Characterization and Classification of Soils of Muger Sub-Watershed, Northern Oromia, Ethiopia

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Abstract: Soil characterization and classification is the main information source for soil management and precision agriculture. However, much of Ethiopia's documented soil information is scanty and inadequate relative to the large size of the country and the wide diversity of soils and landscapes. This study was, therefore, conducted with the objective of characterizing and classifying soils of the Muger sub-watershed in North Shoa Zone of Oromia Regional State, Ethiopia. Three slope classes were considered and eight representative pedons (P01-P08) were opened and described at the study area. Soil samples collected from identified horizons of each pedon were analyzed following standard procedures. The field as well as the laboratory data revealed that the textural classes of most of the pedons were sandy clay loam followed by sandy clay. The soils are acidic to neutral in reaction (pH 5.59-7.24). Organic carbon, cation exchange capacity, and percent base saturation of the soils range from 0.41 to 4.06%, 26.42 to 60.94 cmol (+)kg^{-1} and 56.58 to 93.97%, respectively. The dominance of exchangeable bases was in the order of $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$. The soils are low to high in available P and total N contents whilst varying from low to high in the contents of available micronutrients measured. The contents of soil organic carbon range from very low to high whereas the CEC and percent base saturation of the soils vary from medium to very high. It is concluded that the soils are classified as Mollic Leptosols (Eutric) (P01, P02, P05, P06 and P08), Pellic Vertisols (Grumic) (P04 and P07), and Rhodic Nitisols (Haplic) (P03) according to the World Reference Base for Soil Resources, and are dominantly sandy clay loam in texture varied contents of organic matter, available phosphorus, total nitrogen, and CEC. The wide variations in the pedons and physico-chemical properties of the soils imply designing land use system appropriate to specific needs of each soil class as well as implementing integrated soil fertility management practices to maintain soil organic matter and essential plant nutrients.

Keywords: Chemical Characteristics; Horizon; Morphological Characteristics; Physical Characteristics; Pedon; World Reference Base

1. Introduction

Soil is the foundation natural resource on which the life supporting system and socio-economic development depends. Soils provide food, fodder and fuel for meeting the basic human and animal needs (Pulakeshi *et al.,* 2014). Since soil is a scarce resource with a carrying capacity that can be stretched only to a limited extent with the help of technology (Buzuayehu *et al.,* 2002), there is an increasing demand for information on it (Fasina *et al.*, 2007; Nicolaescu *et al.*, 2009). Different soil types support different land use systems and require different management options for sustainable productivity. According to Fagbami (1990), the diverse nature of soil is a major reason behind allocation of land to wrong uses. Hence, proper understanding of its nature and properties is necessary for judicious, beneficial, and optimal use on suitable bases (Jagdish *et al.*, 2009).

Soil characterization and classification contribute to alleviating adverse effects of soil diversity. They are the main information source for precision agriculture, land use planning, and management (Ogunkunle, 2005) and also serve as the first milestone to develop database for formulating land use models (Basanta *et al.*, 2013). Soil characterization provides information for our understanding of the soils we depend on to grow crops, sustain forests and grasslands as well as support homes and society structures (Ogunkunle, 2005).

A soil can be characterized by its morphological, physical, chemical, and mineralogical properties (Verma and Jayakumar, 2012). Soil classification helps to organize our knowledge, facilitate transfer of experience and technology from one place to another and helps to compare soil properties (Ogunkunle, 2005). It also links research results and their beneficial extension to field application (Lawal *et al.,* 2012 and Sharu *et al.,* 2013). Moreover, it helps to produce classes that have either similar properties and/or responses to external inputs (Nortcliff, 2006), and soil-related agro-technology transfer (Braimoh, 2002).

Ethiopia is one of the most populated countries in sub-Saharan Africa. Agriculture, which is the backbone of the

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country's economy accounts for 40 percent of the gross domestic product (GDP) (UNDP, 2014), nearly 90 percent of foreign exchange earnings (IFDC, 2012) and supports 73 percent of employment (EATA, 2013).

Although Ethiopia has a long history of collecting basic information on soil characteristics in the form of soil surveys (Eylachew, 1987, 1999; Mitiku, 1987; Mohammed, 2003; Abayneh, 2005; Abayneh and Birhanu, 2006; Mulugeta and Sheleme, 2010; Abay and Sheleme, 2012; Teshome, 2013; Nahusenay *et al.,* 2014), the work is restricted to a few areas. Thus, much of the country's soil information remains rather scanty relative to the large size of the country and the wide diversity of soils and landscapes (Nahusenay *et al.,* 2014). Furthermore, the few existing soil resource inventories that are available are characterized at small scales with high levels of generalization, mainly based on few observations scattered over large areas. The soil resource of the whole country was studied at a scale of 1:2,000,000 (Wijntje-Bruggeman, 1984). Particularly, in Muger sub-watershed, where this research was undertaken, limited information on soil characteristics is a major constraint to application of proper management practices and technology transfer.

Thus, providing up-to-date and site-specific soil information to the beneficiaries based on detailed soil study at watershed level is indispensable. Hence, this study was conducted to characterize the soils from morphological, physical and chemical perspectives determined at field and in laboratory, and to classify the soils of the sub-watershed according to the FAO/WRB classification system.

2. Materials and Methods

2.1. Description of the Study Area

The study area is located in Wuchale district, North Shoa zone of Oromia Regional State, Ethiopia, between 9^{O} 34' 2.13" to 9^{O} 35' 44.7"N latitude and 38^{O} 43' 49.02 " to 38^{O} 45' 41.99" E longitude. The sub-watershed is part of Duber watershed in the central highlands of the country. The total area of the sub-watershed is about 931 ha. The geology of the study area is characterized by thick flood basalt (trap series), with intermediate and silicic lava and pyroclastic sediments interstratified towards the top of the series (FAO, 1984; BFEDO, 2009). The area is largely flat and dissected by seasonal streams and few gentle and steep slopes towards the lowland parts. The highest and lowest elevations are 2672 and 2389 meters above sea level, respectively (Figure1).

A 20-year climate data (1992-2011) indicate that the mean annual rainfall of the area is about 946.1 mm with peak rainy months in July, August, and September. The mean maximum and minimum annual temperatures of the area are 19.2 and 8.2 ^{0}C, respectively, with a mean annual temperature of 14.3 ^{0}C and the warmest and coolest months being occurring in May and November, respectively (Figure 2).

2.2. Site Selection, Field Description, and Soil Sampling

After visiting the preliminary site and gathering land information from elderly farmers, a provisional map was made based on base map (1: 50,000 scale). Representative pedons were selected based on observable site characteristics and described following the guidelines for soil description (FAO, 2006a). 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 to identify variations in soil depth and textural characteristics. A total of eight pedons (P), 1.5 m width, 2 m length and 2 m+ depth (unless soil depth was limited either by stoniness or compactness), were excavated on representative sites on the basis of auger observation and delineation of soil boundary (Table 1 and Figure 1).

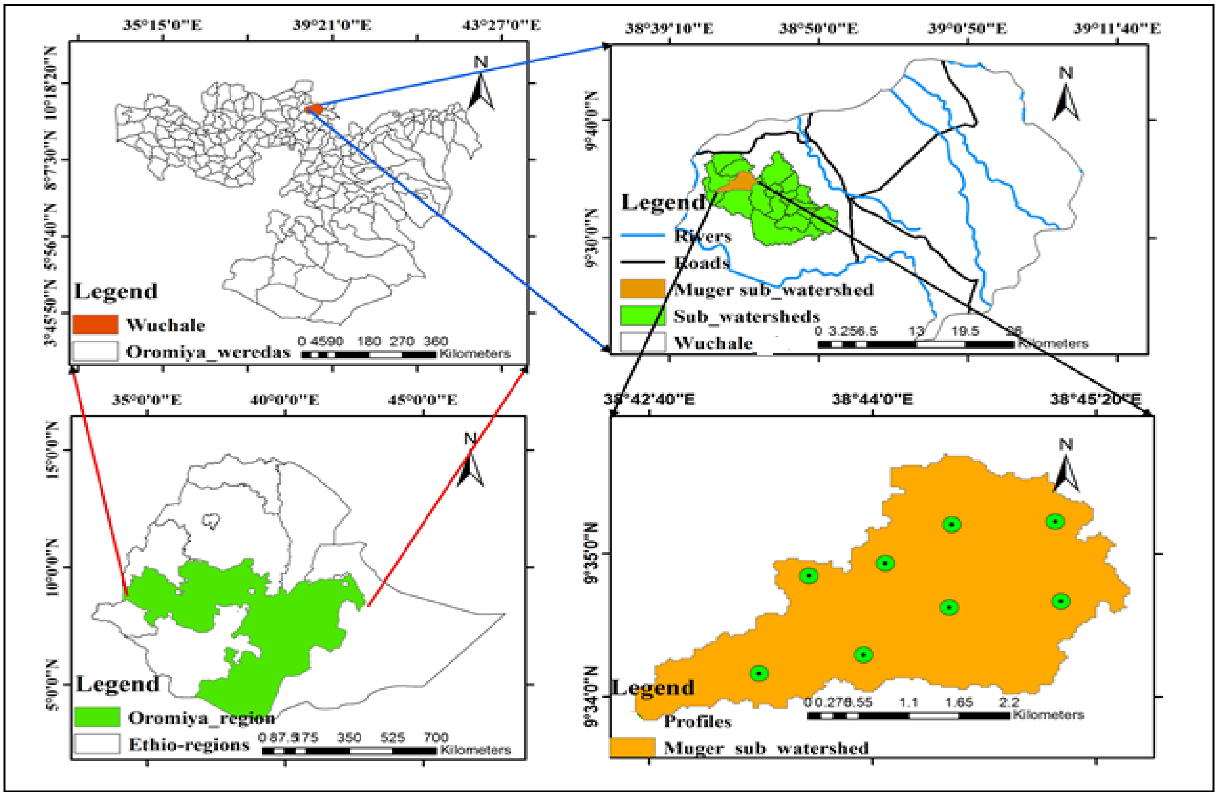

Figure1. Map of the study area,

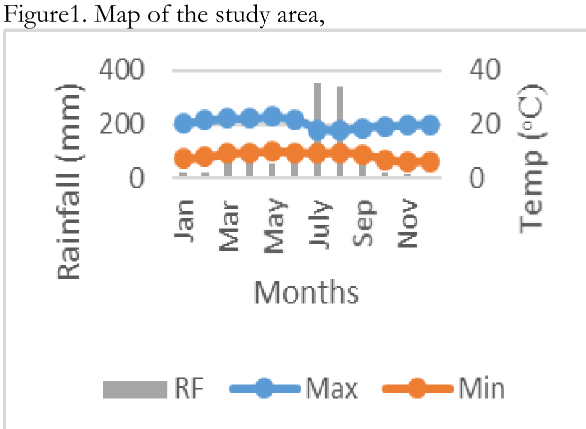

Figure 2. Mean monthly rainfall, maximum and minimum temperature of the study area (1992- 2011).

The pedons on each category were described *in situ* and samples were collected from every identified horizon for laboratory analysis. A total of 21 disturbed (bulk) and 21 undisturbed (core) soil samples were collected depth-wise from each genetic horizon. The core soil samples were used for determination of bulk density and soil moisture retention characteristics. The descriptions of the genetic horizons were carried out following the guidelines for field soil description (FAO, 2006a) and Munsell Color Chart (Munsell Color Company, 1994) was used for soil color notation.

Table 1. Location and land use types of the selected pedons.

Pedons	SP	Easting	Northing	Altitude (masl)	Slope (%)	Land use	Landform
P-01	US	0472320	1059323	2579	*13*	Cultivated *('Tef')*	Undulating
P-02	US	0471605	1059727	2571	11	Cultivated (Wheat)	Undulating
P-03	MS	0470043	1059067	2503	7	Cultivated Wheat	Undulating
P-04	MS	0471746	1059352	2496	9	Grazing land	Undulating
P-05	MS	0470879	1059228	2493	*10*	Cultivated *('Tef')*	Undulating
P-06	MS	0471346	1059047	2482	8	Cultivated (Wheat)	Sloping
P-07	LS	0472737	1059764	2430	5	Grazing land	Undulating
P-08	LS	0470613	1058105	2419	5	Cultivated (Bean)	Undulating

Note: SP = slope position; U S= upper slope; MS = middle slope; LS = lower slope; masl = meters above sea level

2.3. Soil Samples Preparation

The disturbed soil samples were air dried at room temperature, ground, and passed through a 2 mm sieve for analysis of physio-chemical properties. For the analysis of organic carbon (OC) and total nitrogen (total N), however, a 0.5 mm sieve was used.

2.4. Laboratory Analyses

Determination of particle size distribution was carried out by the Bouyoucos hydrometer method (Bouyoucos, 1962). Bulk density was determined using the core-sampling method as described by Black and Hartge (1986). Particle density was determined by the graduated cylinder method as outlined by Bashour and Sayegh (2007). The moisture contents at field capacity (FC) and permanent wilting point (PWP) were measured at the soil water potentials of -1/3 bar (33 kPa) and -15 bars (1500 kPa) respectively, using the pressure plate apparatus technique (Gupta, 2004). The available water content (AWC) was computed from PWP and FC values.

The soil pH (pH-H_2O) and 1M KCl (pH-KCl) were determined in 1: 2.5 soil to water solution ratio using a pH meter as described by Carter and Gregorich (2008). The electrical conductivity was measured by conductivity meter in a soil-water extract (Okalebo *et al.,* 2002). Organic carbon was determined following the Walkley and Black wet oxidation method (Walkley and Black, 1934). Total N of the soils was determined through digestion, distillation and titration procedures of the Micro-Kjeldahl method as described by Bremner and Mulvaney (1982). Available phosphorus in the soil was determined using the sodium bicarbonate extraction solution (pH 8.5) method and the amount was measured by a spectrophotometer as described by Olsen *et al.,* (1954).

Exchangeable bases and cation exchange capacity (CEC) of the soils were determined by the 1M ammonium acetate (pH 7) method (Van Reeuwijk, 1993). Exchangeable Ca and Mg in the extracts were measured by Atomic Absorption Spectrophotometer (AAS), while a flame photometer was used to determine the contents of exchangeable K and Na. Micronutrients (Fe, Mn, Zn and Cu) contents of the soils were extracted by diethylene triaminepenta-acetic acid (DTPA) method (Houba *et al.,* 1989) and the contents in the extract measured by AAS.

2.5. Soil Classification

The soils were classified into different Reference Soil Groups following the World Reference Base for soil resource (FAO, 2014). The presence or absence of specific diagnostic horizons, properties and materials were used to distinguish soil units and subunits. A soil map was prepared using Arc GIS 10.0 software.

2.6. Statistical Analysis

The data from laboratory analyses were subjected to simple correlation analysis to distinguish functional relationships among and within selected soil physico-chemical properties with the help of statistical-package for social sciences (SPSS) software.

3. Results and Discussion

3.1. Site Characteristics of the Pedons

The site characteristics of the pedons indicated differences in slope, permeability, and extent of water erosion. Two (P1 and P2), four (P3, P4, P5 and P6) and two (P7 and P8) pedons were on landscape positions, which are having slopes of 11-13, 7-10 and 5; and are located on slope classes of upper, middle and lower slopes, respectively (Table 1). The slope gradient of the study area was categorized on the basis of FAO slope gradient classes (FAO, 2006a). The gradient varies from strongly sloping (10-15%), to gently sloping (2-5%). The pedon in all slope classes were found to be well drained, maybe due to the sandy clay loam texture and existence of Muger gorge immediately at the outlet of the sub-watershed. The slope and parent materials are the major contributing factors to the differences in the site characteristics. Parent materials determine certain soil properties and drainage condition, which is among other factors to determine the type of soil (David, 2005).

3.2. Morphological Characteristics of the Soils

The morphological properties of soils; horizon, depth, color, structure, consistency and horizon boundary varied along the toposequence at the study site. All the pedons had intermediate to deep profile (50 to 200cm) except P1, P5 and P8 (Table 2). The thickness of the solum varied along the toposequence, whereby the shallowest (20cm) solum with lithic contact within the 50cm depth, which may limit the root penetration for deep rooted crops was observed at upper slope, while deep (>75cm) surface layers were noted on middle and lower slopes (Table 2). The differences in depth of the solum might have been influenced by shape and slope length, which are important in influencing the rate at which water flows into or off the soil if the sites are unprotected. The running water may erode soils on slopes and form thinner surface layer, A-horizon (Broderson, 1994). Mulugeta and Sheleme (2010) also reported that landscapes position influences runoff, drainage, soil temperature, soil erosion, soil depth and hence soil formation.

The distinctness of horizon boundary between surface and subsurface horizons in all pedons were clear with smooth topography, except in pedons 5 and 3 (Table 2). It was clear with wavy topography both in the surface and subsurface horizons of pedon 5; whereas, in pedon 3 the surface horizon had diffused while the subsurface horizon was clear with wavy boundary. The differences in nature of the horizon boundaries may indicate the existence of variations in the processes of soil formation and partly reflecting anthropogenic impacts (Cools and De Vos, 2010).

Biological activity was relatively higher in the surface horizons and decreased with depth of the pedons, which could be associated with decreasing root biomass, aeration, nutrients and management effects down the soil profiles. The roots in different horizons of the pedons also varied from very fine to coarse in size and a few to common in quantity.

The pedons showed a great variability in relation to soil color patterns. Surface soil color varied from very dark gray (7.5YR3/1, dry) to dark brown (7.5YR 3/2, dry) in the upper slope; very dark gray (10YR 3/1, dry) to olive gray (5Y 5/2, dry) in the middle slope; brown (10YR 4/3, dry) to dark gray (2.5Y 4/1, dry) in the lower slope (Table 2). The subsurface color ranged from dark reddish black (5YR 3/3, dry) to light gray (2.5Y 7/2, dry) in the upper slope; dark reddish brown (2.5YR 3/3, dry) to pale yellow (5Y 7/4, dry) in the middle slope; to yellowish brown (10YR 5/4, dry) to light olive brown (2.5Y 5/3, dry) in the lower slopes. Generally, surface horizons have a darker color than their subsurface counterparts owing to the relatively higher organic matter contents in the surface horizons. In line with this result, several authors reported that the surface horizons have a darker color than the corresponding subsurface horizons as a result of relatively higher soil OM contents (Ashenafi *et al.,* 2010; Mulugeta and Sheleme, 2010; Dinku *et al.*, 2014). Concurrent with the findings of this study, Dengiz *et al.* (2012) indicated that soil color could be related to OM, waterlogging, carbonate accumulations and redoximorphic features. Similarly, Nuga *et al.* (2006) also reported that drainage condition and physiographic position may have major influence on the soil color.

There were significant variations in the grade, size and shape of the soil structure among the pedons. The structure of the soils in the surface layers of the pedons varied from strong fine crumby to weak medium angular blocky, whereas in the subsurface horizons it ranged from weak medium sub-angular blocky to strong fine sub-angular blocky (Table 2). The better developed structure of the subsurface layers could be due to the relatively higher clay content of the subsurface horizons than that of the surface horizons (Ahn, 1993). The soil consistence in the pedons varies among the topographic positions, whereby it ranged from loose to hard (dry), loose to firm (moist) and slightly sticky/non-plastic to very sticky/very plastic at upper slope, whereas the pedons in the middle topographic position exhibited soft to hard (dry), loose to very firm (moist) and slightly sticky/ non- plastic to very sticky/ very plastic consistence.

The observed differences in soil consistence could probably be explained by the differences in particle size distribution, particularly clay content, OM and nature of the clay particles. The findings of this study are in agreement with the results reported by Moradi (2013) who indicated that soil consistence varied with soil texture. Mulugeta and Sheleme (2010) also pointed out that the friable consistence observed in the surface soils of the pedons could be attributed to the higher soil OM content.

3.3. Physical Characteristics of the Soils

All profiles of the pedons had high sand and low silt content across the horizons. Sand accounted for over 50 percent by weight of the particle size of the soils at the surface horizons, except for pedon 1, 2, and 3, while silt ranged from 10 to 26 percent for all the pedons. Although, sand content increased with depth in the pedons except for pedons 2, 3, and 5, none of the fractions showed a consistent trend with topographic positions. Similar findings were reported by Mahajan *et al.* (2007) and Lawal *et al.* (2012), where more coarse sand fractions in the soils were recorded due to the presence of sandy type of rocks viz., sand stone, silt stone, granite, etc. The increment in the sand fraction with increased depths might be associated with the parent material.

Table 2. Selected morphological characteristics of soils of Muger Sub-watershed, Northern Oromia.

Pedon	Horizon	Depth (cm)	Matrix Color		Structure *1			Consistence *2				Horizon Boundary
			Dry	Moist	Grade	Size	Shape	Dry	Moist	Stickiness	Plasticity	
Upper Slope Pedon												
	A	0-20	7.5YR3/2	10YR3/2	WE	ME	AB	HA	FR	SST	NPL	C-S
P-01	C	20-98	2.5Y7/2	10YR5/4	WE	ME	MA	SHA	FI	ST	SPL	C-S
	R	98+	_	_	_	_	_	_	_	_	_	_
	Ap	0-80	7.5YR3/1	10YR3/1	ST	ME	SB	HA	VFR	VST	VPL	C-S
	AC	80-90	5YR3/1	5YR2.5/2	ST	FN	SB	SHA	FR	ST	PL	C-S
P-02	CA	90-125	5YR3/2	5YR3/2	MO	ME	SB	SO	FI	SST	SPL	C-S
	C	125-200+	5YR3/3	7.5YR3/2	WE	ME	SB	LO	LO	ST	PL	_
Middle Slope Pedon												
	Ap	0-98	7.5YR3/3	7.5YR3/2	MO	ME	GR	HA	VFR	SST	PL	D-W
P-03	Bt	98- 200+	2.5YR3/4	2.5YR3/2	WE	ME	AB	SO	VFR	ST	SPL	C-W
	A	0-35	5YR2.5/1	10YR3/1	MO	ME	CR	HA	VFR	SST	SPL	C-S
P-04	AB	35-50	2.5YR2.5/1	7.5YR2.5/1	WE	ME	SA	SHA	LO	SST	PL	C-S
	B	50-200+	2.5Y3/1	2.5Y3/1	WE	ME	AB	HA	VFI	ST	VPL	_
	A	0-25	5Y5/2	5Y5/3	ST	ME	GR	HA	FI	VST	VPL	C-W
P-05	CA	25-58	5Y7/4	5Y6/4	MO	FN	SB	HA	FR	SST	SPL	C-W
	R	58+	_	_	_	_	_	_	_	_	_	_
	A	0-60	10YR3/1	7.5YR2.5/1	ST	ME	SB	HA	FR	ST	SPL	C-S
P-06	C	60-200+	10YR6/6	10YR4/3	MO	FN	MA	SHA	FR	SST	NPL	_
Lower Slope Pedon												
	A	0-90	2.5Y4/1	7.5YR2.5/1	ST	FN	CR	HA	FI	VST	PL	C-S
P-07	B	90-150	2.5Y5/3	2.5Y4/3	MO	ME	AB	SHA	FI	SST	SPL	C-S
	R	150+	_	_	_	_	_	_	_	_	_	_
	A	0-20	10YR4/3	10YR3/2	MO	ME	GR	LO	VFR	SST	SPL	C-S
P-08	C	20-90+	10YR5/4	7.5YR4/4	MO	ME	AB	LO	VFR	SST	SPL	_

Note: 1: ST= strong, MO= moderate, WE=weak, FN= fine/thin, ME=medium, WE= wedge-shaped, AB= angular blocky, MA=massive, SB= sub-angular blocky, CR= crumb, GR= granular, 2*: HA=hard, SHA= slightly hard, LO= loose, SO= soft, VHA= very hard, FI=firm, VFR=very friable, FR= friable, VFI=very firm, NST= non-sticky, SST= slightly sticky, ST= sticky, VST= very sticky, NPL=non-plastic, SPL= slightly plastic, PL= plastic, VPL= very plastic, C=clear, D=diffused, S= smooth, W=wavy.*

The silt/clay ratio ranged from 0.19 -1.44 across the profiles. This ratio is one of the indices used to assess the rate of weathering and determine the relative stage of development of a given soil. According to Ashaye (1969) the silt/clay ratio <1 could mean that the soil had undergone feralitic pedogenesis. Accordingly, the silt to clay ratio is generally below a unit indicating that the soils of the sub-watershed are at an advanced stage of development, except for pedon 8 (Abayneh, 2005; Basava *et al.,* 2005).

The total porosity in the surface layers of the soils ranged from 42.9 to 59.5% (Table 3) and decreased consistently with soil depth. The decrease in the total porosity with soil depth could be due to the effect of management, limited penetration of crop roots into subsurface layers as well as relatively higher OM contents in the surface horizons. This finding is in agreement with that of Pravin *et al.* (2013) who reported decrease in total porosity with soil depth as a result of increasing compaction, decreasing of rooting effect, and organic matter content with depth.

The soil water content retained at field capacity (33kPa) ranged from 20.9 to 54.3% whereas at permanent wilting point (1500kPa), it was between 13.3 to 44.7% (Table 3). The low water retention values for both suctions are indication for absence of waterlogging problem at the study site, which could be related with amount of clay content and OM. In accordance with the report of Edoga (2010), clay offers a higher resistance to movement of water because of its high proportion of micro-pores that hygroscopically or in film store water. The available water holding capacity (AWHC) of the soil varied from 3.1 to 9.6% on horizon basis and could be rated as very low to low in accordance with Beernaert (1990). Accordingly, the limited amounts of finer fractions, particularly in subsurface soils, could decrease the water holding capacity of the soils and limit longer period of soil water retention for uptake by plants.

3.4. Chemical Characteristics of the Soils

Soil pH, electrical conductivity and calcium carbonate content

The pH values of the soils in the pedons ranged from moderately acidic to neutral (5.6 – 7.3), in accordance with the rating of Jones (2003). The pH-H_2O values varied from 5.59 to 6.42 in the surface layers and 5.78 to 7.24 in the subsurface horizons with an increasing trend with depth in all pedons except for P-5 (Table 4). Similarly, the pH – KCl values ranged from 4.56 to 5.46 and 4.53 to 6.31 in the surface and subsurface soils, respectively, and the values increased with depth. This increment in pH value of soil at the bottom layers might be attributed to the accumulation of exchangeable bases and $CaCO_3$. The soil pH was positively and significantly correlated (r= 0.792;

$r=0.587$, $p < 0.01$) with both Na and K contents respectively, while it was negatively and significantly ($r= -0.447$, $p < 0.05$) correlated with Fe (Table 9).

Irrespective of the topographic positions, the soils of all pedons showed very low electrical conductivity values that ranged from 0.06 to 0.07dS/m, indicating that the soils are non-saline (FAO, 1988). Similarly, calcium carbonate ($CaCO_3$) content of the soils ranged from 2.29 to 4.78% showing an increasing trend with soil depth, except for P-6. The relatively higher concentration of $CaCO_3$ at the subsurface than at the surface horizons might be ascribed to effects of leaching and parent material; similar findings were reported by Ozsoy and Aksoy (2007), in which case the $CaCO_3$ contents increased with depth.

Table 3. Selected physical characteristics of soils of Muger sub-watershed, Northern Oromia.

Pedon	Horizon	Depth (cm)	Particle size distribution Sand	Silt	Clay	Textural Class	S:C ratio	BD (g cm^{-3})	PD (gcm^{-3})	TP (%)	FC (%)	PWP (%)	AWHC (%)
Upper slope pedon													
	A	0-20	46	22	32	SCL	0.69	1.08	2.46	56.10	28.03	23.87	4.15
P-01	C	20-98	52	15	33	SCL	0.45	1.11	2.73	59.49	54.33	44.79	9.54
	R	98+	_	_	_	_	_	_	_	_	_	_	_
	A	0-80	44	13	43	Clay	0.30	1.35	2.62	48.31	39.85	33.21	6.65
P-02	AC	80-90	43	20	37	CL	0.54	1.44	2.6	44.55	31.08	25.56	5.52
	CA	90-125	49	20	31	SCL	0.65	1.45	2.61	44.44	27.08	23.98	3.10
	C	125-200+	45	21	34	CL	0.62	1.45	2.61	44.44	34.11	24.71	9.41
Middle slope pedon													
	Ap	0-98	47	19	34	SCL	0.56	1.31	2.3	42.93	30.26	21.04	9.22
P-03	Bt	98-200+	38	10	52	Clay	0.19	1.47	2.61	43.59	31.82	24.90	6.92
	A	0-35	49	21	30	SCL	0.70	1.06	2.62	59.50	45.11	36.14	8.96
P-04	AB	35-50	47	19	34	SCL	0.56	1.35	2.6	48.23	36.24	32.11	4.13
	B	50-200+	50	11	39	SC	0.28	1.42	2.48	42.85	44.54	39.62	4.92
	A	0-25	52	11	37	SC	0.30	1.14	2.64	56.82	49.27	41.60	7.67
P-05	CA	25-58	51	24	25	SCL	0.96	1.23	2.3	46.52	44.30	35.53	8.78
	R	58+	_	_	_	_	_	_	_	_	_	_	_
	A	0-60	54	16	30	SCL	0.53	1.37	2.66	48.50	27.17	20.43	6.73
P-06	C	60-200+	70	16	14	SL	1.14	1.46	2.23	34.59	20.94	13.33	7.61
Lower slope pedon													
	A	0-90	53	10	37	SC	0.27	1.19	2.37	49.79	42.98	36.37	6.61
P-07	B	90-150	54	19	27	SCL	0.70	1.26	2.18	42.12	41.97	33.12	8.84
	R	150+	_	_	_	_	_	_	_	_	_	_	_
	A	0-20	56	26	18	SL	1.44	1.31	2.61	49.98	33.54	23.90	9.63
P-08	C	20-90+	73	15	12	SL	1.25	1.37	2.48	44.90	31.30	24.62	6.68

Note: SC= Sandy clay, SCL=Sandy clay loam, SL= Sandy loam, CL= Clay loam, BD= Bulk density, PD= Particle density, TP= Total porosity, FC= Field capacity, PWP= Permanent wilting point, AWHC= Available water holding capacity.

Organic carbon, total nitrogen, C: N ratio, and available phosphorus

The organic carbon (OC) content varied depth-wise from 0.41 to 3.45, 0.77 to 4.06 and 0.65 to 2.56% in the upper, middle and lower topographic positions, respectively (Table 5). It did not show a consistent trend across topographic positions, but generally decreased with soil depth in all pedons except P-4. According to the ratings suggested by Tekalign (1991), the OC contents of the soils in the study area can be categorized as having from very low to high contents of organic carbon. Lower OC contents was recorded for cultivated lands compared to grazing lands, owing to intensive cultivation with low external organic inputs coupled with soil burning *'gaye system'* which is a common practice in the area.

Table 4. Soil pH, EC and calcium carbonate content of Muger sub-watershed, Northern Oromia.

			pH (1:2.5)				
Pedon	Horizon	Depth (cm)	H_2O	KCL	ΔpH	EC (dSm^{-1})	$CaCO_3$ (%)
Upper slope pedon							
	A	0-20	5.71	4.68	1.03	0.07	3.95
P-01	C	20-98	5.89	4.53	1.36	0.06	3.95
	R	98+	_	_	_	_	_
	A	0-80	6.42	5.46	0.96	0.06	3.85
P-02	AC	80-90	7.07	6.29	0.78	0.07	4.06
	CA	90-125	7.16	6.31	0.85	0.07	4.78
	C	125-200+	7.02	6.23	0.79	0.07	4.68
Middle slope pedon							
	Ap	0-98	5.73	4.64	1.09	0.06	2.29
P-03	Bt	98-200+	5.78	5.31	0.47	0.06	3.02
	A	0-35	5.66	5.21	0.45	0.07	4.16
P-04	AB	35-50	5.91	5.27	0.64	0.06	4.78
	B	50-200+	6.87	5.7	1.17	0.07	4.47
	A	0-25	6.18	4.97	1.21	0.06	3.12
P-05	CA	25-58	5.93	5.25	0.68	0.06	3.22
	R	58+	_	_	_	_	_
	A	0-60	5.93	4.63	1.3	0.06	3.74
P-06	C	60-200+	6.46	5.34	1.12	0.06	3.54
Lower slope pedon							
	A	0-90	6.07	5.07	1	0.06	3.95
P-07	B	90-150	7.24	6.3	0.94	0.07	4.26
	R	150+	_	_	_	_	_
	A	0-20	5.59	4.56	1.03	0.06	4.26
P-08	C	20-90+	5.84	4.98	0.86	0.06	4.78

Note: EC= Electrical conductivity

This finding is in agreement with the report of Wakene and Heluf (2004) with respect to intensive cultivation and leading to gradual loss of soil organic matter and that of Habtamu *et al.* (2009) with respect to land clearing for cultivation, which aggravate OM oxidation and hence reduces OC content.

The total N content of the soils ranged from 0.04 to 0.25% across the different topographic positions (Table 5), and could be rated as low to high in accordance with the rating of Havlin *et al.* (1999). The distribution pattern of total N with soil depth was similar to that of OC. This was also evident from the positive and highly significant ($r=0.912$, $p<0.01$) correlation between TN and OC indicating OM is the main source of N (Table 9). This finding is in agreement with that of Meysner *et al.* (2006) who indicated that as much as 93 to 97% of the total N in soils is closely associated with OM.

Available P content of the soils in the pedons ranged from 11.71 mg kg^{-1} in the Bt horizon of P3 to 22.01 mg kg^{-1} in the A horizon of P1 (Table 5) and ranged from medium to high as per the rating suggested by Cottenie (1980). Generally, the available phosphorus content of the soils decreased with profile depth in all pedons, which could be attributed to the relatively higher OC contents in the surface layers, and application of phosphorous containing fertilizer and compost by farmers on cultivated lands.

Cation exchange capacity, exchangeable bases and percent base saturation

The cation exchange capacity of the soils ranged from 26.42 to 60.94 cmol(+) kg^{-1} (Table 6) which is high to very high according to the rating of Hazelton and Murphy (2007). Generally, the pedons at upper and middle slope positions had relatively higher CEC than those on the lower slope position; this could be associated with soil OC and relatively high clay contents. The high CEC results showed that the soil of the study area has good nutrient retention and buffering capacity. However, CEC did not show a consistent trend at different soil depths.

Table 5. Soil organic carbon, TN, C: N ratio and Av. P of Muger sub-watershed, Northern Oromia.

Pedon	Horizon	Depth	OC%	TN (%)	C:N ratio	Av. P (mg kg^{-1})
Upper slope pedon						
	A	0-20	3.45	0.25	13.9	22.01
P-01	C	20-98	0.69	0.06	11.8	15.73
	R	98+	_	_	_	_
	A	0-80	1.10	0.09	12.5	18.64
P-02	AC	80-90	1.01	0.10	9.9	18.10
	CA	90-125	0.69	0.07	9.5	14.49
	C	125-200+	0.41	0.04	9.3	14.25
Middle slope pedon						
P-03	Ap	0-98	3.41	0.32	10.6	16.80
	Bt	98-200+	1.10	0.10	10.7	11.71
	A	0-35	3.73	0.23	16.0	15.79
P-04	AB	35-50	4.06	0.29	13.9	14.25
	B	50-200+	2.35	0.13	18.0	13.90
	A	0-25	2.03	0.13	15.5	18.16
P-05	CA	25-58	1.70	0.09	19.5	13.19
	R	58+	_	_	_	_
P-06	A	0-60	1.99	0.15	13.7	16.03
	C	60-200+	0.77	0.09	8.6	15.02
Lower slope pedon						
	A	0-90	2.03	0.07	29.0	13.66
P-07	B	90-150	0.65	0.09	7.4	13.13
	R	150+	_	_	_	_
	A	0-20	2.56	0.16	16.0	20.53
P-08	AC	20-90+	0.73	0.06	12.5	15.02

Note: OM = Organic matter, C: N = Carbon to nitrogen ratio, TN = Total nitrogen, Av.P = Available Phosphorus

Exchangeable Ca was the dominant cation on the exchange sites followed by Mg, K and Na across the pedons (Table 6), showing appropriate basic cation distribution in accordance with FAO (2006b). The contents of exchangeable Ca and Mg varied from 9.52 to 27.68 and 3.97 to 12.04 cmol (+) kg^{-1}, respectively, whereas exchangeable K and Na varied from 0.14 to 4.33 and 0.66 to 2.49 cmol (+) kg^{-1}, respectively. Generally, the contents of exchangeable bases increased with increasing soil depth, perhaps due to leaching. The exchangeable K, Ca and Mg contents of the surface layers of the soils are above the critical values (Sims, 2000). The Ca: Mg ratio of the soils was in the range of 1.63-3.71. Accordingly, as per Eckert (1987) ratings, the results indicate Mg induced Ca deficiency in the soils. On the other hand, the values of K: Mg ratio varied from 0.06-0.37, and in accordance with the ratings by Loide (2004), Mg induced K deficiency is also expected in crop production on the soils. The results suggest the need for soil management to balance the cations for optimum crop production, although their absolute values are above the critical levels.

The percent base saturation of the soil of the study area varied from 56.58 to 93.97% with an increasing trend with depth, which might be due to leaching of bases from the overlying layers and subsequent accumulation in the subsurface horizons. The percent base saturation in the soils of the area was also in the moderate to very high ranges (Hazelton and Murphy, 2007).

Table 6. Exchangeable bases, CEC and PBS of Muger sub-watershed, Northern Oromia.

			Exchangeable Bases (cmol (+) Kg^{-1})							
Pedon	Horizon	Depth (cm)	Ca	Mg	K	Na	CEC	Ca:Mg	K:Mg	PBS (%)
Upper slope pedon										
	A	0-20	16.44	7.68	1.25	0.79	38.90	2.14	0.16	67.25
P-01	C	20-98	27.68	12.04	0.66	0.66	60.94	-	-	67.33
	R	98+	-	-	-	-	-	-	-	-
	A	0-80	18.92	8.80	3.13	1.40	41.18	2.15	0.36	78.31
P-02	AC	80-90	19.33	7.78	4.13	1.57	40.56	-	-	80.91
	CA	90-125	19.47	8.34	4.33	1.66	48.26	-	-	70.05
	C	125-200+	20.43	8.57	3.73	1.49	39.73	-	-	86.12
Middle slope pedon										
	Ap	0-98	9.52	5.83	1.21	0.74	30.58	1.63	0.21	56.58
P-03	Bt	98-200+	10.25	6.58	1.93	0.87	29.12	-	-	67.40
	A	0-35	22.59	9.49	0.58	1.44	53.66	2.38	0.06	63.54
P-04	AB	35-50	20.38	8.19	0.47	1.14	52.42	-	-	57.58
	B	50-200+	24.97	9.28	0.64	2.23	54.50	-	-	68.13
	A	0-25	23.09	10.91	0.87	0.87	60.74	2.12	0.08	58.85
P-05	CA	25-58	22.63	10.64	0.89	0.79	56.78	-	-	61.54
	R	58+	-	-	-	-	-	-	-	-
P-06	A	0-60	15.07	6.83	1.07	0.83	48.18	2.21	0.16	57.78
	C	60-200+	12.08	4.83	1.05	1.00	28.29	-	-	67.03
Lower slope pedon										
	A	0-90	21.44	7.70	1.10	1.05	41.18	2.79	0.14	75.96
P-07	B	90-150	24.33	8.26	1.26	2.49	42.85	-	-	84.81
	R	150+	-	-	-	-	-	-	-	-
	A	0-20	20.68	5.57	2.06	1.40	31.62	3.71	0.37	93.97
P-08	C	20-90+	14.97	3.97	0.14	1.27	26.42	-	-	77.03

Note: CEC = Cation exchange capacity; PBS = Percent base saturation

Extractable micronutrient

The concentrations of DTPA extracted micronutrients were in the order of Fe > Mn > Cu > Zn in all the slope positions, except pedon 5 where the concentration of Cu was the smallest. However, horizons with relatively higher clay content showed a relatively higher extractable Cu content and Cu was also highly significantly and positively correlated ($r = 0.550$, $p < 0.01$) with clay content but negatively and significantly correlated ($r= -0.518$, $p < 0.05$) with sand (Table 9).

As per the rating recommended by Jones (2003), the soils of the study area were found to be high; medium; very low to high and low to high for Fe, Mn, Zn and Cu respectively. This finding is in line with that of Abayneh (2005) who reported Fe and Mn were in adequate levels across Ethiopian soils. Soil micronutrients are influenced by several factors among which soil OM content, soil reaction, and clay contents are the major ones (Fisseha, 1992). In line with this, a significant and positive correlation ($r = 0.510$; $p < 0.05$) was observed between Fe and organic carbon (Table 9), while Cu also exhibited highly significant and positive correlations ($r = 0.741$; $r = 0.736$, $p < 0.01$) with OC and total N, respectively (Table 9).

3.5. Classification of the Soils According to FAO – WRB System

All pedons had well-structured dark surface horizons of more than 20 cm thickness having color values and chroma of less than 3 when moist. The surface layers of the pedons contained more than 0.6 percent of OC; base saturation (by 1M NH_4OAc, pH 7) of $\geq$ 50 percent or more throughout the horizons (Table 5 and 6) meeting the criteria for a Mollic diagnostic horizons.

Pedon 3 had deep, well-drained soil with an effective depth of 200^{+}cm; a subsurface horizon thicker than 30 cm with more than 30% clay; moderate to strong angular blocky structure with shiny pedfaces; silt/clay ratio of <0.4 meeting the criteria for Nitic sub-surface horizon. The pedon had a diffused boundary between the surface and subsurface layers; without ferric, plinthic or vertic horizon and no gleyic color pattern starting within 100 cm of the surface meeting the requirements of Nitisols (FAO, 2014). Furthermore, the subsurface layer started at 98 cm; had high Fe content; dusky red (2.5 YR3/2 moist) to dark reddish brown (2.5YR3/4 dry) color; qualifying for rhodic prefix. Thus, the soils represented by this pedon were classified as Rhodic Nitisols (Haplic) in accordance with the World Reference Base for Soil Resources (FAO, 2014).

The pedons 4 and 7 had thick (>150 cm) subsurface horizons with greater than 30 percent clay, wedge shaped soil aggregates and slickensides produced by shrink and swell cracks starting at the surface qualifying for vertic horizon (FAO, 2014). Consequently, the pedons were classified as Vertisol. The surface layers (0-50cm) 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 these pedons were classified under Pellic Vertisols (Grumic) in accordance with World Reference Base for Soil Resources (FAO, 2014).

Table 7. Extractable micronutrient status of soils of Muger sub-watershed, Northern Oromia.

			Micronutrients (mg Kg^{-1})			
Pedon	Horizon	Depth	Fe	Mn	Zn	Cu
Upper slope pedon						
	A	0-20	41.66	6.30	1.50	6.58
P-01	C	20-98+	44.77	14.36	0.06	3.06
	R	98+	-	-	-	-
	A	0-80	52.01	15.86	0.11	2.84
P-02	AC	80-90	43.38	8.53	0.04	1.91
	CA	90-125	36.14	7.33	0.12	1.40
	C	125-200+	35.00	9.49	0.05	1.53
Middle slope pedon						
	Ap	0-98	98.11	5.12	4.72	7.94
P-03	Bt	98-200+	36.14	17.45	0.04	3.57
	A	0-35	97.17	18.16	0.94	5.14
P-04	AB	35-50	46.32	17.23	0.60	7.51
	B	50-200+	41.14	13.13	0.49	4.33
	A	0-25	61.32	17.77	4.11	2.80
P-05	CA	25-58	52.53	16.16	5.32	1.95
	R	58+	-	-	-	-
P-06	A	0-60	78.40	8.15	0.97	3.78
	C	60-200+	44.48	9.01	0.09	0.59
Lower slope pedon						
	A	0-90	92.37	17.68	0.81	6.32
p-07	B	90-150	51.66	8.10	0.02	1.32
	R	150	-	-	-	-
P-08	A	0-20	76.84	17.39	0.07	0.81
	C	20-90+	54.24	13.31	0.08	0.30

Table 9. Correlation between properties of the soils in Muger sub-watershed

	ϱb	AWH	Ps	pH	OC	Sand	Silt	Clay	Ec	TN	Av.P	Fe	Mn	Zn	Cu	Ca	Mg	K	Na	CEC	PBS
ϱb	1	-.270	.140	.427	-.447*	-.037	-.164	.110	-.076	-.278	-.335	-.393	-.304	-.340	-.296	-.452*	-.501*	.500*	.270	-.502*	.223
AWH		1	-.016	-.132	-.120	.225	.170	-.265	-.134	-.081	.171	.311	.237	.079	-.269	.247	.087	-.152	-.029	.023	.280
ϱs			1	.032	-.051	-.496*	-.116	.457*	-.073	-.012	.079	-.033	.207	-.397	.002	.074	.248	.455*	-.090	.157	.091
pH				1	-.404	-.177	.085	.101	.549*	-.317	-.116	-.447*	-.401	-.315	-.312	.338	.138	.587**	.792**	.126	.452*
OC					1	-.206	.195	.071	.292	.912**	.293	.510*	.178	.278	.741**	-.041	.012	-.437*	-.216	.166	-.445*
Sand						1	.138	-.875**	-.211	-.251	.102	.029	.055	.071	-.518*	.059	-.389	-.430	.053	-.144	.089
Silt							1	-.601**	.412	.201	.310	-.051	-.137	.388	-.269	.140	-.013	.148	.064	.076	.134
Clay								1	-.031	.104	-.234	.001	.023	-.247	.550**	-.117	.320	.275	-.074	.079	-.137
Ec									1	.328	.353	-.025	-.276	.103	.074	.201	.094	.384	.517*	.177	.119
TN										1	.324	.438*	-.099	.203	.736**	-.244	-.134	-.307	-.210	-.015	-.444*
Av.P											1	.063	-.024	-.007	-.041	.164	-.048	.154	-.057	.019	.233
Fe												1	.108	.174	.458*	-.154	-.167	-.335	-.230	-.128	-.165
Mn													1	.085	-.062	.417	.310	-.314	-.083	.378	.015
Zn														1	.067	-.037	.246	-.306	-.378	.303	-.553**
Cu															1	-.219	.082	-.295	-.334	.052	-.501*
Ca																1	.727**	-.051	.434*	.801**	.252
Mg																	1	-.012	.009	.914**	-.233
K																		1	.281	-.169	.495*
Na																			1	.083	.559**
CEC																				1	-.335
PBS																					1

*Note: *. Correlation is significant at P < 0.05; **. Correlation is highly significant at P < 0.01*

Pedon1, 2,5, 6, and 8 were situated within the altitudinal range of 2,400 – 2,600 meters above sea level; and had a shallow depth with gravelly subsurface. The pedons had <20% (by volume) fine earth, averaged over a depth of 75cm from the soil surface. The effective depths of pedons 1, 5, and 8 were <25 cm, whereas that of pedons 2 and 6 were 80 and 60 cm, respectively. The soils of these pedons are categorized under Leptosols according to WRB (FAO, 2014). The pedons also revealed absence of duric or gypsic horizons, dominated by sandy clay loam textural class. Hence, these soils were grouped under Mollic Leptosols (Eutric) in accordance with the WRB classification system.

Table 8. Diagnostic horizons, properties and soil types of Muger sub-watershed.

Pedon	Diagnostic horizon		Diagnostic properties	Soil type
	Surface	Sub-surface		
U-01	Mollic	-	-	Mollic Leptosols (Eutric)
U-02	Mollic	-	-	Mollic Leptosols (Eutric)
M-03	-	Nitic	-	Rhodic Nitisols (Haplic)
M-04	Mollic	Vertic	Vertic	Pellic Vertisols (Grumic)
M-05	Mollic	-	-	Mollic Leptosols (Eutric)
M-06	Mollic	-	-	Mollic Leptosols (Eutric)
L-07	Mollic	Vertic	Vertic	Pellic Vertisols (Grumic)
L-08	Mollic	-	-	Mollic Leptosols (Eutric)

Note: U = upper; M = middle; L = lower

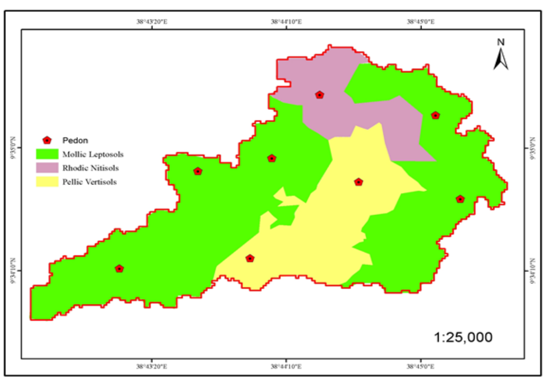

Figure 3. Soil map of the study area.

4. Conclusion

Soils of Muger sub-watershed, central Ethiopia, showed variability in distribution, which were conditioned by topographic features. The studied soils were formed from an Arero group of lower complex Archean volcanic rock dominantly basalt parent material. Topography influenced the soil formation, whereby the soils in the higher slope positions were developed from *in situ* weathering of the parent material whereas continuous deposition of materials from the upper slope resulted in the development of different soil types in the lower slope positions. Consequently, three soil types, Rhodic Nitisols (Haplic), Pellic Vertisols (Grumic), and Mollic Leptosols (Eutric) were identified. The results revealed different degrees of limitations, potential and management requirements, the consideration of which is fundamental for sustainable use of soil resources.

The results of the study have demonstrated that the major limitations for augmenting agricultural production on a sustainable basis are low levels of organic carbon, total nitrogen, zinc, calcium, potassium, and shallow soil depth. 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 qualities. 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 show a less costly way of acquiring soil formation.

Conflict of Interests

The author(s) have not declared any conflicts of interest.

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