently sloping landscapes, perhaps due to the removal of bases from the higher slope gradient and their accumulation on gentle and moderate slopes (Table 5) corroborating the findings of Mulugeta and Sheleme (2010), although this could not explain the low soil pH obtained in the depression.

The cation exchange capacity (CEC) of the soils ranged from 21.4 to 67.2 cmol (+) kg^{-1} (Table 5) and showed variation with depth of the profiles. The higher CEC values in surface layers of the pedons along the upslope positions (CR, US, MS and LS) as compared to their subsurface counterparts could be attributed to the effect of the relatively higher organic matter content of the surface layers, since organic matter is strongly associated with CEC as was also discussed by Ashenafi et al. (2010). Generally, the CEC of the soils was medium to high (Landon, 1991) and the exchange complex was dominated by Ca followed by Mg, K and Na (Table 5). Total exchangeable bases and base saturation of the soils were influenced by slope classes, whereby the pedons at lower slope (LS) and depression (DE) had higher exchangeable bases and base saturation as compared to those on upslope positions (CR, US and MS). This could be attributed to the transport of soil materials from upslope positions and their deposition on the lower slope and depression. The exchangeable Ca, Mg and K contents of the soils are above the critical values of 1.25-2.5, 0.25–0.5 and 0.28–0.51 cmol kg^{-1} soil, respectively (Landon, 1991). The Ca:Mg ratio of the soils was in the range between 2.7 and 4.7, which is within the acceptable range for crop production. However, the Mg:K ratios in surface soils of LS and DE positions, 2.4 and 3.8 respectively, indicate Mg induced K deficiency (Loide, 2004).

Table 4. Selected physical properties of the soils in the pedons.

Pedon[†]	Depth (cm)	Horizon	Particle-size distribution (%)			Textural class	Silt: clay ratio
			Sand	Silt	Clay		
CR	0-33	Ap1	22	26	52	Clay	0.50
	33-55	Ap2	18	18	64	Clay	0.28
	55-123	B1	10	11	79	Clay	0.14
	123-00+	B2	8	7	85	Clay	0.08
US	0-18	Ap1	26	20	54	Clay	0.37
	18-41	Ap2	28	18	54	Clay	0.33
	41-90	B	18	12	70	Clay	0.17
	90-150	BC	20	14	66	Clay	0.21
	150+	R	-	-	-	-	
MS	0-25	Ap1	24	18	58	Clay	0.31
	25-52	Ap2	30	18	52	Clay	0.35
	52-200+	B	13	9	78	Clay	0.12
LS	0-25	Ap1	31	29	40	Clay	0.73
	25-86	Ap2	25	26	49	Clay	0.53
	86-200+	B	14	11	75	Clay	0.15
DE	0-14	A	14	24	62	Clay	0.39
	14-50	C	16	44	40	Silty Clay	1.10
	50-100	2B	11	7	82	Clay	0.09
	100-200+	2Bi	12	6	82	Clay	0.07

[†]CR, US, MS, LS and DE refer pedons on crest, upper slope, middle slope, lower slope and depression, respectively

Similar to CEC, higher values of total exchangeable bases were noted in the surface layers than in the subsurface counterparts of the pedons, except for DE pedon (Table 5). This might be due to the relatively higher organic matter contents of the surface layers and an indication of limited leaching of bases in the profiles. The results corroborate previous findings (Mulugeta and Sheleme, 2010) from the nearby district in Southern Ethiopia, but are in contrast to the findings of Heluf and Wakene (2006), Sheleme (2011) and Dinku et al. (2014), who reported increments of exchangeable bases with soil depth. Generally exchangeable Na increased with soil depth, but the exchangeable sodium percentage (ESP) was below 3 in all the pedons indicating absence of sodicity problem in the soils.

In pedon DE however, higher CEC, exchangeable bases and base saturation values were recorded in the B horizons owing to the very high smectite clay content, which contributes higher CEC/kg clay (Abayneh, 2005). The high silicon concentration coupled with higher Mg content (Table 5) in seasonally waterlogged depression position of the DE pedon is responsible for the resilication process and thereby formation of smectite clays as indicated by Buol et al. (2003).

The organic carbon, total nitrogen and available phosphorus contents of the soils decreased with

Table 5. Chemical properties of the soils in the pedons.

Pedon[†]	Depth (cm)	pH-H_2O	Exchangeable cations (cmol (+) kg^{-1})				TEB	CEC	BS	OC (%)	TN	C:N	Av P (mg kg^{-1})	Si
			Ca	Mg	K	Na								
CR	0-33	6.22	6.11	1.80	2.66	0.30	10.88	38.1	29	2.70	0.22	12.3	6.78	745.5
	33-55	5.34	5.89	1.68	0.80	0.38	8.75	36.2	24	1.31	0.11	11.9	0.74	685.2
	55-123	5.10	5.95	1.96	0.62	0.61	9.14	32.0	29	0.66	0.08	8.7	0.43	587.1
	123-200+	5.06	5.99	1.57	1.02	0.67	9.25	25.7	36	0.41	0.06	7.2	0.43	569.3
US	0-18	6.69	6.23	2.12	2.31	0.10	10.76	34.5	31	1.45	0.12	12.0	4.04	985.5
	18-41	7.06	5.91	1.74	1.98	0.20	9.83	28.0	35	0.84	0.07	11.4	5.22	1,061.1
	41-90	7.13	5.91	2.43	2.33	0.24	10.91	28.0	39	0.48	0.04	12.3	4.99	999.4
	90-150	7.32	6.45	1.90	2.51	0.23	11.09	21.4	52	0.31	0.04	7.1	0.23	993.6
	150+	-	-	-	-	-	-	-	-	-	-	-	-	-
MS	0-25	6.06	5.93	2.24	0.95	0.37	9.49	27.2	35	1.50	0.12	12.6	0.69	756.1
	25-52	6.16	5.99	1.98	0.67	0.39	9.03	34.0	27	1.29	0.09	14.0	0.85	782.2
	52-200+	6.54	5.89	1.21	0.77	0.27	8.14	25.8	32	0.49	0.06	8.2	1.33	674.8
LS	0-25	6.97	8.58	1.83	2.01	0.11	12.53	34.0	37	2.43	0.19	13.2	8.45	987.0
	25-86	7.06	7.29	1.26	1.87	0.17	10.59	30.3	35	1.29	0.11	11.4	3.05	997.2
	86-200+	6.72	6.19	1.81	1.99	0.22	10.21	26.5	39	0.44	0.07	6.3	1.76	870.6
DE	0-14	5.17	9.40	2.60	0.68	0.60	13.28	46.1	29	3.67	0.30	12.2	2.40	757.9
	14-50	5.88	9.86	2.01	0.24	0.72	12.83	35.0	37	1.01	0.09	11.3	1.60	990.6
	50-100	7.30	5.87	2.19	1.30	2.03	11.39	62.2	18	1.17	0.08	14.8	2.30	1,386.0
	100-200+	7.64	14.01	2.49	1.22	2.06	19.78	67.2	29	0.55	0.03	16.4	3.32	1,669.7

[†]CR, US, MS, LS and DE refer to pedons on crest, upper slope, middle slope, lower slope and depression, respectively.

soil depth (Table 5) which might be due to the concentration of most of the root activities and incorporation of organic materials in the surface layers. The organic carbon (OC) and total nitrogen (TN) concentrations in the pedons were in the very low to optimum range (EthioSIS, 2016). In general, the OC and TN increased with decreasing slope gradient, which could be attributed to the transport of organic materials from areas having higher slopes to landscapes with gentle or flat gradient corroborating the previous findings (Sheleme, 2011; Dinku et al., 2014). The C:N ratio of the soils ranged from 7.1 to 16.4 and decreased with soil depth, except for the DE pedon (Table 5). The ratio is within the range to provide nitrogen in the excess of microbial needs (Landon, 1991) indicating optimum microbial activities for humification and mineralization of organic residues.

Available P content in the pedons ranged from 0.23 mg kg^{-1} in the BC horizon of US to 8.45 mg kg^{-1} in the A horizon of LS (Table 5) and was very low to low (EthiSIS, 2016). The low availability of P might be due to the inherent P deficiency of the

Table 6. Selected chemical properties of the surface soils as influenced by land use.

Land use	pH-H_2O	OC (%)	Av.P (mg kg^{-1})	Exchangeable bases (cmol (+) kg^{-1})				TEB	CEC	BS (%)
				Ca	Mg	K	Na			
Cultivated	5.81	1.73^{b}	7.23^{a}	16.88^{b}	2.24^{b}	1.19^{b}	0.38	23.69^{b}	44.6^{b}	59
Grassland	5.91	2.33^{a}	4.24^{b}	19.40^{a}	6.10^{a}	2.11^{a}	0.35	27.96^{a}	50.4^{a}	57
LSD $_{0.05}$	NS	0.25	1.93	0.99	0.49	0.60	NS	1.83	4.4	NS
CV (%)	4.5	16.5	44.6	7.23	11.3	48.4	18	9.37	12.2	17

Values followed by the same letter(s) within a column are not significantly different at P≤ 0.05.

soils and the fixation of P with Fe and Al. Previous reports (Tigist, 2007; Mulugeta and Sheleme, 2010; Wondwosen and Sheleme, 2011; Alemayehu and Sheleme, 2013) also showed that the available P content of most soils in the region is low and P fertilizer application is required for optimum crop production. Higher available P contents were recorded in the surface layers of CR and LS pedons that decreased with depth in line with the OC contents. The decrease in available P down the profile in these pedons could also be attributed to the increase in clay contents of lower horizons that fix P (Sheleme, 2011; Alemayehu et al., 2016). Phosphorus fixation tends to be more pronounced and P release could be lowest in soils with higher clay content (Havlin et al., 1999). Additionally, Dinku et al. (2014) have also argued that the relatively higher available P in the surface as compared to subsurface horizons could be due to the difference in organic matter contents and application of P-containing fertilizers on cultivated lands. The relatively higher available P content of the surface soils in CR and LS as compared to DE pedon could therefore be due to the application of P fertilizers on these cultivated lands.

Chemical properties of surface soils as influenced by land use along the slopes

The chemical properties of the surface soils including organic carbon, available P, exchangeable bases and CEC were significantly affected by land use (Table 6). Significantly higher OC was noticed under grassland compared to cultivated lands. The lower OC in arable soils as compared to that of the grasslands could be due to low amount of organic materials applied to the soil, complete removal of biomass from the fields and aggravated oxidation of OC by intensive tillage (Yihenew, 2002; John et al., 2005; Mulugeta et al., 2012). Additionally, the relatively high amount of OC in grassland might be due to the dominance of roots and humus in the grassland as compared to the other land use type (Heluf and Wakene, 2006). The slightly higher pH values exhibited by soils samples collected from grassland as compared to those from cultivated land (Table 6) also demonstrate higher rate of organic matter oxidation, which produces organic acids and provide H-ions to soil solution, resulting in lower pH values, in cultivated lands (Gebeyaw, 2007). Furthermore, the relatively lower pH values of cultivated fields might also be due to depletion of basic cations through crop harvest corroborating the finding of Sheleme (2011).

Grassland soils also exhibited significantly higher values of total exchangeable bases and CEC compared to the cultivated soils (Table 6). These could be attributed to the relatively higher organic matter contents of the grassland soils and indicate lower loss of bases from grassland soils as compared to their cultivated counterparts as discussed by Dinku et al. (2014). On the other hand, available P was higher in cultivated soils than in the grassland (Table 6) which could be due to application of P-containing fertilizers on cultivated lands as was also reported by Alemayehu and Sheleme (2013).

The chemical properties of the surfaces soils under cultivated and grasslands including pH, OC, available P, exchangeable bases and CEC were also significantly affected by topographic positions in the landscape (Table 7). Irrespective of the land use types, the lowest values of the considered parameters; pH, OC, exchangeable Ca, Mg, K, Na, and CEC, were recorded at the topographic position with the highest slope gradient (MS) indicating the removal of OC and bases from steep slope areas in line with previous findings

Table 7. Selected chemical properties of the surface soils under cultivated and grassland as influenced by slope positions along the toposequence.

Slope position	pH-H_2O	OC (%)	Av.P (mg kg^{-1})	Exchangeable bases (cmol (+) kg^{-1})				TEB	CEC	BS (%)
				Ca	Mg	K	Na			
CR	5.79^b	2.52^a	6.92^{ab}	10.27^d	4.19^c	1.40^{bc}	0.24^{bc}	16.1^d	59.7^{ab}	27^d
US	6.28^a	1.92^b	9.21^a	23.17^b	6.85^a	2.80^a	0.29^b	33.1^b	64.2^a	52^c
MS	5.39^c	1.34^c	4.31^{bc}	8.89^d	4.76^c	1.31^{bc}	0.16^c	15.1^d	24.4^d	62^{bc}
LS	5.95^b	1.71^b	5.06^{bc}	17.93^c	5.90^b	1.91^{ab}	0.22^{bc}	25.9^c	34.9^c	78^a
DE	5.88^b	2.88^a	3.16^c	30.45^a	6.63^{ab}	0.84^c	0.92^a	38.8^a	54.4^b	72^{ab}
$LSD_{0.05}$	0.32	0.40	3.06	1.57	0.77	0.96	0.08	2.9	6.94	11.9
CV (%)	4.5	16.5	44.6	7.23	11.3	48.4	18	9.37	12.2	17

Values followed by the same letter(s) within a column are not significantly different at P≤ 0.05.

(Sheleme, 2011; Dinku et al., 2014).

Generally, the organic carbon content increased with decreasing slope gradient (Table 2 and 7) and varied from low (1.34%) at the highest slope gradient to optimum (2.88%) at the depression (Landon, 1991). Similarly, the lowest and highest values of total exchangeable bases were noticed at the highest slope gradient position and depression, respectively, indicating the removal of exchangeable bases from steep slopes and their accumulation in nearly flat areas. Exchangeable Ca was the dominant cation on exchange sites followed by Mg > K > Na. The saturations of both Ca (17-56%) and Mg (7-19%) ranged from very low to optimum, whereas the K concentration (0.8-2.8 cmol (+) kg^{-1}) was in the optimum to very high range (Landon, 1991). These results indicate that Ca:Mg ratios (3.0-4.6) at LS, US and DE positions were in adequate range, whereas their ratios of 1.8 and 2.4 at MS and CR respectively, show Mg induced Ca deficiency at these positions (Loide, 2004) corroborating previous finding in nearby district (Sheleme, 2011). On the other hand, the K:Mg ratio (0.13-0.41) in surface soils of all positions was low and indicative of Mg induced K deficiencies (EthioSIS, 2016).

Although the absolute values of K concentration were about optimum threshold in clay soils, deficiency of K could result from its imbalance with Mg. Potassium-to-magnesium ratio of 0.7:1 was suggested as optimum (Loide, 2004) and values lower than 0.5 may affect K uptake in clayey soils. In line with this, Wodwosen and Sheleme (2011) also reported that K is a potentially limiting nutrient for supporting good crop growth in Alfisols of the neighboring district.

Classification of the soils

All pedons in upslope positions (CR, US, MS and LS) had well-structured dark surface horizons of more than 20 cm in thickness having color values and chroma of less than 3 when moist. The surface layers of the pedons contained more than 0.6% OC, but base saturation (by 1 M NH_4OAc, pH 7)) of less than 50% (Table 5) meeting the diagnostic criteria of Umbric diagnostic horizon.

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The subsurface horizons of all pedons in the upslope positions (CR, US, MS and LS) were greater than 15 cm in thickness with moderately developed angular blocky structures and distinct higher clay content, more than 1.4 times more clay, than the overlying layers, indicating predominant formation of clay in the subsoils with CEC(by 1 M NH_4OAc, pH 7) of more than 24 $cmol_c$ kg^{-1} clay. Consequently, the four pedons were classified as Alisols (FAO, 2014). The layers were greater than 30 cm in thickness, clayey in texture and having Munsell color redder than 5YR and values less than 4 (moist) qualifying for Rhodic prefix and Clayic suffix. Thus, the soils were grouped under Rhodic Alisols (Clayic) in accordance with World Reference Base for Soil Resources (FAO, 2014).

The pedon at depression had a thick (>150 cm) buried subsurface horizons with greater than 30% clay, wedge-shaped soil aggregates and slickensides produced by shrink and swell cracks qualifying for Vertic horizon (FAO, 2014). The layers above the buried horizons also contained more than 30% clay throughout and shrink-swell cracks starting at the surface. Consequently, the pedon was classified as Vertisol. The surface layers (0-50 cm) had Munsell color values of 3 and chroma 2 and less both moist, and self-mulching granular structure qualifying for Pellic and Grumic, prefix and suffix, respectively. The soils of this pedon were classified under Pellic Vertisols (Grumic) in accordance with World Reference Base for Soil Resources (FAO, 2014).

Conclusions

Soils of Humbo Larena-Ofa Sere toposequence, Southern Ethiopia, showed variability in distribution, which were conditioned by topographic features. Topography influenced the soil formation along the toposequence, whereby the soils on higher slope positions were developed from *in situ* weathering of the parent material, whereas continuous deposition of materials from the present toposequence and the surrounding hilly slopes on the pedon at depression resulted in development of soils of different geological origin and causing lithological discontinuities. Consequently, two soil types, Rhodic Alisols (Clayic) and Pellic Vertisols (Grumic) were identified in upslope positions (crest, upper-, middle- and lower-slope) and at depression respectively. High Si and Mg contents at seasonally waterlogged depression position enhanced resilication process and the formation of smectite clays. Thus, soil management practices to control erosion should be implemented on upslope positions to reduce runoff and surface soil removal.

Grassland soils had higher amount of organic carbon, exchangeable bases and CEC, but lower available P as compared to their cultivated counterparts. Magnesium induced deficiencies of basic cations, particularly K and to a lesser extent Ca, is expected in the soils at different topographic positions. Thus, integrated soil fertility management should be employed to manage the cation balances and build up soil organic matter as it influences soil physical, chemical and biological quality. In general, the observed relationships between features of landscape, soil characteristics and soil types will help to advance soil-landscape relations in the study area, and showed less costly way of acquiring soil information. These are critical for making informed decision with respect to management practices for sustainable agricultural production.

CONFLICTS OF INTERESTS

The author has not declared any conflict of interests.

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REFERENCES

Abay A, Sheleme B, Walley F (2015). Characterization and classification of soils of selected areas in southern Ethiopia. J. Environ Earth Sci. 5(11):116-137.

Abayneh E (2005). Characteristics, Genesis and Classification of Reddish Soils from Sidamo, Ethiopia. PhD Thesis University of Putra, Malaysia.

Alemayehu K, Sheleme B (2013). Effects of different land use systems on selected soil properties in Southern Ethiopia. J. Soil Sci. Environ. Manage. 4(5):100-107.

Alemayehu K, Sheleme B, Schoenau J (2016). Characterization of problem soils in and around the south central Ethiopian Rift Valley. J. Soil Sci. Environ. Manage. 7(11):191-203.

Ashenafi A, Abayneh E, Sheleme B (2010). Characterizing soils of Delbo Wegen watershed, Wolayita zone, southern Ethiopia, for planning appropriate land management. J. Soil Sci. Environ. Manage. 1(8):184-189.

Belayneh A (2009). Effects of land use/land cover on selected soil physicochemical properties in the western part of Mount Guna, south Gonder zone, Amhara Region. MSc Thesis, Mekele University, Ethiopia.

Brady NC, Weil RR (2002). The Nature and Properties of Soils. 13th ed. Prentice Hall Inc., New Jersey.

Bremner JL, Mulveny CS (1982). Nitrogen Total, In: AL Page (ed). Methods of Soil Analysis, Part Two, Chemical and Microbiological properties, 2nd ed. Am. Soc. Agron. Wisconsin pp. 595-624.

Buol SW, Southard RJ, Graham RC, McDaniel PA (2003). Soil Genesis and Classification, 5th ed., Iowa State Press, Ames, USA.

Dinku D, Sheleme B, Nand Ram, Walley F, Gala TS (2014). Effects of Topography and land use on soil characteristics along the toposequence of Ele watershed in southern Ethiopia. Catena, 115:47-54.

Ethiopian Soil Information System (EthioSIS) (2016). Soil Fertility Status and Fertilizer Recommendation Atlas of the Southern Nations, Nationalities and Peoples' Regional State, Addis Ababa, Ethiopia.

Fantaw Y, Ledin S, Abdu A (2006). Soil property variations in relation to topographic aspect and vegetation community in southeastern highlands of Ethiopia. Forest Eco. Manage. 232:90-99.

Food and Agriculture Organization (FAO) (2006). Guidelines for Field Soil Description, 4th ed., Management Service Information Division Pub., FAO, Rome.

Food and Agriculture Organization (FAO) (2014). World reference base for soil resources, International soil classification system for naming soils and creating legends for soil maps, World soil resources reports 106, FAO, Rome.

Foth HD (1990). Fundamentals of Soil Science, 8th ed., John Willey and Sons Inc., New York: 360p.

Gebeyaw T (2007). Soil fertility status as influenced by different land uses in Maybar areas of south Wello Zone, north Ethiopia. MSc Thesis, Haramaya University, Ethiopia.

Havlin JL, Beaton JD, Tisdale SL, Nelson WL (1999). Soil Fertility and Fertilizers: An Introduction to Nutrient Management, 6th ed., Prentice Hall Inc., NJ, USA.

Heluf GK, Wakene N (2006). Impact of land use and management practices on chemical properties of some soils of Bako area, western Ethiopia. Ethiopian J. Nat. Res. 8(2):177-197.

John B, Yamashita T, Ludwig B, Flessa H (2005). Storage of organic carbon in aggregate and density fractions of soils under different types of land use, Geoderma. 128:63-79.

Korres W, Reichenau TG, Schneider K (2013). Patterns and scaling properties of surface soil moisture in agricultural landscape: An ecohydrological modelling study. J. Hydrol. 489:89-102.

Landon JR (1991). Booker: Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in Tropics and Subtropics, Longman, London.

Loide V (2004). About the effects of the contents and ratios of soil's available calcium, potassium and magnesium in liming acid soils. Agron. Res. 2(1):71-82.

Mehlich A (1984). Mehlich-3 Soil Test Extractant: A modification of Mehlich-2 Extractant, Commun. Soil Sci. Plant Anal. 15(12):1409-1416.

Mulugeta D, Sheleme B (2010). Characterization and classification of soils along the toposequence of Kindo Koye watershed in southern Ethiopia. East Afr. J. Sci. 4 (2):65-77.

Mulugeta D, Sheleme B, Mulugeta L (2012). Impact of slope position on soil carbon and total nitrogen stocks along a catena in Kindo Koye watershed, southern Ethiopia. Ethiopian J. Nat. Res. 12(2):185-195.

Olsen SR, Sommers LE (1982). Phosphorus. In: AL Page (ed). Methods of Soil Analysis, Part Two, Chemical and Microbiological properties, 2nd ed. Am. Soc. Agron. Wisconsin pp. 403-429.

Sahlemedhin S, Taye B (2000). Procedures for soil and plant analysis, National Soil Research Center, EARO, Technical Paper No. 74, Addis Ababa, Ethiopia. 110p.

Sheleme B (2011). Soil characterization along toposequence in Gununo area, southern Ethiopia. J. Sci. Dev. 1(1):31-39.

Statistical Analysis Systems (SAS) (2009). The SAS Institute Inc., Cary, NC, US.

Teshome Y, Sheleme B, Kibebew K (2016). Characterization and classification of soils of Abobo area, western Ethiopia. Applied and Environ. Soil Sci. 1-16.

Thompson LM, Troeh RF (1993). Soils and Soil Fertility, 5th ed., Oxford University Press, NY, USA. P 462.

Tigist Y (2007). Soil phosphorus forms as influenced by land use systems and topography in the Ultisols of Kindo Koye watershed, southern Ethiopia. MSc Thesis, Hawassa University, Ethiopia.

Van Reeuwijk LP (1993). Procedures for Soil Analysis, International Soil Reference and Information Center (ISRIC)", The Netherlands, 4th ed.

Walkley A, Black IA (1934). Method for determining soil organic matter and a proposed modification of the chromic soil titration method. Soil Sci. 37:29-38.

Wang J, Fu B, Qiu Y, Chen L (2001). Soil nutrients in relation to land use and landscape position in semi-arid small catchment of the loess plateau in China. J. Arid Environ. 48:537-550.

Wondwosen T, Sheleme B (2011). Identification of growth limiting nutrient(s) in Alfisols: Soil physico-chemical properties, nutrient concentrations and biomass yield of maize. Am. J. Plant Nut. Fert. Technol. 1(1):23-35.

Xiao M (2009). Soil Testing Laboratory Manual. Bent Tree Press, Reno, Nevada.

Yihenew GS (2002). Selected chemical and physical characteristics of soils of Adet Research Center and its testing sites in northwestern Ethiopia. Ethiopian J. Nat. Res. 4(2):199-215.