The nature of soils and their agricultural potential at Enemor Ener woreda, southern Ethiopia

Abstract

***Rational**: Availability of accurate soil data is necessary in understanding the nature of the soil and its status of the agricultural potential. **Aim**: Thus, a research was carried out to investigate physicochemical and morphological properties of the soils and characterize, classify and mapping them accordingly at Enemor Ener woreda, southern Ethiopia. **Methods:** Nineteen (19) representative pedons were opened from lower, middle and upper slopes and described them according to WRB (2014). Soil samples from each horizon were analysed for physicochemical properties. **Results**: Soils in the study area are so variable in their formation and nutrient availability. The major soil textural classes are clay loam and clay. Calcium the most dominant exch. bases whereas, Magnesium, sodium and potassium follow in decreasing order. The soil pH was ranged from strongly acidic to neutral reaction. Total nitrogen and organic carbons contents in all soils of the pedons are low to very low. Phosphorous content was ranged from optimum to very low content. Cation exchange capacity and percentage of the base saturation were ranged from very high to optimum, in regards to the micronutrients such as iron, manganese, copper and zinc in the soils were ranged from sufficient III to sufficient I. Major soil types revealed in the study area are Chromic Luvisols, Haplic Nitisols, Mollic Leptosols and Mesotrphic Vertisols. **Conclusion**: Soil properties and their potential status influenced by topography and land use type. Therefore, practice of soil integrated fertility management is vital for their sustainability.*

***Keywords:** Characterization, Classification, Soil types, Topographic Position and Landscape*

Introduction

Natural entity especially soil is very important resource, and sustainable management for the better agricultural production and sustainable environment (Jagdish et al., 2009). Since minerals, soil organic matter (SOM), water, and air are major components (Khadka et al., 2017; Flores Magdaleno et al., 2011). Due to natural variability of soils need variable land use type respect with appropriate management approaces for sustainbale production. As many researches concluded that, soil variability in their formation is ensured through deatail studies of physicochemical and morphological characterstics of the soils in the particular area (Basanta et al., 2013; Lawal et al., 2012; Ogunkunle, 2005; Sharu et al., 2013). Furthermore, it helps to produce categories that have either related properties and/ or response to external inputs, either natural or man-made.

According to Ali et al. (2010) the nature of the soil and their characteristics show great variable along different locations of the Ethiopian regions due to geology, climate, topography, biotic and land use/land cover changes. In addition to this, diverse physiographic landscapes such as gentle slopes, steep slopes and strongly slopes and mountainous surfaces are predominant effects of the topographic features, climate, and vegetable coverage. Also they are influencing the soil properties are observed (Zamir et al., 2012). Moreover, topography mentioned as the dominant factors such as surface runoff, drainage and soil erosion are influencing soil property variation along a toposequences (Dinku et al., 2014; Fantaw et al., 2006; Mulugeta and Sheleme, 2010). Soil chemicals for instance, soil reactions; organic carbon, total nitrogen, available phosphorus, exchangeable cations and cation exchange capacity vary with slope position (Dinku et al., 2014; Mulugeta and Sheleme, 2010; Teshome et al., 2016).

Many research results showed that sustainable soil management for soil quality in respect to high crop production is crucial (Wakene, 2001). This suggests that understanding the characteristics of soils is requirement for designing suitable management approaches thus solving numerous challenges that the Ethiopians are facing in the crop and livestock production sectors and in their efforts towards natural resource conservation and management for sustainable development. Soil fertility losing and lack of its management are the great problem in the study site. By alleviating such limitations the crop productivity enhances and ensure food security. The objective of this research therefore, was initiated to characterize the morphological, physical and chemical properties, and classify the soils of the Enemor Ener Woreda to reveals its agricultural potential for sustainable development according to the WRB soil classification system.

Materials and Methods

Description of the Study Areas

The study was carried out at Enemor Ener woreda located in southern, Ethiopia (Figure 1).

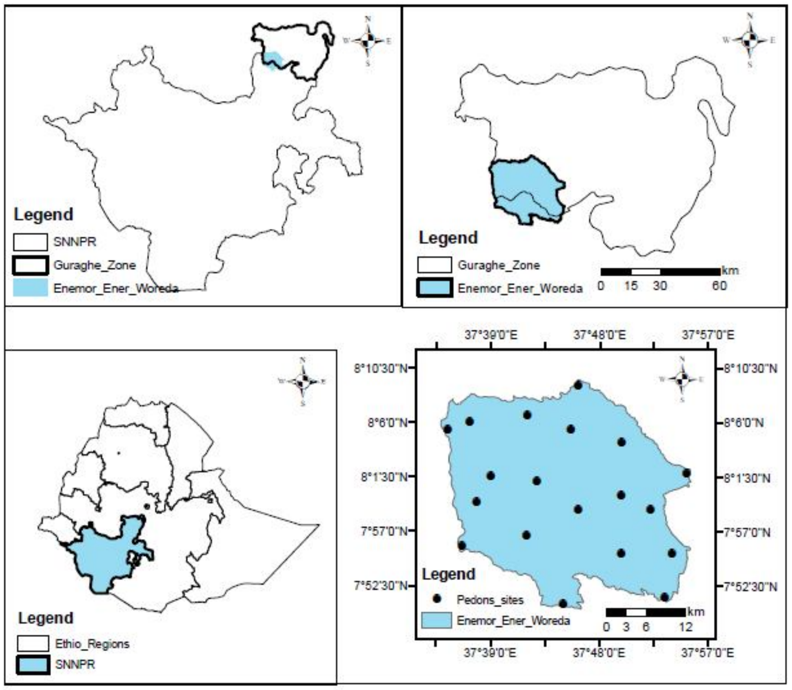

Fig.1: Pedons location map of the study site

Study site

The Enemor Ener study site exists in Guraghe Zone, and southern Ethiopia. It is found at about 452km from Hawassa. Enemor Ener is found between 7.35 - 8.13 North and 37.58- 37.93 East (Figure 1). The mean maximum and minimum temperature is 25 and 10.5°C respectively. The Woreda receives a mean annual rainfall between 801-1400 mm (Fig. 2) with bimodal distribution. Majority of the area is part of the *Woinedega* (intermediate highland between 1500-2300 m) agro-climate zone (ACZ), cover about 59.4% of the total land. It is followed by *Kola* (hot lowland between 500-1500 m) with a total coverage of 25.4%, and *dega (*cold highland between 2300-3200 m) (FAO, 1986), accounting for the rest of the area

(16.3%). Henricksen et al. (1984) describe the geomorphology of Enemor Ener Woreda as moderately dissected side slopes of extinct central volcanoes and other relic volcanic forms, often with small volcanic vent (basalt volcanic materials) and cone remnants, major river gorges, canyons and escarpments, slightly dissected extinct central volcanoes, caldera remnants and associated forms of high to mountainous relief are major geomorphic units in the study site. The total population of the Werda is estimated at over 167,745, of which 88,515 are women and 79,230 are men. There are a total of 22,668 households with an average family size of 7.4 on a total area of 107,584 ha (EEWARDO, 2005; CSA, 2007). Arable land includes 23.9%, pasture land 27.5%, forest and bush land 6%, dwelling and mineral resources 11.6%, and water bodies 0.95%, arable but uncultivated land 28%, and other 2.1% of the total area of Werda (EEWARDO, 2005). The majority of farmers in the study area are smallholders engaged in mixed farming with arable farming and animal husbandry. There are relatively suitable conditions for rainfed agriculture and animal husbandry. The main crops grown in the area include tef (Zucc.), maize (*Zea Mays* L.), wheat (*Triticum Aestivum* L.), sorghum (*Sorghum Bicolor* L.), barley (*Hordeum Vulgare* L.), pulses like pea (*Pisum Satvum* L.), haricot bean (Phaseolus Vulgaris L.), faba bean (*Vicia Faba* L.), chick pea (*Cicer Arietinum* L.), root crops like potato (*Solanum Tuberosum* L.), enset (*Ensete Ventricosum* (welw.)

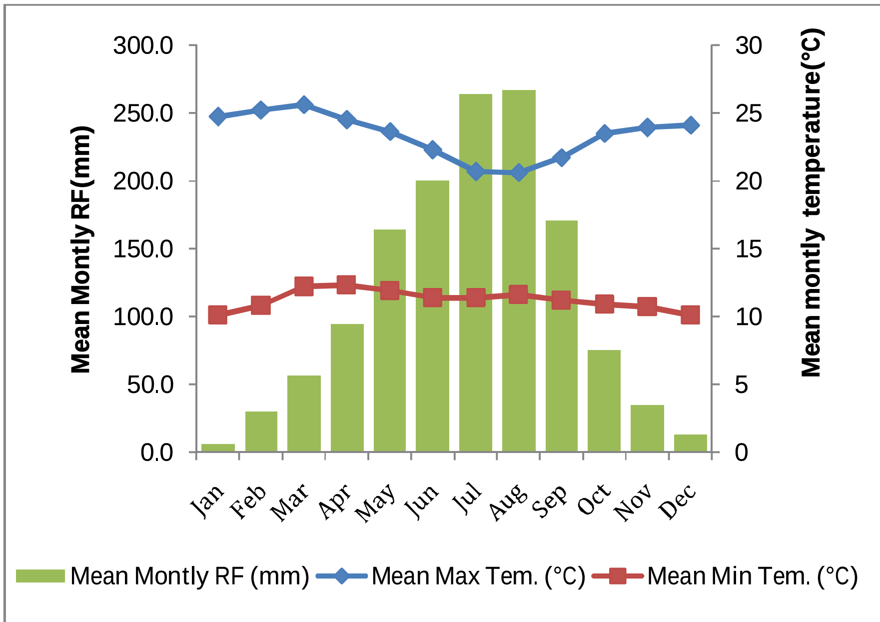

Fig. 2: Mean monthly rainfall, maximum and minimum temperatures of the Enemor Ener woreda from 2010-2019 years (Wolkite meteorology station, 2020)

Selection and Description of the Pedons

Based on the topographic map of each study site, pedons of 2*1.5*2m were excavated by hand digging. The slopes of toposequences were selected along east-west facing slopes encompassing landform components from upper slope to bottom slope of the woreda. Typical Pedons were selected based on site and soil profile characterization following the Guidelines for Field Soil Descriptions (FAO, 2006). Topographic features and land/soil characteristics were used as the basis in land use identification according to field observation and topographic maps. Soil augering were done using 'Edelman auger' to classify dissimilarity 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. Geographical Positioning System (GPS) was used to geo-referenced predefined pedons. Twenty pedons were opened and identified profiles were described *insitu* according to the Guidelines for Field Soil

Descriptions (FAO, 2006). While the soil colour was identified using Munsell soil colour chart (Munsell Colour Company, 2002).

Soil Sampling and Sample Preparation

Every identified horizons/ profiles were used in composite soil samples, for the further laboratory analysis. After collection of the soil samples were allowed to air dry and prepared composite samples about 1kg disturbed soils were transferred in to plastic bags and label. A total of 86 disturbed and 86 undisturbed soil samples 19 predefined pedons. In addition, the B-horizons of each pedons were sampled at 5 cm interval to check the variation in clay content with depth. Soil samples were prepared based on standard. 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 at Hawassa University (Wondo Genet), Wolkite regional soil lab and Wachemo University soil laboratory.

Soil analysis

Particle-size distribution was determined by modified hydrometer as outlined by Sahlemedhin and Taye (2000) Soil bulk density was determined by the undisturbed core sampling method after drying the soil samples in an oven at 105^{o}C to constant weights, while particle density was assumed to be 2.65 mg m^{-3}. The pH of the soils was measured in water and potassium chloride (1M KCl) suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combination electrode (Van Reeuwijk, 1992). The OC content of the soils was determined by wet digestion method (Walkely and Black, 1934) while total N was determined by Kjeldahl wet digestion and distillation method (Bremner and Mulveny, 1982) and available P by modified Olsen method (Olsen, 1982). Cation exchange capacity and exchangeable bases were extracted by 1 M ammonium acetate (pH 7) method (Van Reeuwijk, 1993). Ca and Mg extraction were done using atomic absorption spectrophotometer (AAS) and exchangeable K and Na by flame photometer. Available micronutrients (Fe, Cu, Zn, B and Mn) were extracted by diethylene triaminepentaacetic acid (DTPA) as described by Tan (1996) and all were quantified using atomic absorption spectrophotometer.

Data analysis

Simple linear correlation analysis was carried out to assess the relationships between and among selected physicochemical properties of the soils according to the procedures described by Gomez (1984) and used in the interpretations of data. Mean comparisons (LSD) were carried out for the selected physicochemical properties of the soils using the SPSS software SPSS (20), to see the relationship between parameters.

Results and Discussions

Description of the pedosn sites

Pedons shown the difference in the topography and vegetation coverage. Strongly sloping to sloping land forms were observed in the pedons of the upper and middle slopes. Whereas gently sloping landforms were observed in lower slope positions as depicted in table 1. Soil conditions of the pedons in both upper and lower slope positions were well drained. While pedons on the lower slope positions were poorly drained and with hardpans and shallow depth (Table 1). During the description of the pedons sites topographic feature and parent materials were identified as major threats that affect their characteristics (David, 2005; Dinku et al., 2014).

All pedons mentioned in both upper and middle slopes were suspected for soil and water erosion. The lower slope positions pedons at study site showed signs of accelerated water erosion as evidenced by gullies on the surrounding landscape, while the soils of the pedons with gently sloping land forms were no water erosion problem rather than water logging condition. The soils of pedons at different topographic positions in the study site was developed from *in situ* weathering of basaltic parent material; although the influence of material deposition was noted on the surface layer of LS pedon at the site. Similarly, Sheleme (2017) also reported that soils on depression landscapes are influenced by settlement of materials transported from the high slopes.

Table 1. Location and land use types of the selected pedons in Enemor Ener, southern Ethiopia

Pedon	Lat (Decimal Degree)	Long (Decimal Degree)	Altitude (ma.s.l)	Slope (%)	Land form	Surface drainage	Erosion	Land use	Parent materials
US	7.920	37.900	2646	15	Strongly sloping	Well drained	Moderate water erosion	Wheat	Basalt volcanic material
US	7.980	37.870	2607	14	Strongly sloping	Well drained	Moderate water erosion	Barley	Basalt volcanic material
US	7.860	37.890	2605	12	Strongly sloping	Well drained	Moderate water erosion	Wheat	Basalt volcanic material
US	7.850	37.70	2565	8	Sloping	Well drained	Moderate water erosion	Wheat	Basalt volcanic material
US	7.920	37.830	2498	9	Sloping	Well drained	Moderate water erosion	Barley	Basalt volcanic material
US	7.945	37.699	2496	6	Sloping	Well drained	Moderate water erosion	Wheat	Basalt volcanic material
MS	8.019	37.713	2337	10	Sloping	Well drained	Moderate water erosion	Wheat	Basalt volcanic material
MS	8.000	37.830	2243	11	Strongly sloping	Well drained	Moderate water erosion	Barley	Basalt volcanic material
MS	8.030	37.920	2181	7	Sloping	Well drained	Slightly/sheet erosion	Wheat	Basalt volcanic material
MS	8.073	37.830	2124	13	Strongly sloping	Well drained	Slightly/sheet erosion	Teff	Basalt volcanic material
MS	7.980	37.770	2026	15	Strongly sloping	Well drained	Slightly/sheet erosion	Maize	Basalt volcanic material
LS	7.930	37.610	1988	2	Gently sloping	Poorly drained	No	Maize	Basalt volcanic material
LS	8.090	37.590	1980	5	Gently sloping	Poorly drained	No	Sorghum	Basalt volcanic material
LS	7.990	37.630	1978	3	Gently sloping	Poorly drained	No	Maize	Basalt volcanic material
LS	8.100	37.620	1974	4	Gently sloping	Poorly drained	No	Teff	Basalt volcanic material
LS	8.110	37.700	1969	3	Gently sloping	Poorly drained	No	Teff	Basalt volcanic material
LS	8.026	37.649	1938	13	Strongly sloping	Excessive drained	Sheet and gully active	Sorghum	Weathered rocks
LS	8.090	37.760	1926	10	Sloping	Excessive drained	Sheet and gully active	grazing	Weathered rocks
LS	8.150	37.770	1908	7	Sloping	Excessive drained	Sheet and gully active	Sorghum	Weathered rocks

SP= Slope Position, US=Upper Slope; MS= Middle Slope; LS=Lower Slope

Morphological Characteristics of the Soils

The toposequence influenced soil depth, horizon, colour, structure, consistency and horizon boundary in the study area. All the pedons had very deep profile (>200 cm) except pedons 17, 18, and 19 Table 2. Pedon (1) was characterized by Ap, Ah, Bt1, Bt2 and Bt3; (P2) by Ap, AB, Bt1, Bt2 and C; (P3) by Ap, Ah, AB, Bt1 and Bt2; (P4) by Ap, Ah, Bt1, Bt2 and C; (P5) by Ap, Ah, AB, Bt1 and Bt2; (P6) by Ap, Ah, AB, Bt1 and Bt2; (P7) by Ap, Ah, Bt1, Bt2 and BC; (P8) by Ap, Ah, AB, Bt1 and Bt2; (P9) by Ap, Ah, Bt1, Bt2 and Bt3; (P10) by A, AB, Bt1, Bt2 and Bt3; (P11) by Ap, AB, Bt1 and Bt2; (P12) and (P13) by Ap, AC, C1, C2 and C3 ; (P14) by Ap, AC1, AC2, C1 and C2; (P15) by Ap, AC, C1, C2 and C3; (P16) by Ap, AC, C1, C2 and C3; (P17), (P18) and (P19) were characterized by Ap and A (Table 2). The soil morphological properties varied along the different slope positions at the study site and within the horizons, soil depths, color, structure, and consistency and horizon boundaries in accordance with FAO (2006).

The pedons showed a great variability in relation to soil colour patterns (Table 2). Surface soil color is varies 5YR2.5/1(Black), 2.5YR2.5/1 (Reddish black), 5YR2.5/1(Black), 7.5YR3/2 (Dark brown), 5YR3/2 (Dark reddish brown) and 7.5YR3/4 (Dark brown) pedons in the upper slopes; 7.5YR2.5/2 (Very dark brown), 5YR3/2 (Dark reddish brown), 5YR4/6 (Yellowish red), 5YR ¾ (Dark reddish brown) and 5YR3/3 (Dark reddish brown) pedons in the middle slopes; 5Y6/2 (Light olive gray), 10YR4/3 (Brown), Glay1/3/10Y (Very dark greenish gray), 5Y4/1(Dark gray), 5Y6/2 (Light olive gray), 10YR 3/3 (dark brown) and 10YR 3/3 (dark brown) pedons in the lower slopes. Whereas, in the subsurface soil color is varies 5YR3/4 (Dark reddish brown), 10R2.5/1 (Reddish black), 5YR2.5/1 (Black) pedons in the upper slopes; 5YR2.5/2 (Dark reddish brown), 10 R3/3 (Dusky red) and 10YR3/3

(Dark brown) pedons in the middle slopes; 5Y6/2 (Light olive gray), 2.5Y4/2 (Dark grayish brown), 10YR4/4 (Dark yellowish brown), Glay1/3/10Y (Very dark greenish gray) and GLAY 1 4/10/GY (Dark greenish gray) pedons in the lower slopes. Generally, surface horizons had darker color as compared to their sub-surface might be due to attributed the relatively higher organic matter contents in the surface horizons. In line with this finding, numerous research findings supported that surface soils being darker than corresponding subsurface horizons was due to having higher organic matter contents (Ashenafi et al., 2010; Mulugeta and Sheleme, 2010; Dinku et al., 2014). Soil color differences were also observed among the slope position, which might be due to drainage conditions. On other hands, soil colour also influenced with soil organic carbon and the status of soil aeration (Dengiz et al., 2012). Additionally, Nuga et al. (2006) also reported that drainage condition and physiographic position might have major influence on the soil color.

Soil profiles with 50 to 200 cm were categorized as deep and the shallowest with 20cm and the thickness of the solum varied along the toposequences (Table 2). The shallow depth at the lower positions may limit the root penetration for deep-rooted crops (Table 2). The variation in the depth of solum might have been due to the landscape configurations (Slope gradient and length), which are important in influencing the rate at which water flows into or off the soil if the sites are unprotected Borderson (1994) also reported landscapes position influences runoff, drainage, soil temperature, soil erosion, soil depth and hence soil formation as described by Mulugeta and Sheleme (2010).

The distinctness of horizon boundary between surface and subsurface horizons were gradual smooth boundary (G, S), clear smooth boundary (C, S) and diffuse smooth boundary (D, S) among pedons in the surfaces, while diffuse smooth boundary (D, S), gradual smooth boundary (G, S) and clear smooth boundary (C, S) were observed pedons in the upper, middle and lower slopes of subsurface (Table 2). Variation of the boundaries might be due to anthropogenic interferences in addition to the natural phenomena (Cools and De Vos, 2010). A biological activity was relatively higher in the subsurface horizons and decreased with increasing soil depth might be due to the abundance of roots and having favourable soil conditions.

The nature of the soils shown the variation in the soil structure for instance, the grade, size and shape as depicted in the table 2. The soil structure in the surface layers of the pedons varied from very fine to fine/medium, coarser angular to weak moderate angular block, sub-angular blocky and crumby in their structure. On the other hand, in the subsurface horizons it ranged from weak moderate angular and sub-angular blocky to strong fine angular blocky (Table 2). 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 (Ali et al., 2010).

The soil consistence in the pedons varied among the topographic positions (Table 2). The soil consistencies characterized by friable to firm (moist), slightly sticky/ non-plastic to slightly sticky/ slightly plastic and slightly sticky/plastic to sticky/plastic at upper and middle slopes, whereas the lower topographic position pedons exhibited very friable to firm (moist), slightly sticky/ slightly plastic to sticky/ plastic and sticky/plastic to very sticky to 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 are in agreement with Moradi (2013) who indicated that soil consistence varied with soil texture.

Table 2. Selected morphological characteristics of the soils in Enemor Ener woreda, southern Ethiopia

Pedon	SP	Hori.	Depth	Soil color (moist)	Structure			Consistence			Root Abundance	Horizon boundary
					Grade	Size	Shape	Moist	Wet			
									Stickiness	Plasticity		
P1	US	Ap	0-28	5YR2.5/1 Black	MO	FN, ME	GR	FR	SST	NPL	Few fine roots	C, S
		Ah	28-62	5YR3/4 Dark reddish brown	MO	FN, ME	SAB	FR	SST	SPL	Very few fine roots	G, S
		Bt1	62-121	2.5YR2.5/3Dark reddish brown	MO	FN, ME	SAB	FR	ST	PL	Faint clay coating	D, S
		Bt2	121-175	2.5YR3/4 Dark reddish brown	MO	FN, CO	AB	FI	ST	PL	Clay coating	D, S
		Bt3	175+	2.5YR2.5/4 Dark reddish brown	MO	FN, CO	AB	FI	ST	PL	Distinct clay coating	-
P2	US	Ap	0-30	2.5YR2.5/1 Reddish black	MO	VFN, FN	GR	FR	SST	SPL	Fine roots	G, S
		AB	30-75	10R2.5/1 Reddish black	MO	VFN, FN	AB	FR	SST	SPL	Very fine roots	G, S
		Bt1	75-110	2.5YR/3/3 Dark reddish brown	MO	VFN, FN	AB	FR	ST	PL	Very fine roots	G, S
		Bt2	110-155	10R2.5/1 Reddish black	MO	VFN, FN	AB	FR	ST	PL	Very fine roots	G, S
		C	155+	10 R3/3 Dusky red	MO	FN, CO	AB	FI	ST	PL	Very fine roots	-
P3	US	AP	0-21	5YR2.5/1 Black	WE	VFN, FN	GR	VFR	NST	NPL	Fine roots	D, S
		Ah	21-52	5YR2.5/1 Black	MO	FN, ME	SAB	VFR	NST	NPL	Fine roots	C, S
		AB	52-109	2.5YR3/3 Dark reddish brown	ST	FE, ME	SAB	FR	ST	PL	Faint clay coating	D, S
		Bt1	109-131	2.5YR3/3 Dark reddish brown	MO	FN, CO	SAB	FI	ST	PL	Clay coating	D, S
		Bt2	131+	2.5YR3/3 Dark reddish brown	MO	FN, CO	MA	FI	ST	PL	Clay coating	--
P4	US	Ap	0.25	7.5YR3/2 Dark brown	MO	VFN, FN	GR	FR	NST	NPL	Few fine roots	G, S
		Ah	25-67	5YR2.5/2 Dark reddish brown	MO	VFN, FN	SAB	FR	SST	SPL	Fine roots	D, S
		Bt1	67-92	2.5YR3/4 Dark reddish brown	MO	FN, ME	SAB	FI	ST	PL	Clay coating	D, S
		Bt2	92-138	2.5YR3/4 Dark reddish brown	MO	FN, ME	AB	FI	ST	PL	Clay coating	C, S
		C	138+	7.5YR3/2 Very Dark brown	MO	FN, ME	AB	FI	ST	PL	Clay coating	---
P5	US	Ap	0-22	5YR3/2 Dark reddish brown	WE	VFN, FN	GR	SO	SST	SPL	Fine roots	D, S
		Ah	22-75	5YR2.5/2 Dark reddish brown	MO	VFN, ME	SAB	FR	ST	PL	Fine roots	D, S
		AB	75-110	5YR3/3Dark reddish brown	MO	FN, ME	SAB	FR	ST	PL	Faint clay coating	G, S
		Bt1	110-145	2.5YR 3/3Dark reddish brown	MO	FN, ME	SAB	FR	ST	PL	Clay coating	D, S
		Bt2	145+	2.5YR3/3 Dark reddish brown	MO	FN, ME	SAB	FR	ST	PL	Clay coating	--
P6	US	Ap	0-21	7.5YR3/4 Dark brown	MO	VFN, FN	GR	FR	NST	NPL	Fine roots	C, S
		Ah	21-43	5YR 3/2 Dark reddish brown	MO	FN, ME	SAB	FR	SST	SPL	Fine roots	G, S
		AB	43-85	2.5YR2.5/3Dark reddish brown	MO	FN, CO	SAB	FR	SST	SPL	Faint clay coating	D, S
		Bt1	85-155	2.5YR3/4 Dark reddish brown	MO	FN, CO	AB	FR	ST	PL	Clay coating	D, S

		Bt2	155+	2.5YR3/3 Dark reddish brown	MO	FN, CO	AB	FR	ST	PL	Clay coating	--
P7	MS	Ap	0-22	7.5YR2.5/2 Very dark brown	WE	VFN	GR	FR	SST	NPL	Fine roots	G, S
		Ah	22-48	5YR2.5/2 Dark reddish brown	MO	FN, CO	SAB	FR	SST	SPL	Faint clay coating	G, S
		Bt1	48-71	2.5Y2.5/3Dark reddish brown	MO	FN, CO	SAB	FR	SST	SPL	Fine roots	G, S
		Bt2	71-120	10 R3/3 Dusky red	MO	VFN, ME	SAB	FI	NST	NPL	Clay coating	C, S
		BC	120+	10YR3/3 Dark brown	WE	VFN, ME	SAB	FI	NST	NPL	Clay coating	--
P8	MS	Ap	0-25	5YR3/2 Dark reddish brown	MO	VFN, ME	GR	LO	NST	NPL	Fine roots	G, S
		Ah	25-60	2.5YR3/3 Dark reddish brown	MO	FN, ME	GR	FI	NST	NPL	Fine roots	D, S
		AB	60-100	2.5YR3/4 Dark reddish brown	MO	FN	SAB	VFR	SST	SPL	Fine roots	D, S
		Bt1	100-150	2.5YR2.5/3Dark reddish brown	MO	FN, ME	AB	FR	ST	PL	Clay coating	D, S
		Bt2	150+	2.5YR2.5/3Dark reddish brown	MO	ME, CO	AB	FI	SST	SPL	Clay coating	--
P9	MS	Ap	0-35	5YR4/6 yellowish red	WE	FN, ME	GR	FR	NST	NPL	Fine roots	C, S
		Ah	35-68	5YR3/4 Dark reddish brown	MO	FN, ME	SAB	FI	ST	PL	Fine to roots	G, S
		Bt1	68-105	2.5YR2.5/3Dark reddish brown	MO	FN, ME	SAB	FR	ST	PL	Clay coating	D, S
		Bt2	105-140	2.5YR2.5/3Dark reddish brown	MO	ME, CO	AB	FR	ST	PL	Clay coating	D, S
		Bt3	140+	2.5YR2.5/3Dark reddish brown	MO	ME, CO	AB	FI	SST	PL	Clay coating	--
P10	MS	A	0-15	5YR 3/4Dark reddish brown	MO	VFN, ME	GR	FR	NST	NPL	Fine roots	G, S
		AB	15-42	2.5YR3/4 Dark reddish brown	MO	VFN, ME	SAB	FR	SST	SPL	Fine roots	G, S
		Bt1	42-105	5YR3/3Dark reddish brown	ST	FN, ME	AB	FI	SST	SPL	Fine roots	D,S
		Bt2	105-145	2.5YR3/3 Dark reddish brown	ST	VFN, ME	AB	FR	SST	SPL	Clay coating	D, S
		Bt3	145+	5YR 3/4Dark reddish brown	WE	VFN, ME	SAB	FR	ST	PL	Clay coating	--
P11	MS	Ap	0-20	5YR3/3Dark reddish brown	MO	VFN, FN	GR	FI	SST	SPL	Fine roots	G, S
		AB	20-65	2.5YR3/3 Dark reddish brown	MO	FN	AB	FR	SST	SPL	Fine roots	D, S
		Bt1	65-140	2.5Y3/3 Dark reddish brown	MO	FN, ME	AB	FR	ST	PL	Faint clay coating	G, S
		Bt2	140+	7.5YR 4/4 Brown	MO	FN, ME	SAB	FI	ST	PL	Clay coating	--
P12	LS	Ap	0-25	5Y6/2Light olive gray	FN	VFN, FN	GR	FI	SST	NPL	Fine roots	C, S
		AC	25-65	5Y6/2Light olive gray	MO	FN, ME	AB	FR	SST	SPL	Fine roots	D, S
		C1	65-90	5Y5/2Olive	MO	VFN, FN	AB	FR	ST	PL	Fine roots	G, S
		C2	90-120	10 YR4/2	MO	FN, ME	AB	FR	ST	PL	Fine few pores	C, S
		C3	120+	5YR3/4 Dark reddish brown	MO	FN, ME	AB	FR	ST	PL	Clay coating	--
P13	LS	Ap	0-25	10YR4/3Brown	MO	VFN, FN	GR	FI	SST	NPL	Fine roots	C, S
		AC	25-90	5Y6/2Light olive gray	MO	VFN, FN	GR	FI	SST	NPL	Many fine roots	C, S
		C1	90-128	2.5Y4/2 Dark grayish brown	MO	FN, CO	FN, M	FR	ST	PL	Few roots	C, S
		C2	128-162	5YR4/2 Dark reddish gray	MO	VFN, FN	AB	FR	VST	VPL	-	G, S
		C3	162+	10YR4/4 Dark yellowish brown	MO	FN, ME	SAB	FR	ST	PL	-	--

P14	LS	Ap	0-25	Glay1/3/10Y Very dark greenish gray	ST	FN, ME	AB	FI	VST	VPL	Fine roots	G, W
		AC1	25-65	Glay1/3/10Y Very dark greenish .g	ST	FN, ME	AB	FI	VST	VPL	Fine roots	C, W
		AC2	65-92	Gley1/3/10Y dark greenish gray	MO	ME, CO	AB	FR	VST	VPL	Very few fine roots	C, W
		C1	92-160	GLAY23/5PB very dark bluish .g	MO	ME, CO	AB	FR	VST	VPL	Distinct slickenside	G, W
		C2	160+	GLAY 2 3/10B very dark bluish .g	MO	ME, CO	AB	FR	VST	VPL		--
P15	LS	Ap	0-20	5Y4/1Dark gray	MO	FN, ME	SAB	FR	VST	VPL	Fine roots	C, S
		AC	20-70	5Y 3/1 very dark greenish gray	MO	ME, CO	AB	FI	VST	VPL	Fine roots	G, W
		C1	70-110	Gley1/3/10Y dark greenish gray	MO	FN, CO	AB	FI	VST	VPL	Very fine roots	C, W
		C2	110-155	GLAY 1 4/10/GY Dark greenish .g	MO	FN, CO	AB	FI	VST	VPL	Very fine roots	C, W
		C3	155+	5Y5/3 Olive	WE	VFN, FN	SAB	FI	VST	VPL	Very fine roots	--
P16	LS	Ap	0-25	5Y6/2Light olive gray	FN	VFN, FN	GR	FI	SST	NPL	Fine roots	C, S
		AC	25-65	5Y6/2Light olive gray	MO	FN, ME	AB	FR	SST	SPL	Few roots	D, S
		C1	65-90	5Y5/2Olive	MO	VFN, FN	AB	FR	ST	PL	Fine roots	G, S
		C2	90-120	10 YR4/2	MO	FN, ME	AB	FR	ST	PL	Fine few pores	C, S
		C3	120+	5YR3/4 Dark reddish brown	MO	FN, ME	AB	FR	ST	PL	-	--
17	LS	Ap	0-10	10YR 3/3 dark brown	MO	FN, ME	CR	FR	ST	PL	Fine roots	G, S
		A	10-25	7.5YR 3/3 dark brown	MO	FN, ME	SAB	FR	SST	SPL	Very few fine roots	D, S
P18	LS	Ap	0-10	10YR 3/3 dark brown	MO	FN, ME	SAB	FR	ST	PL	Fine roots	G, S
		A	10-25	7.5YR 3/3 dark brown	MO	FN, ME	SAB	FR	SST	SPL	Very few fine roots	D, S
P19	LS	Ap	0-10	10YR 3/3 dark brown	MO	FN, ME	MA	FR	ST	PL	Fine roots	G, S
		A	10-25	7.5YR 3/3 dark brown	MO	FN, ME	SAB	FR	SST	SPL	Very few fine roots	D, S

Note: ST= strong, MO= moderate, WE=weak, FN= fine/thin, ME=medium, WE= wedge-shaped, AB= angular blocky, MA=massive, SAB= 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, G=Gradual, S= Smooth

Physical Characteristics of the Soils

The textural classes of the soils in the study area were identified mostly clay and clay loam as depicted in the table 3. This could be attributed to the basaltic parent material, which weathers into fine-textured soils (Buol et al., 2003). The soils at all slope positions showed distinct increase in clay content with depth indicating high rates of clay formation in subsoil horizons. According to Mulugeta and Sheleme (2010) pedogenic eluviation- illuviation process influenced change in clay percentage. Thus, the accumulation of clay in the subsoil horizons of the pedons could have been due to main *in situ* synthesis of clay from the weathering of primary minerals in B-horizons. A negative and highly significant $r = -0.806^{**}$, $p < 0.01$) correlation was observed between clay and sand indicating that elimination of clay caused in relative increment of sand in the surface layers. This finding is in agreement with Satyavathi and Suryanarayan (2003), who reported that the surface enrichment of sand fraction in red soils was due to the removal of finer particles by eluviations and surface runoff. Negatively significant ($r = -0.232^{*}$, $p < 0.05$) correlation also prevailed between clay and silt as depicted in the table 7 this shows that weathering of some silt size particles enhances in increment of clay percentage.

The silt to clay ratio ranged from 0.25 to 0.76, 0.25 to 0.74 and 0.16 to 1.21 across the profiles of the pedons in the upper, middle and lower slopes respectively. But the study site silt/clay was average ranged from 0.16 to 1.21. The indices of the silt to clay ratio help to assess the rate of weathering and the relative stage of development of the give soil. According to Young (1976), a ratio of silt to clay below 0.15 is considered as low and is indicative for advanced stage of weathering and/ or soil development, whereas a ratio greater than 0.15 indicates that the soil is young containing easily weatherable minerals. In respect to this, Ashaye (1969) reported that the silt/clay ratio <1 could mean that the soil had undergone feralitic pedogenesis. Accordingly, the silt to clay ratio of the soil under study is generally below a unity indicating that the soils are at an advanced stage of development (Abayneh, 2005; Basava et al., 2005).

The bulk density of soils in the surface horizons ranged from 0.87 to 1.25g cm^{-3}, while the corresponding values for the subsurface horizon ranged from 0.95 to 1.31g cm^{3} (Table 3). The bulk density values did not exhibit consistent relation with topographic positions, and the lower and the higher bulk density values were recorded at the lower slope position (Table 3). However, the bulk density values showed discernible increments with depth across all the pedons (Table 3). This could be attributed to reduced OM content, aggregation and root penetration in the subsurface layers compared to their surface counterparts and weight of the overlying soils. Bulk density and organic carbon correlate with a negatively significant relationship ($r = -0.578^{**}$, $p<0.01$) as depicted in the table 7. Soils with bulk density within the suitable range (1.0 – 1.5g cm^{-3}) are conducive for the agricultural use (White et al., 1997), hence, the results indicate the absence of more compaction and restriction to root development in all the pedons corroborating the report (Werner, 1997).

Table 3. Selected physical characteristics of the soil in pedons at Enemor Ener woreda, southern Ethiopia

Pedon	Horizons	Depth	Sand (%)	Silt (%)	Clay (%)	Textural class	Silt/Clay	Bulk density (gcm^{-1})
US	Ap	0-28	40.76	23.24	36.0	Clay Loam	0.65	1.02
	Ah	28-62	50.04	18.06	31.9	Sandy Clay Loam	0.57	1
	Bt1	62-121	36.53	27.47	36.0	Clay Loam	0.76	1.1
	Bt2	121-175	36.84	24.65	38.5	Clay Loam	0.64	1.08
	Bt3	175+	36.72	26.78	36.5	Clay Loam	0.73	1.05
US	Ap	0-30	36.34	20.15	43.5	Clay	0.46	1
	AB	30-75	35.76	21.44	42.8	Clay	0.50	1.07
	Bt1	75-110	32.09	20.50	47.4	Clay	0.43	1.07
	Bt2	110-155	30.46	22.83	46.7	Clay	0.49	1.08
	C	155+	37.73	20.07	42.2	Clay	0.48	1.18
US	AP	0-21	48.55	18.85	32.6	Sandy Clay Loam	0.58	1
	Ah	21-52	36.97	26.23	36.8	Clay Loam	0.71	1.02
	AB	52-109	36.52	26.87	36.6	Clay Loam	0.73	1.16
	Bt1	109-131	32.69	18.91	48.4	Clay	0.39	1.17
	Bt2	131+	21.84	27.45	50.7	Clay	0.54	1.24
US	Ap	0.25	36.68	15.11	48.2	Clay	0.31	0.99
	Ah	25-67	29.45	15.14	55.4	Clay	0.27	0.95
	Bt1	67-92	19.84	24.55	55.6	Clay	0.44	1.1
	Bt2	92-138	26.65	19.44	53.9	Clay	0.36	1.18
	C	138+	26.47	21.63	51.9	Clay	0.42	1.24
US	Ap	0-22	37.33	20.18	42.5	Clay	0.47	1.06
	Ah	22-75	30.62	28.18	41.2	Clay	0.68	1.12
	AB	75-110	26.76	22.62	50.6	Clay	0.45	1.18
	Bt1	110-145	24.96	23.58	51.5	Clay	0.46	1.15
	Bt2	145+	19.24	28.36	52.4	Clay	0.54	1.16
US	Ap	0-21	58.7	14.79	26.5	Sandy Clay Loam	0.56	1.1
	Ah	21-43	49.32	17.97	32.7	Sandy Clay Loam	0.55	1.14
	AB	43-85	49.4	10.00	40.6	Sandy Clay	0.25	1.14
	Bt1	85-155	36.53	15.86	47.6	Clay	0.33	1.14
	Bt2	155+	36.17	17.03	46.8	Clay	0.36	1.17
MS	Ap	0-22	60.7	9.29	30.0	Sandy Clay Loam	0.31	1.15
	Ah	22-48	41.95	24.25	33.8	Clay Loam	0.72	1.18
	Bt1	48-71	35.61	17.18	47.2	Clay	0.36	1.09
	Bt2	71-120	24.83	17.17	58.0	Clay	0.30	1.09
	BC	120+	46.39	11.50	42.1	Sandy Clay	0.27	1.09
MS	Ap	0-25	31.31	24.68	44.0	Clay	0.56	0.93
	Ah	25-60	44.69	20.21	35.1	Clay Loam	0.58	0.98
	AB	60-100	27.63	25.57	46.8	Clay	0.55	1
	Bt1	100-150	32.59	23.50	43.9	Clay	0.54	1.1
	Bt2	150+	33.78	19.22	47.0	Clay	0.41	1.07
MS	Ap	0-35	41.85	17.94	40.2	Clay	0.45	1.01
	Ah	35-68	30.38	17.92	51.7	Clay	0.35	1.1
	Bt1	68-105	22.31	26.6	51.1	Clay	0.52	1.14
	Bt2	105-140	24.08	28.22	47.7	Clay	0.59	1.13
	Bt3	140+	25.99	31.11	42.9	Clay	0.73	1.15
MS	A	0-15	38.66	12.44	48.9	Clay	0.25	1.06
	AB	15-42	25.58	31.42	43.0	Clay	0.73	1.06
	Bt1	42-105	22.95	32.75	44.3	Clay	0.74	1.1
	Bt2	105-145	23.83	29.6	46.6	Clay	0.64	1.21
	Bt3	145+	28.23	25.36	46.4	Clay	0.55	1.3
MS	Ap	0-20	32.88	27.22	39.9	Clay Loam	0.68	1.02
	AB	20-65	31.83	26.17	42.0	Clay	0.62	1.05
	Bt1	65-140	23.18	28.41	48.4	Clay	0.59	1.19

	Bt2	140+	22.86	28.93	48.2	Clay	0.60	1.24
LS	Ap	0-25	48.91	19.79	31.3	Sandy Clay Loam	0.63	0.99
	AC	25-65	37.09	27.80	35.1	Clay Loam	0.79	1.09
	C1	65-90	38.69	30.61	30.7	Clay Loam	1.00	1.24
	C2	90-120	40.22	17.08	42.7	Clay	0.40	1.22
	C3	120+	26.39	23.81	49.8	Clay	0.48	1.19
LS	Ap	0-25	32.41	36.99	30.6	Clay Loam	1.21	1.01
	AC	25-90	35.81	30.48	33.7	Clay Loam	0.90	1.02
	C1	90-128	31.53	31.57	36.9	Clay Loam	0.86	1.24
	C2	128-162	28.94	22.16	48.9	Clay	0.45	1.27
	C3	162+	28.26	25.33	46.4	Clay	0.55	1.21
LS	Ap	0-25	26.47	24.83	48.7	Clay	0.51	0.95
	AC1	25-65	20.11	15.48	64.4	Clay	0.24	1.21
	AC2	65-92	18.93	15.56	65.5	Clay	0.24	1.15
	C1	92-160	18.9	11.29	69.8	Clay	0.16	1.14
	C2	160+	20.63	24.57	54.8	Clay	0.45	1.24
LS	Ap	0-20	24.22	21.48	54.3	Clay	0.40	1.25
	AC	20-70	24.63	25.87	49.5	Clay	0.52	1.18
	C1	70-110	21.39	26.61	52.0	Clay	0.51	1.14
	C2	110-155	11.16	20.04	68.8	Clay	0.29	1.14
	C3	155+	20.08	33.72	46.2	Clay	0.73	1.07
LS	Ap	0-25	46.91	18.79	34.3	Sandy Clay Loam	0.55	0.87
	AC	25-65	35.09	26.80	38.1	Clay Loam	0.70	0.97
	C1	65-90	36.69	29.61	33.7	Clay Loam	0.88	1.12
	C2	90-120	38.22	16.08	45.7	Clay	0.35	1.1
	C3	120+	24.39	22.81	52.8	Clay	0.43	1.07
LS	Ap	0-10	43.5	29.7	26.8	Loam	1.11	1.25
	A	10-25	24.6	27.30	48.1	Clay	0.57	1.31
LS	Ap	0-10	48.91	19.79	31.3	Sandy Clay Loam	0.63	0.95
	A	10-25	37.09	25.80	37.1	Clay Loam	0.70	1.21
LS	Ap	0-10	35.47	22.83	41.7	Clay	0.55	1.10
	A	10-25	30.11	15.49	54.4	Clay	0.28	1.14

SP=Slope position; US=Upper slope; MS =Middle slope; LS= Lower slope

Chemical Characteristics of the Soils

Soil pH, Organic carbon, TN% and soil available Phosphorus (mg kg-1**) of the study area**

As (EthioSIS, 2014; Jones, 2003; Tekalign, 1991) set in the study area, the soil pH ranged from strongly acidic to neutral (4.2 to 7.65). The pH-H_2O values varied from 4.2 to 7.65 in the pedons with increasing trend with depth in all pedons as depicted in the table 4. The soil pH was positively significant correlated (r= 0.10; p <0.05) with K, while it was a negatively significant (r = -0.509**; r = -0.07; r = -0.461**; and r = -0.413**; P<0.01) correlated with Fe, Cu, Mn and Zn respectively (Table 7).

Availability of soil organic carbon content ranged from 0.11 to 4.28%, the mean value was 1.33% in the study area within a given topographic position as depicted in table 4. There was consistent availability of organic carbon shown along with topographic positions; in addition to this it decreased as soil depth increased. This finding confirms that as soil organic carbon content in the study area was ranged from very low to optimum ranges; According Tekalign (1991) and EthioSIS (2016) suggestion ratings. In line with land degradation with respect to clearing the land cover and intensive cultivation have negative effect on soil organic carbon (Wakene and Heluf, 2004; Habtamu et al., 2009). Whereas, a total nitrogen content was ranged from a 0.012 to 0.5% along with their landscape (Table 4). According to Hazelton and Murphy (2007) rating standards results found in very low to optimum. Moreover, as stated by Hartz (2007) soils with less than 0.07% total N have limited N mineralization potential, while those having greater than 0.15% total N would be expected to have a significant amount of nitrogen mineralization during the succeeding crop cycle. Accordingly, most of the soils in the study area have a good potential of N mineralization. The total N (TN %) distribution pattern looks like that of the OC with soil depth. In sum up, the OC and TN availability highly mattered by slope gradient, it might be due to materials transport from upstream to downstream (Sheleme, 2011; Dinku et al., 2014).

The carbon to nitrogen ratio (C/N) showed difference along soil depths in the study area (Table 4). The carbon to nitrogen ratio (C/N) content of the soils among pedons was ranged from 1.4 to 16.0 across the different topographic positions (Table 4). As stated by Hazelton and Murphy (2007) carbon to nitrogen ratio (C/N) of the study soils were reveals that very low. The carbon to nitrogen ratio (C/N) for most arable land is between a numbers of 10 to 12. Thus the study was somewhat close to the optimum. The narrow C/N ratio at the surface layers might be due to the effect of microbial activities that result in relatively fast decomposition of OM and the consequent CO_2 evolution (Alem et al., 2015). The present finding is in agreement with that of Nahusenay et al. (2014) showing high C/N ratio of the soils indicating the OM was not fully decomposed and N loss was seized.

Soil available Phosphorus was under category of the very low to low, which was ranged from 4.66 to 56.2 (mg kg-1) (Table 4) according to Cottenie, 1980 and EthioSIS, 2016 rating suggestions. Mostly available soil phosphorus more on the surface soils however decreased as depth increased, it might be due to abundance of organic carbon by application of P containing fertilizer and compost by farmers. This finding is in line with that of Awdenegest et al. (2013) who argued that the higher available P in the topsoil layer of agricultural lands might be related to the application of animal manure, compost, household wastes like ashes and DAP fertilizer for soil fertility management. The results revealed that the available Phosphorus could not be the limiting nutrients for crop production in the area.

Table 4. Organic carbon (OC), TN%, and pH, C/N and Available P (mg kg-1) of the study site

Pedon	Horizons	Depth	pH	OC (%)	TN (%)	C/N	Av. P (mg kg-1)
US	Ap	0-28	5.94	3.42	0.28	12.2	33
	Ah	28-62	5.28	3.9	0.33	11.8	25.9
	Bt1	62-121	4.57	0.87	0.09	9.7	18.8
	Bt2	121-175	4.75	0.63	0.06	10.5	11.7
	Bt3	175+	4.84	0.55	0.04	13.8	4.66
US	Ap	0-30	4.96	3.13	0.27	11.6	20.1
	AB	30-75	5.22	2.06	0.22	9.4	13.5
	Bt1	75-110	5.44	1.27	0.13	9.8	11.2
	Bt2	110-155	5.31	1.16	0.12	9.7	10.2
	C	155+	5.35	0.86	0.1	8.6	9.8
US	AP	0-21	5.29	4.28	0.34	12.6	25.6
	Ah	21-52	4.49	4.03	0.31	13.0	18.5
	AB	52-109	4.88	1.41	0.16	8.8	11.4
	Bt1	109-131	5.64	1.26	0.13	9.7	10.3
	Bt2	131+	5.04	0.3	0.03	10.0	9.71
US	Ap	0.25	5.94	3.48	0.33	10.5	56.2
	Ah	25-67	5.53	3.08	0.32	9.6	50.1
	Bt1	67-92	4.9	0.79	0.07	11.3	42.3
	Bt2	92-138	4.84	0.52	0.06	8.7	30.9
	C	138+	5.07	0.13	0.02	6.5	28.8
US	Ap	0-22	5.53	2.33	0.19	12.3	33
	Ah	22-75	4.56	2.02	0.17	11.9	25.9
	AB	75-110	4.68	1.85	0.17	10.9	18.8
	Bt1	110-145	4.83	1.79	0.13	13.8	11.7
	Bt2	145+	4.2	1.56	0.11	14.2	10.6
US	Ap	0-21	5.25	3.45	0.31	11.1	21.7
	Ah	21-43	6.27	1.85	0.22	8.4	18.6
	AB	43-85	6.32	1.16	0.13	8.9	17.5
	Bt1	85-155	5.67	0.65	0.07	9.3	11.4
	Bt2	155+	4.66	0.63	0.06	10.5	10.8
MS	Ap	0-22	6.07	3.09	0.25	12.4	30.6
	Ah	22-48	7.35	1.76	0.21	8.4	23.5
	Bt1	48-71	6.31	1.32	0.13	10.2	16.4
	Bt2	71-120	5.03	0.7	0.07	10.0	10.3
	BC	120+	7.65	1.1	0.1	11.0	9.2
MS	Ap	0-25	4.48	3.8	0.28	13.6	15.7
	Ah	25-60	4.79	2.14	0.22	9.7	15.5
	AB	60-100	4.93	1.02	0.12	8.5	10.9
	Bt1	100-150	5.12	0.65	0.06	10.8	9.8
	Bt2	150+	4.91	0.41	0.04	10.3	9.3
MS	Ap	0-35	4.72	2.83	0.22	12.9	19.5
	Ah	35-68	4.58	1.24	0.1	12.4	15.4
	Bt1	68-105	4.63	0.54	0.04	13.5	12.3
	Bt2	105-140	4.8	0.46	0.03	15.3	10.8
	Bt3	140+	4.89	0.27	0.02	13.5	10.9

MS	A	0-15	4.63	1.7	0.19	8.9	24.1
	AB	15-42	4.67	1.51	0.16	9.4	20.4
	Bt1	42-105	4.74	0.93	0.13	7.2	19.9
	Bt2	105-145	4.82	0.84	0.1	8.4	12.8
	Bt3	145+	4.84	0.12	0.01	12.0	10.3
MS	Ap	0-20	5.47	2.58	0.25	10.3	26.1
	AB	20-65	4.51	1.59	0.13	12.2	19.3
	Bt1	65-140	4.86	0.59	0.07	8.4	14.9
	Bt2	140+	4.96	0.16	0.01	16.0	11.8
LS	Ap	0-25	4.85	1.8	0.6	3.0	25.3
	AC	25-65	5.34	0.67	0.07	9.6	19.2
	C1	65-90	5.63	0.35	0.04	8.8	17.1
	C2	90-120	5.31	0.3	0.03	10.0	14.2
	C3	120+	5.48	0.23	0.03	7.7	13.1
LS	Ap	0-25	6.02	2.1	0.25	8.4	24.4
	AC	25-90	5.38	1.32	0.13	10.2	17.3
	C1	90-128	5.89	0.6	0.06	10.0	13.2
	C2	128-162	6.53	0.41	0.04	10.3	12.1
	C3	162+	6.65	0.11	0.02	5.5	10.3
LS	Ap	0-25	5.21	2.04	0.17	12.0	29.5
	AC1	25-65	5.37	1.06	0.14	7.6	21.9
	AC2	65-92	6.21	1.03	0.11	9.4	17.8
	C1	92-160	5.34	0.85	0.08	10.6	14.7
	C2	160+	5.39	0.71	0.5	1.4	10.6
LS	Ap	0-20	6.28	1.07	0.11	9.7	32.1
	AC	20-70	5.73	1.03	0.09	11.4	25.1
	C1	70-110	6.08	0.84	0.08	10.5	17.9
	C2	110-155	7.29	0.5	0.05	10.0	10.8
	C3	155+	7.11	0.38	0.03	12.7	9.72
LS	Ap	0-25	4.95	1.79	0.599	3.0	26.3
	AC	25-65	5.44	0.66	0.069	9.6	19.2
	C1	65-90	5.73	0.34	0.039	8.7	15.1
	C2	90-120	5.41	0.3	0.029	10.3	12.2
	C3	120+	5.58	0.23	0.029	7.9	10.5
LS	Ap	0-10	6.9	1.5	0.14	10.7	18.16
	A	10-25	6.8	0.72	0.08	9.0	10.73
LS	Ap	0-10	6.6	1.24	0.18	6.9	19.14
	A	10-25	6.3	0.83	0.11	7.5	10.03
LS	Ap	0-10	7.1	1.2	0.12	10.0	20.16
	A	10-25	7.5	.82	0.06	13.7	10.93

pH = Power of hydrogen; OC=Organic carbon; Total nitrogen= TN%; and available phosphorus =Av. P.

Cation exchange capacity (CEC), exchangeable bases (Exch. Bases) and percent base saturation (PBS)

The cation exchange capacity (CEC) of the soils ranged from 21.9 to 52.90 $cmol_c\,kg^{-1}$ (Table 6) which the CEC of the study site was categorized under medium to very high range, according to Landon (1991) classified cation exchange capacity (CEC) <5, 5-15, 15-25, 25-40 and >40 $cmol_c\ kg^{-1}$ soil as very low, low, medium, high and very high. This might be (associated to soil OC and relatively more in a clay content and the predominance of the 2:1 clay minerals. Also, there is a positive and significant correlation ($r=0.384^{**}P<0.01$) between pH and CEC of the soils in the study site among pedons. This study is in line with that of Abebe et al., 2012; Tagbaru, 2014 finding as CEC and pH positively correlated. Soil structure and nutrient status were influenced by cation exchange capacity. The high CEC results showed that the soil of the study area had good nutrient retention and buffering capacities

Exchangeable K status was ranged from 0.12 - 3.9 $cmol_c\ (+)\ kg^{-1}$ (Table 5). According to the critical level adopted by EthioSIS, 2016 the study site was ranged from optimum to very low. While the contents of exchangeable Ca, Mg and Na varied from 0.53 - 26.52, 3.13 - 15.96 and 0.2 - 0.3 $Cmol_c\ (+)\ kg^{-1}$, respectively. Generally, the contents of exchangeable bases increased with increasing soil depth, perhaps due to leaching of exchangeable cations. And the large presence of calcium throughout the study site relative to others cations could be due to the nature of parent material. According to Sims (2000) the ranges of critical values for K, Ca and Mg for optimum crop production are; 0.28 - 0.51, 1.25 - 2.5, and 0.25 - 0.5 $Cmol_c\ kg^{-1}$ soils, respectively. Accordingly, the exchangeable K, Ca and Mg contents of the surface layers of the soils are above the critical values. The Ca/Mg ratio of the soils was in the range of 0.04 to 6.600. As per Eckert (1987) ratings soils having Ca/Mg ratio of <4:1 are suspected to have Mg induced Ca deficiency; Ca/Mg >8:1 ratio Ca induced deficiency of Mg; and 4-8 ratio is as optimum. Accordingly, the results indicate Mg induced Ca deficiency in the certain sites of soil in the study area. 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 42.2 to 88.0% 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 range as describe by Hazelton and Murphy (2007). Consequently, the soils of the study area could be categorized as fertile soil in line with the rating of Landon (1991) who suggested soils having greater than 60% base saturation as fertile.

Table 5 Exchangeable bases, Cation Exchange Capacity (CEC), and Percentage of base saturation (PBS) of soils in Enemor Ener woreda, southern Ethiopia

Pedon	Horizon	Depth	Exch. bases (Cmolc (+) kg-1				∑ Exch. Bases Cmolc (+) kg-1	CEC Cmol (+) kg-1	BS (%)	Ca/Mg
			Ca	Mg	Na	K				
US	Ap	0-28	13.5	4.22	0.94	0.36	19.0	27.1	70.3	3.20
	Ah	28-62	15.25	5.08	0.77	0.47	21.6	29.5	73.2	3.00
	Bt1	62-121	14.35	5.06	0.88	0.31	20.6	28.0	73.6	2.84
	Bt2	121-175	17.91	6.82	0.72	0.28	25.7	32.0	80.5	2.63
	Bt3	175+	5.98	5.98	0.91	0.27	13.1	31.1	42.2	1.00
US	Ap	0-30	20.35	6.78	1.07	0.53	28.7	36.9	77.9	3.00
	AB	30-75	21.26	7.7	1.10	0.52	30.6	35.8	85.4	2.76
	Bt1	75-110	20.54	6.85	1.01	1.35	29.8	37.2	79.9	3.00
	Bt2	110-155	21.6	6.91	0.98	1.23	30.7	37.1	82.8	3.13
	C	155+	19.32	6.72	0.82	1.33	28.2	34.2	82.3	2.88
US	AP	0-21	15.09	5.03	0.82	0.55	21.5	33.7	63.7	3.00
	Ah	21-52	12.58	4.19	0.84	0.4	18.0	28.3	63.8	3.00
	AB	52-109	13.71	4.28	0.84	0.4	19.2	29.3	65.5	3.20
	Bt1	109-131	18.46	6.71	1.15	1.46	27.8	34.7	80.2	2.75
	Bt2	131+	18.53	5.9	0.97	0.4	25.8	34.8	74.2	3.14
US	Ap	0.25	22.3	7.72	0.97	1.1	32.1	37.3	86.1	2.89
	Ah	25-67	17.26	6.04	1.10	0.89	25.3	36.1	70.0	2.86
	Bt1	67-92	15.32	5.11	1.05	0.7	22.2	32.9	67.5	3.00
	Bt2	92-138	16.31	5.15	1.03	0.45	22.9	33.1	69.3	3.17
	C	138+	18.92	6.02	1.05	0.5	26.5	35.1	75.6	3.14
US	Ap	0-22	17.79	5.93	0.66	0.62	25.0	35.5	70.5	3.00
	Ah	22-75	14.66	5.17	0.88	1.11	21.8	33.8	64.7	2.84
	AB	75-110	13.72	4.29	0.93	0.77	19.7	29.4	67.1	3.20
	Bt1	110-145	18.78	6.83	0.95	0.74	27.3	35.7	76.4	2.75
	Bt2	145+	13.01	4.34	0.96	0.52	18.8	28.3	66.6	3.00
US	Ap	0-21	17.74	5.91	0.68	0.4	24.7	34.0	72.8	3.00
	Ah	21-43	16.43	5.48	0.48	0.5	22.9	32.1	71.4	3.00
	AB	43-85	13.88	5.05	0.61	1.44	21.0	29.7	70.6	2.75
	Bt1	85-155	15.19	5.06	0.92	3.9	25.1	31.2	80.4	3.00
	Bt2	155+	16.96	5.94	0.79	1.57	25.3	30.4	83.0	2.86
MS	Ap	0-22	14.88	5.37	0.34	0.72	21.3	27.3	78.1	2.77
	Ah	22-48	20.22	6.74	0.63	1.13	28.7	38.9	73.8	3.00
	Bt1	48-71	18.8	5.98	0.56	0.65	26.0	39.9	65.1	3.14
	Bt2	71-120	21.24	6.84	1.06	0.62	29.8	40.9	72.8	3.11
	BC	120+	20.08	7.97	0.54	1.67	30.3	40.6	74.6	2.52
MS	Ap	0-25	13.67	4.27	0.8	0.47	19.2	30.2	63.7	3.20
	Ah	25-60	15.26	5.09	1.03	0.43	21.8	30.9	70.6	3.00
	AB	60-100	14.42	5.09	0.94	0.39	20.8	28.1	74.1	2.83
	Bt1	100-150	17.04	6.82	0.85	0.42	25.1	32.4	77.5	2.50
	Bt2	150+	15.32	5.96	1.02	0.5	22.8	31.5	72.5	2.57

MS	Ap	0-35	15.18	5.9	0.95	0.61	22.6	32.1	70.6	2.57
	Ah	35-68	14.31	4.21	1.02	0.45	20.0	32.9	60.7	3.40
	Bt1	68-105	14.42	5.09	1.09	0.52	21.1	30.0	70.5	2.83
	Bt2	105-140	18.97	6.9	1.01	0.48	27.4	31.4	87.1	2.75
	Bt3	140+	19.65	5.98	1.00	0.48	27.1	32.0	84.6	3.29
MS	A	0-15	1.39	15.81	1.14	1.29	19.6	36.2	54.3	0.09
	AB	15-42	0.69	14.28	0.99	0.69	16.7	29.2	57.0	0.05
	Bt1	42-105	0.53	15.12	1.00	0.53	17.2	24.7	69.7	0.04
	Bt2	105-145	0.59	15.96	1.00	0.59	18.1	27.4	66.2	0.04
	Bt3	145+	0.62	15.12	1.02	0.62	17.4	26.5	65.6	0.04
MS	Ap	0-20	14.28	4.2	0.82	1.04	20.3	28.3	71.9	3.40
	AB	20-65	14.28	4.2	1.08	0.9	20.5	29.7	69.0	3.40
	Bt1	65-140	15.96	5.88	1.00	0.59	23.4	27.9	84.1	2.71
	Bt2	140+	18.83	5.99	1.12	0.6	26.5	31.2	85.1	3.14
LS	Ap	0-25	16.64	5.82	0.87	0.38	23.7	33.0	71.8	2.86
	AC	25-65	15.66	5.77	1.11	0.29	22.8	26.9	85.0	2.71
	C1	65-90	14.7	4.9	1.08	0.26	20.9	24.4	85.7	3.00
	C2	90-120	22.11	7.65	1.05	0.53	31.3	37.9	82.7	2.89
	C3	120+	19.82	8.61	0.9	0.6	29.9	34.0	88.0	2.30
LS	Ap	0-25	14.7	5.46	0.79	0.94	21.9	32.0	68.5	2.69
	AC	25-90	17.64	5.88	0.89	1.54	26.0	31.0	83.6	3.00
	C1	90-128	14.77	4.99	0.91	0.79	21.5	25.3	84.7	2.96
	C2	128-162	21.56	7.04	1.03	0.85	30.5	38.3	79.7	3.06
	C3	162+	20.06	6.98	1.25	0.63	28.9	37.0	78.2	2.9
LS	Ap	0-25	21.5	7.74	1.01	0.57	30.8	39.7	77.6	2.8
	AC1	25-65	22.38	8.79	0.67	0.65	32.5	44.0	73.9	2.5
	AC2	65-92	24.32	11.88	1.3	0.74	38.2	52.1	73.4	2.0
	C1	92-160	22.92	10.68	0.81	0.66	35.1	52.2	67.2	2.1
	C2	160+	26.52	8.84	0.81	0.53	36.7	49.5	74.2	3.0
LS	Ap	0-20	23.03	10.71	0.65	0.56	35.0	52.9	66.1	2.2
	AC	20-70	21.44	8.89	0.95	0.7	32.0	44.9	71.2	2.4
	C1	70-110	20.6	9.08	1.01	0.73	31.4	47.4	66.3	2.3
	C2	110-155	23.99	10.6	0.93	0.51	36.0	47.6	75.8	2.3
	C3	155+	21.24	8.9	0.82	0.42	31.4	44.5	70.5	2.4
LS	Ap	0-25	15.14	4.82	0.77	0.28	21.0	30.5	68.9	3.1
	AC	25-65	14.16	4.77	1.01	0.19	20.1	24.4	82.6	3.0
	C1	65-90	13.2	3.9	0.98	0.16	18.2	21.9	83.2	3.4
	C2	90-120	20.61	6.65	0.95	0.43	28.6	35.4	80.9	3.1
	C3	120+	20.32	7.61	1.04	0.5	29.5	36.5	80.7	2.7
LS	Ap	0-10	21.92	4.48	0.24	0.24	26.9	32.8	81.9	4.9
	A	10-25	20.63	4.13	0.52	0.12	25.4	34.2	74.2	5.0
LS	Ap	0-10	17.32	5.79	0.2	0.59	23.9	41.7	57.3	3.0
	A	10-25	22.16	7.22	0.22	0.51	30.1	38.4	78.5	3.1
LS	Ap	0-10	18.42	3.91	0.38	0.54	23.3	30.5	76.2	4.7
	A	10-25	20.63	3.13	0.43	0.39	24.6	31.2	78.7	6.6

SP= Slope Position, US=Upper Slope; MS= Middle Slope; LS=Lower Slope

Selected extractable micronutrients

The concentrations of available micronutrients were in the order of Fe> Mn > Cu> Zn in the entire slope positions, whereas Zn was the smallest. As shown Table 6, the extractable Mn ranged from 19.04 to 168.84 (ppm) for the study site and its mean was 86.97. According to Karitun et al. (2013), critical level for MnAI is 25.When MnAI status of the soils of the study site was compared with the critical level it was more than critical level. This might indicate that Mn toxicity is one of the factors that contribute to the low crop production and productivity in the study site. The result of this study is in line with the finding of Eyob Tilahun et al. (2015) and Wondosen Tena and Sheleme Beyene (2011) who was reported that amount of extractable Mn are generally high in the tropical soils and Mn toxicity is even more common than deficiency. Therefore, liming can be used o reduce Mn extractable and availability of Mn.

Extractable Fe varied from 12.68 to 246.49 (ppm) with a mean value of 123.33 (ppm) as shown in Table 6. It was observed that all of the soils in the pedons were found to be sufficient I to sufficient III in extractable Fe status. This finding is in agreement with the results of (Haque et al., 2000; Abayneh, 2005; Eyob et al., 2015 and Hilette et al., 2015) who reported that Fe was adequate in the soil samples collected from different regions of the country. The existence of adequate Fe content in the soils may be due to the parent material that contains minerals like Feldspar, Magnetite, Hematite and Limonite which together constitute the bulk of trap rock in these soils (Fanjana, 2020). Also, soil reaction (pH) of the study area may contribute to the high amount of extractable Fe since the pH of the majority of soils in the study area is less than 7 that can enhance the solubility of Fe. Diatta et al. (2014) reported that soil reaction (pH) is of prime importance in controlling towards the availability of micronutrients, since it affects directly their solubility as well as activity in the soil environment.

Extractable Cu varied from 0.06 to 31.58 (ppm) with a mean value of 13.45 (ppm) as shown in Table 6. It was observed that all of the soils in the pedons were found to be marginal to sufficient III in extractable Cu status according to the critical level adopted (Kirmani et al., 2011; EthioSIS, 2014).

Extractable Zn varied from 0.34 to 5.94 (ppm) with a mean value of 2.38 (ppm) as shown in Table 6. It was observed that all of the soils in the pedons were found deficient to sufficient II range in extractable Zn status according to the critical level (Kirmani et al., 2011; EthioSIS, 2014). This may be due to the soil conditions such as low pH and parent materials of soil that are high in Zn content. Certain soil conditions reduce the availability of Zn, notably high pH (Jones and Eck, 1973). Thus, a high incidence of Zn deficiency often occurs on calcareous or limed soils. The present study soils were neither limed nor calcareous and the pH values in the majority of the soils were not too high to precipitate available Zn. According to Fisseha (1992) soil micronutrients are influenced by several factors among which soil OM content, soil reaction and clay contents are the major ones.

Table 6 Micronutrients contents of the soils in Enemor Ener woreda soils as influenced by topographic position and parent material

Pedon	Horizons	Depth	Cu (mg kg-1soil)	Mn (mg kg-1soil)	Zn (mg kg-1soil)	Fe (mg kg-1soil)
US	Ap	0-28	10.96	43.12	1.48	71.89
	Ah	28-62	14.03	65.54	1.87	109.52
	Bt1	62-121	17.1	87.96	2.36	147.15
	Bt2	121-175	19.17	100.38	2.75	184.78
	Bt3	175+	20.24	132.8	3.04	222.41
US	Ap	0-30	18.73	76.87	2.84	124.32
	AB	30-75	19.8	97.29	3.29	161.95
	Bt1	75-110	21.87	111.71	3.62	189.58
	Bt2	110-155	24.94	134.13	4.11	217.21
	C	155+	26.01	146.55	4.51	244.84
US	AP	0-21	11.3	62.23	3.58	105.97
	Ah	21-52	13.97	85.65	3.97	133.6
	AB	52-109	14.44	117.07	4.56	171.23
	Bt1	109-131	16.51	130.49	4.85	208.86
	Bt2	131+	17.58	141.91	5.94	246.49
US	Ap	0.25	21.25	87.29	2.84	95.52
	Ah	25-67	16.86	67.02	2.31	100.25
	Bt1	67-92	12.4	63.9	1.24	100.25
	Bt2	92-138	10.6	60.1	1.56	104.98
	C	138+	11.8	57.8	1.34	109.71
US	Ap	0-22	7.48	68.99	0.55	112.71
	Ah	22-75	9.55	91.41	0.94	150.34
	AB	75-110	11.62	113.83	1.43	177.97
	Bt1	110-145	14.69	146.25	1.92	215.6
	Bt2	145+	15.76	158.67	2.11	243.23
US	Ap	0-21	23.3	78.1	0.34	109.93
	Ah	21-43	24.37	100.52	0.73	147.56
	AB	43-85	28.44	132.94	1.42	175.19
	Bt1	85-155	30.51	145.36	1.91	202.82
	Bt2	155+	31.58	157.78	1.29	230.45
MS	Ap	0-22	21.73	59.61	1.16	70.73
	Ah	22-48	23.8	82.03	1.65	109.36
	Bt1	48-71	24.87	114.45	1.94	149.99
	Bt2	71-120	28.94	116.87	2.53	173.62
	BC	120+	31.01	139.29	2.9	211.25
MS	Ap	0-25	4.2	76.6	2.15	83.47
	Ah	25-60	1.82	32.52	1.56	76.31
	AB	60-100	6.98	120.68	2.74	90.83
	Bt1	100-150	9.96	154.76	3.43	99.79
	Bt2	150+	12.34	168.84	3.95	110.95
MS	Ap	0-35	7.01	79.07	3.07	79.88
	Ah	35-68	9.08	101.49	3.46	118.51
	Bt1	68-105	10.15	119.91	3.89	159.14
	Bt2	105-140	12.22	136.33	4.29	182.77

	Bt3	140+	17.29	148.75	4.93	210.4
MS	A	0-15	8.89	79.05	2.07	99.83
	AB	15-42	10.96	101.47	2.66	127.46
	Bt1	42-105	14.03	129.89	2.95	165.09
	Bt2	105-145	16.1	136.31	3.94	202.72
	Bt3	145+	19.17	158.73	3.73	240.35
MS	Ap	0-20	10.46	72.24	1.86	105
	AB	20-65	11.53	93.66	2.35	132.63
	Bt1	65-140	15.6	107.08	2.74	170.26
	Bt2	140+	16.67	129.5	3.03	197.89
LS	Ap	0-25	9.27	84.12	3.5	139.55
	AC	25-65	7.89	74.7	3.91	132.39
	C1	65-90	6.91	66.28	2.72	129.23
	C2	90-120	5.83	59.86	2.63	120.07
	C3	120+	4.75	49.44	2.14	119.91
LS	Ap	0-25	26.54	68.09	1.83	84.66
	AC	25-90	25.16	58.67	1.44	77.5
	C1	90-128	24.78	50.25	1.05	71.34
	C2	128-162	21.4	38.83	1.0 1	69.18
	C3	162+	20.02	30.41	0.97	55.02
LS	Ap	0-25	12.35	72.55	2.54	75.75
	AC1	25-65	10.97	63.13	2.15	68.59
	AC2	65-92	10.59	58.71	1.96	64.43
	C1	92-160	9.21	54.29	1.2 7	59.27
	C2	160+	6.83	44.87	1.07	57.11
LS	Ap	0-20	4.01	49.72	1.92	63.52
	AC	20-70	3.63	40.3	1.53	56.36
	C1	70-110	3.45	37.88	1.19	50.21
	C2	110-155	2.77	26.46	0.94	47.04
	C3	155+	1.59	19.04	0.54	36.88
LS	Ap	0-25	10.1	87.12	3.4	141.35
	AC	25-65	8.72	77.7	3.01	134.19
	C1	65-90	7.34	69.28	2.92	122.03
	C2	90-120	6.96	58.96	2.83	119.87
	C3	120+	5.58	49.94	1.84	102.71
LS	Ap	0-10	0.06	43.42	3.22	18.66
	A	10-25	0.14	28.86	2.73	13.64
LS	Ap	0-10	1.63	51.52	0.45	18.26
	A	10-25	1.02	47.88	0.5	12.68
LS	Ap	0-10	1.6	56.7	0.86	19.5
	A	10-25	1.2	50.9	0.65	17.2

SP= Slope Position, US=Upper Slope; MS= Middle Slope; LS=Lower Slope

Nature of soil properties on micronutrients

The micronutrients availability and solubility mainly influenced by a number of factors like soil organic carbon content, soil reaction and clay content are the major ones (Fisseha, 1992). Therefore, an effort was made to study the relationship between copper, zinc, iron and manganese and some soil properties (pH, organic carbon and particle size) by simple correlation analysis (Table 7), to find the soil factors involved in regulation of amounts of extractable Cu, Zn, Mn and Fe in soils. Significant and positive ($p<0.05$) relationship of extractable Cu with organic carbon ($r = 0.06$) was observed (Table 7) and significant and negative ($p<0.05$) relationship of extractable Fe, Zn and Mn with organic carbon ($r = -0.15$, $r = -0.09$, $r = -0.14$) observed respectively (Table 7). The results were in near agreement with findings of (Yadav, 2011; Adak et al., 2011; Eyob Tilahun et al., 2015). The reason for this might be the ability of soil organic carbon (SOC) to form natural chelates that can continue micronutrients in an available form. Also, organic carbon controls the affinity, attraction strength of micronutrients with most functional groups (Diatta et al., 2014).

Micronutrients such as iron, manganese and zinc were correlated negatively with soil pH as presented in the table 7. This shows the solubility nature of the micrometre with respect to increasing soil pH (Rengel, 2015). As many scholars described in research finding (Sharma et al., 2004; Wang et al., 2009; Najafi-Ghiri et al., 2013), the soil pH is negatively correlated with iron amount in the soil. Since most of the micronutrient availability and solubility increase with soil pH increase and vice versa. This might be due to the hydrolysis reactions. Whereas, iron, copper, zinc and manganese were negatively and significantly related with silt and sand but positively correlated with clay (Table 7)

Table 7 Correlation between properties of soils in study at Enemor Ener woreda, southern Ethiopia

Correlations

	Sand	Silt	Clay	BD	pH	OC	TN	P	Ca	Mg	Na	K	Exch. K	CEC	PBS	Cu	Mn	Cu	Fe
Sand	1.00																		
Silt	-.388**	1.00																	
Clay	-.806**	-.232*	1.00																
BD	-.348**	0.13	.280**	1.00															
pH	0.11	-0.16	-0.02	0.20	1.00														
OC	.493**	-.248*	-.361**	-.578**	-0.12	1.00													
TN	.461**	-.224*	-.343**	-.534**	-0.10	.723**	1.00												
P	0.19	-0.20	-0.07	-.350**	0.00	.541**	.464**	1.00											
Ca	-0.12	-.244*	.286**	0.15	.458**	-0.10	-0.02	-0.02	1.00										
Mg	-.346**	-0.01	.371**	0.20	-0.03	-.215*	-0.12	-0.05	-.306**	1.00									
Na	-.447**	0.18	.359**	-0.04	-.515**	-0.18	-0.19	-0.02	-0.17	.240*	1.00								
K	0.08	-.287**	0.10	0.02	0.10	0.01	-0.04	0.00	0.00	0.07	0.04	1.00							
Exch. K	-.319**	-.273*	.512**	.257*	.438**	-.226*	-0.10	-0.05	.849**	.233*	0.00	0.14	1.00						
CEC	-.332**	-.333**	.564**	0.14	.384**	-0.11	0.01	0.03	.645**	.360**	-0.07	0.08	.851**	1.00					
PBS	-0.03	0.02	0.02	.225*	0.18	-0.17	-0.14	-0.04	.478**	-0.14	0.07	0.12	.429**	-0.06	1.00				
Cu	.226*	-0.18	-0.12	0.03	-0.07	0.06	0.00	-0.06	-0.10	-0.02	0.11	.540**	-0.05	-0.16	0.06	1.00			
Mn	-0.02	0.00	0.02	0.03	-.461**	-0.14	-0.16	-.330**	-.372**	0.05	0.18	.293**	-.313**	-.351**	-0.07	.544**	1.00		
Zn	-0.06	0.18	-0.06	-0.02	-.413**	-0.09	-0.05	-.238*	-0.20	0.04	.357**	-0.08	-0.18	-.283**	0.07	0.14	.578**	1.00	.
Fe	-0.01	0.04	-0.02	0.09	-.509**	-0.15	-0.15	-.297**	-.339**	0.05	.342**	.279**	-.277*	-.351**	-0.04	.602**	.854**	.580**	1.00

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Soil classification

According to FAO- WRB all pedons on the upper and middle slope positions had well-structured dark surface horizons of more than 25 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% of OC; base saturation (by 1M NH4OAc, pH 7) of >50 % or more throughout the horizons this meeting the criteria for Mollic diagnostic horizons.

Pedon 3, 4, 5, 6, 7, 8, 9, 10 and 11 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, slightly plastic and sticky, friable with shiny ped faces; silt/clay ratio of <0.54 meeting the criteria for Nitic subsurface horizon. The pedon had a gradual smooth and clear smooth boundary between the surface and subsurface layers; without ferric, plinthic or vertic horizon, and there was 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; it had high Fe content; dark reddish brown (2.5YR3/4 moist) to color; qualifying for rhodic prefix. Thus, the soils represented by this pedon were classified as Rhodic Nitisols (Haplic) according to the World Reference Base for Soil Resources (FAO, 2014).

The subsoil horizons of P12, P13, P14, P15 and P16 exhibit predominantly intersecting slickensides and high clay contents (> 30%) up to 25 cm. Observations of the profile in dry spells show the existence of periodic cracks. These morphological characteristics meet requirements for vertic properties, which are considered to be diagnostic of a vertic horizon. The CEC/clay values of the vertic horizons also indicate the existence of appreciable amounts of expanding clay minerals such as smectite. These conditions are typical characteristics of vertisol mapping units (WRB, 2014). These soils show a base saturation (by 1M NH4OAc) of less than 75% between 20 cm and 100 cm from the soil surface, and meet requirements for a mesotrophic qualifier. Therefore, these are recoginezed and classified as Mesotrophic Vertisols at the subunit level.

Soils characterize in both pedons 1 and 2 have Reddish brown (2.5YR4/3) colour at the surface followed by dark reddish brown (2.5YR3/3) at sub surface and very dusky red below 90 cm. These major soil groups are distributed within study site. They have argic horizons and have high activity clays and high base saturation throughout the pedons. These soils have potentially high soil fertility, provided that the land is not eroded. Exposure to raindrop impact and direct sunlight often leads to surface crusting, runoff and sever erosion. The soils are developed in well-drained areas at higher altitude. They are mainly developed in variable parent materials such as acid to intermediate volcanic rocks, basalts, alkali trachytes and rhyolite. The soils are generally deep, predominantly heavy clays; their structure is moderately developed, medium sub angular blocky. Consistence is hard (dry), friable to firm (moist) and sticky and slightly plastic (wet). The soils have good permeability. Their typical characteristic is that they are found in areas where climatic conditions permit clay movement. They are found commonly on gently sloping to strongly sloping topography. Based on the information available, the soils are classified as Chromic Luvisols.

Since the morphological and physicochemical characteristics of soils of the lower slope position with strongly sloping to sloping landforms pedons, especially pedon 17, 18 and 19 were categorised as Leptosols are soils either restricted in depth by continuous hard rock with 25 cm from the surface; or having mollic horizon with a thickness between 10 and 25 cm directly overlaying material with a calcium carbonate equivalent of more than 40%; containing more than 10% (by weight) fine earth from the soil surface to a depth of 75 cm; and having no diagnostic horizon other than mollic (FAO/WRB, 2006). Therefore, pedons 17, 18 and 19 were limited in the depth by lithic and paralithic contacts within 25 cm from the soil surface and qualified for classification under Mollic Leptosls reference group and classified accordingly. Moreover, it had very dark brown color well aerated, massive in structure and PBS more than 50%. Considering these and other soil properties, the surface horizon of these soils met the requirement for Mollic Leptosols soil unit of the FAO/WRB soil classification system. As the soil map depicted in the fig. 3 majority of the soil in the study site are Haplic/Rhodic Nitisol and Mesotrophic Vertisol.

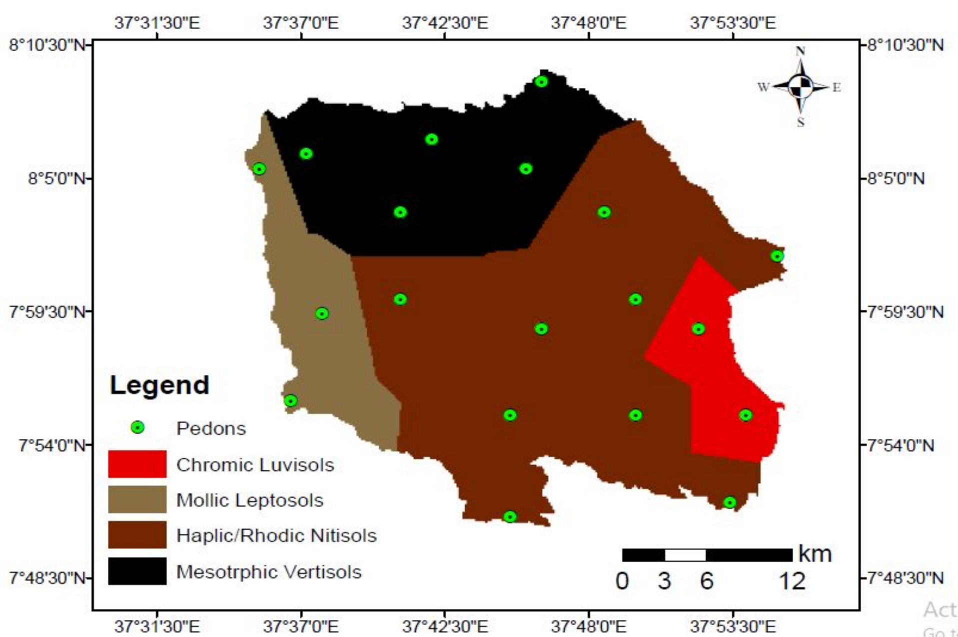

Fig. 3: Soil map of the Enemor Ener Woreda

Conclusion

Soil utilization in a scientific way is the best option in the crop production system. Therefore, to make better production and utilize the soil resource in a sustainable manner, the knowledge of this resource is indispensable. In view of this, (Chromic Luvisols, Haplic/Rhodic Nitisols, Mollic Leptosols and Mesotrphic Vertisols) soil types were identified in the study site. Accordingly, their nature influenced by topographic features and parent materials (basaltic). The major limitations for augmenting agricultural production at Enemor Ener woreda on a sustainable basis soil organic carbon and total nitrogen were ranged from low to very. The soil chemical reaction had strongly acidic to neutral reaction. Available soil phosphorus in the study area was low. While both cation exchange capacity and percentage base saturation were revealed for most soils in an optimum. Concerning to micronutrients for instance, iron, manganese, zinc, and copper were ranged from sufficient III to sufficient I, very high, sufficient II to deficient, and sufficient III to marginal respectively. Some basic cations were result of magnesium induced deficiencies especially exchangeable potassium and calcium content in some extent. Thus, sustainable soil nutrient flow balance could be maintained using integrated soil fertility management approach. In overall, landscape mainly influences nature and distribution of the soil type as shown in the study area. Therefore, implementing cost effective methods such as, using accessible and available materials in the local area to keep the soil fertility as well as soil quality for better crop production to ensure food security.

Data Availability

Data used to support the findings of this study are available from the corresponding author upon request.

Consent for publication: Not applicable

Ethical approval and Consent to participation: Not applicable

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