IMPACT OF TOPOGRAPHY ON SOIL PROPERTIES IN DELBOATWARO SUBWATERSHED, SOUTHERN ETHIOPIA

Abstract

Soil characterization and classification are prerequisites for better agricultural productivity and sustainable soil fertility management. This study was previously conducted to characterize and classify DelboAtwaro, a watershed in southern Ethiopia. Three pedons classes were inspected and three representative pits (pedons) opened, i.e. one in each pedon. Pedons were described in accordance with FAO (2006) and WRB (2014) in the study area, and then soil samples were collected from recognized horizons of each pedon and analyzed for selected physicochemical properties. The pedons confirmed the variability of the physical, chemical and morphological properties of the soils in the study area. Based on the result of field and laboratory soil analysis, the soil structure was early clay in both aboveground and subterranean strata. The soil chemical reaction used to be somewhat acidic to neutral in reaction (pH 6.1-7.0). The organic carbon (OC) content varied between 1.23 and 1.78% between the respective topographical positions. The cationexchange capacity (CEC) of the soils ranged from 39.8 to 79.9 cmol (+) kg-1 (intermediate to optimal), while the percent base saturation (PBS) ranged from 23.7 to 40.7%. The dominance of the exchangeable bases was once, in descending order, Ca>Mg>K>Na. Soils ranged from low to optimal in TN and very low to low in available P, while the concentrations of micronutrients in the soils were best (Fe), very high (Mn), adequate (Zn), and optimum (Cu). The soil had a molly epipedon with humic diagnostic houses in the subsurface. Hence the soil was categorized as Rhodic Nitisols (Haplic) (US, MS, and LS) according to the WRB for soil resources. In general, slope and land use influenced soil properties in the different topographical locations of the Delbo Atwaro Underwater Catchment, suggesting the need for integrated soil fertility management to sustainably conserve soil organic matter and nutrients.

Keywords: Classification, Pedons, Soil characterization, Soil properties, Topographic position

1.1 Introduction

Especially in Ethiopia, the financial system is mainly based on agricultural production. On average, agriculture accounts for about 33.9% of gross domestic product (GDP) (Plecher, 2020). “Ethiopia has remarkable agricultural potential due to its significant fertile land, diverse climate and large available labor pool” (IMF, 2009). “Despite this potential, Ethiopian agriculture remained underdeveloped with low agricultural output and productivity. The low US agricultural production of a should be related to a number of factors including agriculture's dependence on rainfall, lack of modern technology, inadequate land management practices, lack of appropriate evidence on soil properties and management practices, and soil fertility depletion”, Sanchez et al. (1997).

Soil types and properties show outstanding differences in different regions of Ethiopia (Ali et al., 2010). Natural conditions such as geology, climate, topography, biotics and land use/land ridge change are mainly responsible for the development of regional and local differences in soil types and properties. Agricultural land productivity is related to these different soil properties. For example, in the western and southwestern parts of the country, extending on a gentle slope to mountainous topography, Nitosols and Acrisols are used for grain and coffee development, while Vertisol, occupying the area with a decreasing slope, is used for grain production with poor drainage and tolerance is used for animal grazing (FAO/UNDP, 1984a,b; Mesfin, 1998; Mitiku, 1987).

“In a given geographic location, the place where various physiographic features such as steep slopes, hilly land and mountainous surfaces are prevalent, the role is played with the help of topographic features (slope steepness and elevation changes), climatic factors (precipitation and temperature), and vegetation influence the soil properties are immense" (Ahmed, 2002). Soil conditions tend to change with topography because the orientations of hilly surfaces where soil structure can have a significant impact on the microclimate and adjacent vegetation distribution, ultimately affecting the variation in soil properties (Foth 1990). Within a given geographic region, topography affects the depth of the solum, the thickness and organic matter content of the surface soil horizon, the relative humidity of the soil profile, the soil aeration and color of the profile, the level of soluble salts, and the properties of the subsoil parent material (Buol et al., 1997). On hilly areas such as steep slopes and mountain flanks, the slope steepness and height differences, the high achievable erodability and geological interventions tend to keep the soils particularly young (Demel, 2001).

"Topography has been identified as a predominant problem affecting the variation of soil properties along topo-sequences due to its influence on runoff, drainage and soil erosion and its end result on soil improvement" (Fantaw et al., 2006; Mulugeta and Sheleme, 2010; Dinku et al., 2014). "Soil properties such as particle size distribution, pH, organic carbon, total nitrogen, available phosphorus, exchangeable cations and cation exchange capacity vary with slope location" (Mulugeta and Sheleme, 2010; Dinku et al., 2014; Teshome et al., 2016). "The research confirmed the strong relationships between topographical locations and soil properties, such that the distribution of a given soil property can also vary with topographical attributes. Different soil habitats along the landscape affect patterns of crop production, litter production and decomposition, which affect soil carbon and nitrogen content" (Mulugeta et al., 2012). "Soil properties such as clay content and its distribution at depth, sand content, and pH were strongly correlated with landscape location (Wang et al., 2000; Mulugeta and Sheleme, 2010), while organic matter varied with slope location" (Mille et al., 1998). "The depth of the A horizon decreases with increasing slope, with shoulder soils becoming shallow from erosion and foot slopes becoming thicker from deposition” (Mulugeta and Sheleme, 2010).

“According to many scientists, the results confirmed that the success of soil management to maintain soil quality depends on how soils respond to agricultural uses and practices over time” (Wakene, 2001). Because physical, biological and chemical properties influence the different uses and yields of the soil. Knowing the dominant soil type at a given site helps predict the potential opportunities, limitations and required management activities for sustainable development. Soil erosion is one of the major global environmental problems, affecting both on-site and off-site (Guo et al., 2015; Sutherland and Ziegler, 2007). The economic impacts of soil erosion are more severe, especially in producing countries, particularly Ethiopia due to the lack of ability to deal with it and additionally replace lost nutrients (de Melenaere et al., 2014; Gessesse et al., 2014; Lanckriet et al., 2014). In the study area, the unclaimed soil area accelerates water-assisted soil erosion and soil acidification, leading to loss of soil nutrients and reduced crop yields.

Agricultural interventions such as relocation of cultivation, sufficient fallow periods, intensive cultivation, lack of soil protection measures and improper fertilization lead to extreme soil degradation in the study area. Land degradation manifests itself in soil erosion, nutrient depletion and organic matter loss, acidification (Bewket and Teferi, 2009; Haile and Fetene, 2012). The soil loss load from water in Ethiopia ranges from sixteen to over 300 Mg ha1 yr1 and generally depends on the grade of slope, intensity, type of land cover and type of precipitation intensity (Tamrie, 1995; Tesfaye et al., 2014). Knowledge about the distribution of soil types in the landscape, together with different layers of data, can be used as a useful resource for management decisions. The aim of this research was therefore originally to present the morphological, physical and chemical characteristics and to classify and map the soils of the DalboAtwaro to show its agricultural feasibility for sustainable improvement according to the FAO/WRB soil classification system.

Therefore, this study was done characterization and classification of the soils in the study site DelboAtwaro subwatershed, southern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Areas

The study was conducted at DelboAtwaro sub-watershed located in southern, Ethiopia (Figure 1).

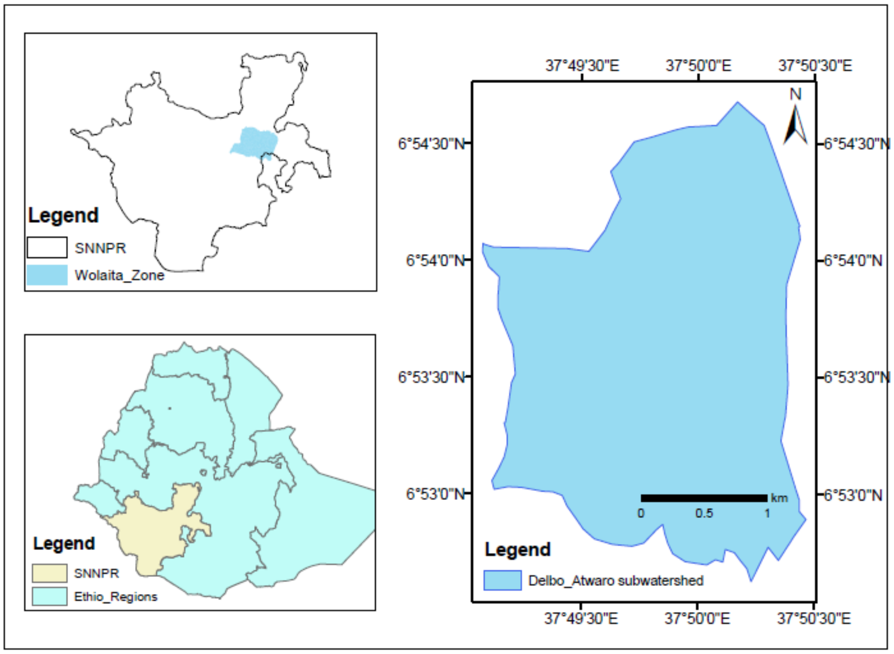

Figure 1.Location map of the study site

The DelboAtwaro study area exists in Soddo ZuriaWoreda, Wolaita Zone, and southern Ethiopia. It is located about 10 km east of Soddo city and is positioned at 6^0 53' 40" N and 37^0 49' 49" E. The altitude is ranging from 1500 to 3500 m a.s.l having a Woina-dega to Dega climatic characteristics. The mean annual precipitation of the site is 1297 mm with bimodal distribution and the suggest annual temperature is 200C (Wolaita sodo meteorology station, 2008-2018) (Fig.2)

Nitosols area mainly dominant soil type in the Wolaita soddo area, and its parent material is basalt (FAO/UNESCO, 1974), which is sesquioxidic and relatively to strongly acidic (Mesfin, 1998). The major vegetation grown in the study area include; cereals such as eragrostis 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.)*

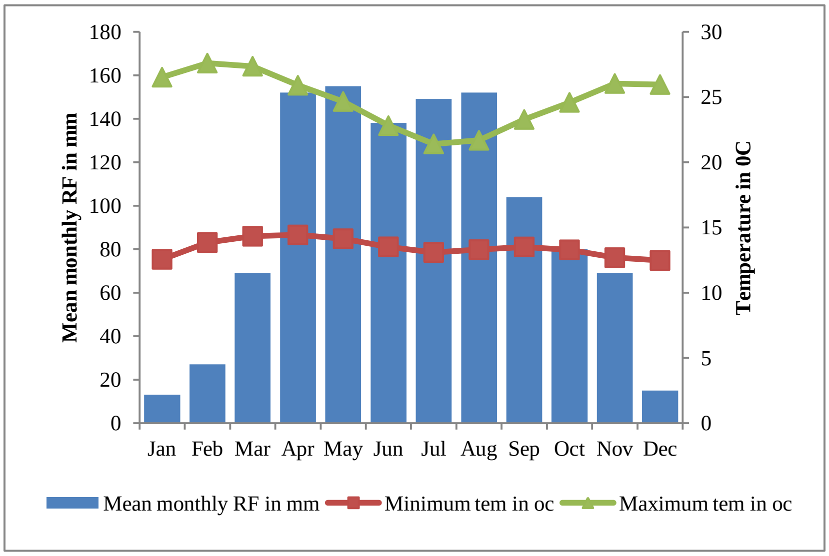

Figure 2.Ten years (2008-2018) mean monthly rainfall, maximum and minimum temperatures of the DelboAtwaro sub-watershed

2.2. Selection and Description of the Pedons

Based on the topographic map of the site, 2 * 1.5 * 2 m pedestrians were excavated earlier by hand excavation. The three toposequences were chosen along an east west route and deal with slopes encompassing landscape aspects from the upper slope to the lower slope of the sub-watershed (Figure 3). Representative pedons were selected primarily based on site and soil profile characterization according to the Field Soil Description Guidelines (FAO, 2006). The land units were identified based on topographic facets and land/soil features using object observations and topographic maps. Soil borer observations were conducted using Edelman borers to discover variations in soil depth and textural characteristics along the slope gradient. Points with identical soil depth and texture classes in a given slope class were considered pedons. Pedon observation points were geo-referenced with the assist of geographical positioning system (GPS) and positioned on the 1:50,000 scale base three soil pits have been opened and the soil profiles of all pedons had been described in situ following the Guidelines for Field Soil Descriptions (FAO, 2006) and the soil colour used to be decided the use of Munsell soil shade chart (Munsellcolour company, 2002).

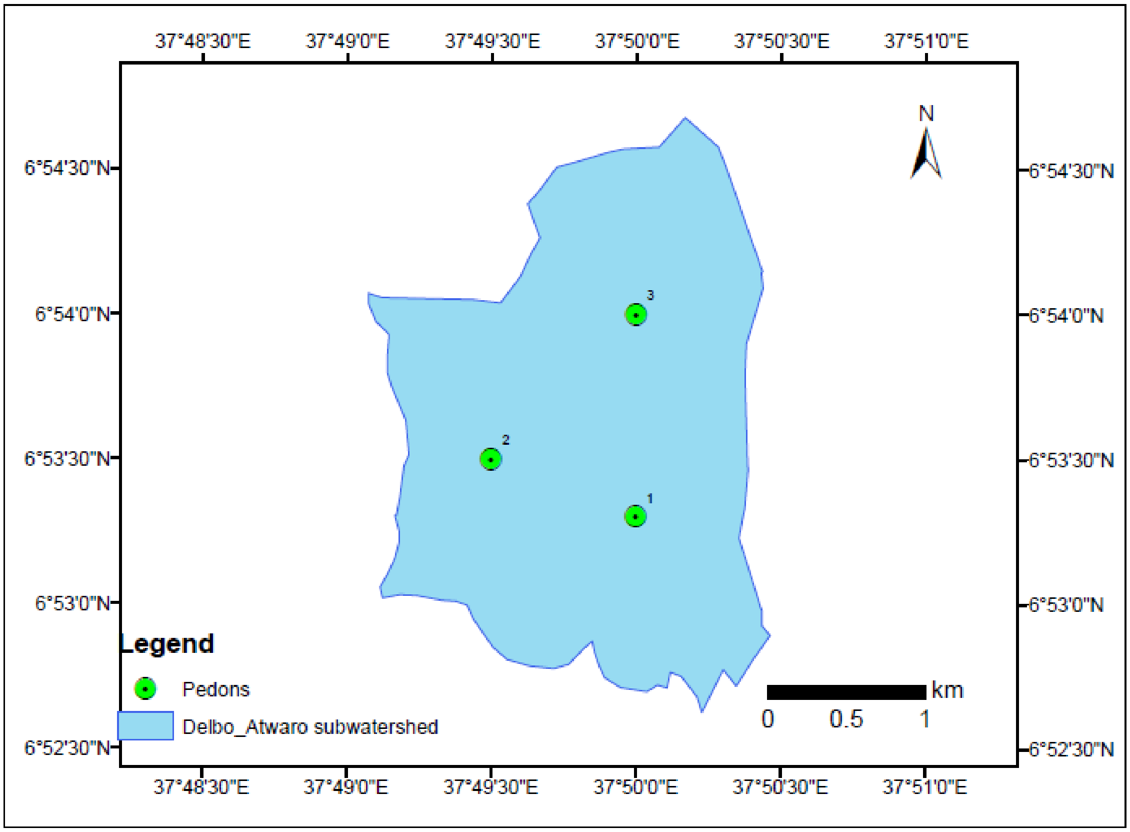

Figure 3.Pedons sites

2.3. Soil Sampling and Sample Preparation

Soil samples were collected from each identified horizon. A total of 12 disturbed and 12 undisturbed soil samples were collected from identified genetic horizons from the three representative pits. All soil samples were air dried, ground and sieved through a 2mm sieve. A 0.5 mm sieve was previously used for total nitrogen (TN) and organic carbon (OC) determinations. Physicochemical property analyzes were performed at Hawassa University using standard laboratory procedures.

2.4. Laboratory Analysis

The particle size distribution was determined once using a modified hydrometer as outlined using Sahlemedhin and Taye (2000). Whereas previously a particle density of 2.65 Mg m-3 was assumed. The pH of the soils was measured once in a suspension of water and potassium chloride (1M KCl) in a ratio of 1:2.5 (soil: liquid ratio) using a glass-calomel mixing electrode (Van Reeuwijk, 1992). . The electrical conductivity (EC) of soils was measured once at a soil/water ratio of 1:2.5 stored for one hour as described by Sahlemdhin and Taye (2000). Soil OC content was formerly determined by wet pulping methods (Walkely and Black, 1934), while total N was formerly calculated by Kjeldahl wet pulping and distillation methods (Bremner and Mulveny, 1982) and available P was calculated by the modified Olsen method (Olsen and Sommers, 1982). Cation exchange capacity and exchangeable bases were extracted using a 1 M ammonium acetate (pH 7) approach (Van Reeuwijk, 1993). In the extract, Ca and Mg were determined by atomic absorption spectrophotometer (AAS) and exchangeable K and Na by flame photometer. Available micronutrients (Fe, Cu, Zn and Mn) were extracted using diethylenetriaminepentaacetic acid (DTPA) as described by Tan (1996) and all were quantified using an atomic absorption spectrophotometer.

2.5. Data Analysis

A simple linear correlation analysis was performed once to examine the relationships between and between selected soil physicochemical properties according to the methods described by Gomez (1984) and used in the interpretation of data.

3. Results and Discussion

3.1. Site Characteristics of the Pedons

In particular, pedons in the study areas showed variability in their inclination, permeability and extent of erosion. The pedons at US, MS, and LS were in upper, middle, and lower landscape positions and had slopes of 20, 15, and 5, respectively, and all pedons were well drained (Table 1). Locations differ based on salient factors such as slope and feedstock. Starting materials influence the type and its composition, e.g. B. Drainage status and clay indices (mineralogy) (Dinku et al., 2014; David, 2005).

Formation of gorges and erosion of streams. In contrast, soils on the lower slopes of other sites in different physiographic-topographical positions experienced less water erosion and deposition of eroded material. Similarly, Sheleme (2017) reported that soils in depression landscapes are affected by the accumulation of materials from the upper slopes.

Table 1. Pedons characteristics in the study area.

Pedon	Lat (Decimal Degree)	Long (Decimal Degree)	Altitude (ma.s.l)	Slope (%)	Landform	Surface drainage	Erosion	Local name of the soils	Parent materials
US	6.888333	37.83333	2152	20	Strongly sloping	Well drained	Moderate water erosion	Chincha Biita	Basalt volcanic material
MS	6.891667	37.82500	2136	15	Strongly sloping	Well drained	Moderate water erosion	Chincha Biita	Basalt volcanic material
LS	6.9000	37.83333	2120	5	Sloping	Well drained	Slightly /sheet erosion	Chincha Biita	Basalt volcanic material

US=Upper slope; MS= Middle slope; LS=Lower slope

3.2. Morphological Characteristics of the Soils

Soil morphology is primarily influenced by soil type, maturity or depth, soil structure, color, consistency, and horizon line. All pedons had a very low profile (> 200 cm) Table 2. Pedon (1) was characterized by Ap, AB, Bt and C; P2 from Ap, A, AB and Bt and P3 from Ap, Ah, B and Bt2 (Table 2). The soil morphological properties varied along the different slopes at the study site and within the horizons, soil depths, color, structure and consistency as well as the horizon boundaries according to FAO (2006).

Variability in color composition was shown in pedons (Table 2). Soils at the surface have different colors 5YR 3/3 (dark red-black) in P1, 2.5YR2.5/3 (dark red-brown) in P2 and 5YR3/3 (black) in P3. For the most part, surface horizons were darker in color compared to their subsurface counterparts, which may be due to the comparatively surface horizons having higher organic matter content compared to lower horizons. These results are consistent with many authors who reported that surface horizons are darker in color than the corresponding subsurface horizons due to relatively higher soil OM levels (Ashenafi et al., 2010; Mulugeta and Sheleme, 2010; Dinku et al., 2014). Differences in soil color were also observed between slopes, which could be due to drainage conditions. Dengize et al. (2012) showed that soil color could be correlated with organic matter, waterlogging and the oxidation-reduction nature of chemicals. In addition, Nuga et al. (2006) also found that drainage conditions and physiographic position could have a major impact on soil color.

Pedons with a soil depth between (50 to 200 cm) are characterized by deeply matured soils (Table 2). The depth of the solum varied along the toposequence, with the shallowest (20 cm) solum with lithic contact observed within 50 cm depth on the upper slope, while deep (>75 cm) surface layers were observed on the middle and lower slopes (Table 2). The shallow depth at the upper locations can limit root penetration for deep-rooted plants (Table 2). The variations in the depth of the solum could be due to the landscape configurations (slope slope and length) important in influencing the rate at which water flows in or out of the ground when sites are exposed Borderson (1994) also reported landscape position influences runoff, drainage, soil temperature, soil erosion, soil depth and hence soil formation, as described by Mulugeta and Sheleme (2010).

Horizons featured a regular smooth boundary between surfaces and subsurface in Pedon 1; clear surface smooth boundary and diffuse underground smooth boundary in P2, and clear surface smooth boundary and gradually underground smooth boundary in P3 (Table 2). Human activities have seen that, alongside nature, there is a major influence on soil composition in horizon formation (Cools and De Vos, 2010). Based on the abundance of roots, the surface horizons show higher biochemical activity compared to the subsurface horizons. This could indeed be related to an unfavorable enabling environment. The size of the roots in different horizons of the pedons also ranges from very fine to coarse in size and insufficient to common in quantity.

Significant differences were found among pedons at the study site due to soil granularity, size and morphology (Table 2). The soil structure in the surface layers of the pedons varied in structure from fine-grained to slightly moderately angular-blocky and sub-angularly blocky. On the other hand, in the subsurface horizons it varied from weak moderately angular and sub-angularly blocky to strongly finely angularly blocky (Table 2). The more advanced structure of the subsurface strata may be due to the moderately higher clay content of the subsurface horizons than that of the surface horizons (Ahn, 1993).

Soil consistencies were characterized by brittle to firm (moist) and slightly sticky/not plastic to slightly sticky/slightly plastic on the upper slope, while pedons in the middle topographical position were very brittle to firm (moist) and slightly sticky/slightly plastic to sticky were/plastic consistency consistent with landscapes (Table 2). Variations in soil structures in pedons resulted from soil physicochemical properties such as organic carbon, clay mineralogy, particle size distribution, and soil nutrient availability. Similarly, Mulugeta and Sheleme (2010) also observed a friable consistency in the surface layers of pedons and attributed this to the higher soil organic matter content.

3.3. Physical Characteristics of the Soils

As the results of both the field and the laboratories show, the clay composition in the soil and in the soils under the pedons is almost more pronounced under the clay soil texture class category (Table 4). As Buol et al. (2003) found that basaltic parent materials contribute to finer-grained soils during weathering, which could account for the formation of clay fractions. All pedons in the study area increase in depth with increasing depth, and tone formation also increases.

Table 2. Selected morphological characteristics of the soils in DelboAtwaro sub-watershed, southern Ethiopia

Pedon	Horizon	Depth	Soil color (moist)	Structure			Consistence			Root abundance	Horizon Boundary
				Grade	Size	Shape	Moist	Wet Stickiness	Plasticity		
(P3) US	Ap	0-22	5YR3/3 (black)	MO	FN	GR	FR	SST	NPL	F	C, S
	Ah	22-68	5YR3/4(dark reddish brown)	MO	F N	SAB	FR	SST	SPL	F	G, S
	Bt1	68-120	2.5YR2.5/3 (dark reddish brown)	MO	F N	SAB	FR	ST	PL	VF	D, S
	Bt2	120-195+	2.5YR2.5/4(dark reddish brown)	MO	F N	AB	FI	ST	PL	VF	--
(P2) MS	Ap	0-30	2.5YR2.5/3(dark reddish brown)	WE	VFN	SAB	VFR	SST	SPL	F	C, S
	A	30-75	2.5YR 4/4(reddish brown)	ME	VFN	AB	VFR	ST	PL	F	D, S
	AB	75-130	2.5YR2.5/3(dark reddish brown)	MO	FN	SAB	FR	SST	SPL	F	D, S
	Bt	130-180+	2.5YR3/3(dark reddish brown)	MO	FN	AB	FR	ST	PL	F	---
(P1) LS	Ap	0-20	5YR 3/3 (dark reddish black)	MO	VFN	GR	FR	SST	NPL	F	G, S
	AB	20-86	2.5YR3/3(dark reddish brown)	MO	ME	AB	FR	ST	PL	F	G, S
	Bt	86-160	7.5YR 4/4(brown)	MO	FN	SAB	FI	ST	PL	F	G, S
	C	160-200+	7.5YR4/4 brown)	WE	FN	AB	VFR	ST	PL	VF	--

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

According to (Mulugeta and Sheleme, 2010), washing of material from the surface by infiltration to subsurface by material deposition showed a variation in loam content between horizons and pedons. Vertical movement of clay down the profile, however, was not evident in the current finds as no clay cutans were observed in the B horizons during field delineation of the profiles. Thus, the accumulation of clay in the subsoil horizons of the pedons could be due to a predominant in situ synthesis of clay from weathering of primary minerals in B-horizons. An adverse and highly significant ($r = -0.831$, $p < 0.05$) correlation was observed between clay and sand, suggesting that clay removal resulted in a relative increase in sand in the surface layers. Similarly, Satyavathi and Suryanarayan (2003) found that the surface enrichment of the sand fraction in red soils was due to the removal of finer particles through leaching and surface runoff. A positive and significant ($r = 0.861$ $p < 0.05$) correlation also existed between clay and silt (Table 7), suggesting that some silt-sized particles may contribute to an increase in clay fraction upon weathering.

Through the profiles under pedons, the silt-to-clay ratio was varied from 0.22 to -0.68. It shows the degree of soil formation and determines the speed of weathering. As Young (1976) noted, a soil with a silt-to-clay ratio below 0.15 is considered low and indicates a higher stage of weathering and/or soil development, while a ratio greater than 0.15 implies that the soil is underdeveloped with easily weatherable minerals. Ashaye (1969) reported that the silt-to-clay ratio is less than one (1), which could mean that the soil underwent feral pedogenesis. Accordingly, the silt-to-clay ratio of the soils studied is generally below the consensus indicated that the soils are at a higher stage of development (Abayneh, 2005; Basava et al., 2005).

The surface soil bulk density was varied from 1.00 to 1.07 gcm3 while the resulting subsurface horizon values ranged from 1.01 to 1.11 gcm3 (Table 3). The results did not show a consistent relationship to topographic locations, and the lowest and highest bulk density values were recorded at the mid-slope location. However, bulk density values showed noticeable increases with depth for all pedons (Table 3). This could be attributed to lower organic matter content, lower root abundance, and greater compaction in subsurface strata compared to their surface counterparts and the weight of overlying soils. Correlation analysis also revealed a negative and significant ($r=-0.273$, $p<0.05$) relationship between bulk density and organic carbon (Table 7). In addition, the bulk density values of the cultivated soils were higher than those of the non-cultivated soils, which could be associated with OM degradation and compaction by tillage implements. After the review by White et al. (1997) the bulk density standards of the most frequently examined soils at the sites were placed in the range (1.0 1.5 g cm-3) suitable for agricultural practice. Therefore, the results show the absence of extreme compaction and hindrance to root development in all pedons reviewing the report of (Werner, 1997).

Table 3 . Selected physical characteristics of the soil in pedons at DelboAtwaro, southern Ethiopia

Pedon	Horizon	Depth	Sand (%)	Silt (%)	Clay (%)	Textural class	Silt/Clay	Bulk density (g/cm^3)
(P3)US	Ap	0-22	28	22	50	Clay	0.44	1.07
	Ah	22-68	32	15	53	Clay	0.28	1.08
	Bt1	68-120	26	19	55	Clay	0.30	1.11
	Bt2	120-195+	29	13	58	Clay	0.22	1.11
(P2)MS	Ap	0-30	28	24	49	Clay	0.45	1.04
	A	30-75	31	17	52	Clay	0.33	1.06
	AB	75-130	28	16	56	Clay	0.29	1.06
	Bt	130-180+	29	13	58	Clay	0.22	1.07
(P1)LS	Ap	0-20	33	27	40	Clay	0.68	1.00
	AB	20-86	36	22	42	Clay	0.52	1.01
	Bt	86-160	32	20	48	Clay	0.50	1.02
	C	160-200+	33	17	50	Clay	0.33	1.03

Upper slope; MS =Middle slope; LS= Lower slope

3.4. Chemical Characteristics of the Soils

3.4.1 Soil pH, electrical conductivity, organic carbon, total nitrogen and available phosphorus of the study sites

The soils in the study area were found to be moderately acidic to neutral (6.02 to 7.23) in chemical reaction according to (Jones, 2003; Tekalign, 1991). The soil chemical response showed an increasing trend through the horizons in pedons (pH-H2O 6.10 to 7.00) as shown in Table 4. Soil pH was positive and exceptionally remarkable ($r = 0.547$; $r = 0.432$, $p<0.05$) with both K and OC corresponding, while it was adverse and remarkable ($r=-0.479$; $r = -0374$, $p<0.05$) (Table 7). Considering the landscape, the electrical conductivity in the study area was very low and its values varied between 0.02 and 0.80 mS/cm, which means that the soils are not affected by salinity (FAO, 1988). The low electrical conductivity could be due to higher rainfall levels in the study area and allowable drainage situations favoring leaching of drained bases with infiltrating water.

The soil organic carbon (SOC) value varied from 1.23 to 1.78 in the pedons at three different hanging positions (Table 4). Its trend varied across landscapes, however, the SOC decreases across horizons with depth. Consistent with assessments recommended by Tekalign (1991) and EthioSIS (2016), soil organic carbon below low levels. This finding is consistent with Wakene and Heluf's (2004) report of exhaustive management and agricultural expansion through clearing of forest and vegetation, which accelerates the oxidation of organic matter and thereby lowers SOC, levels in particular.

Total nitrogen availability in the study area was classified as low to moderate (0.12 to 0.22%) (Table 4) in agreement with Hazelton and Murphy (2007), reported as N<0.2, 0.2–0 .5 and > 0.5% low, medium and high. As Hartz (2007) reported, soils with less than 0.07% total N have reduced N mineralization capacity, but soils with more than 0.15% total N can be expected to have a vital amount of nitrogen mineralization. Consequently, most soils in the study area show good potential for N mineralization. The distribution scheme of total N with soil depth was similar to that of SOC. Overall, SOC and TN become higher with decreasing slope, which could be due to the movement of organic materials from upstream to downstream via water erosion (Sheleme, 2011; Dinku et al., 2014).

The carbon to nitrogen ratio showed a larger difference and uneven distribution at soil depth (Table 4). The C/N ratio of the soils in pedons was varied from 7.6 to 11.5 in the different topographic views (Table 4). In general, the C/N ratios of the soils examined were very low, in line with the values recommended by Hazelton and Murphy (2007), where a number of 10- to -12 is considered normal for arable soils. The narrow C/N ratio at the surface layers could be due to the influence of microbial activities leading to a comparatively rapid decomposition of organic matter and the resulting CO2 evolution (Alem et al., 2015). The current result is related to that reported by Nahusenay et al. (2014) showing a higher C/N ratio of the soils representative of the OM not being completely destroyed and the N loss-taking place.

Table 4. Organic carbon (OC), TN%, and pH, EC (mS/cm), C/N and Av.P (mg/kg) of the study site

Pedon	Slope position (SP)	Horizon	Depth	pH	EC (mS/cm)	TN (%)	OC (%)	C/N	Av.P (mg/kg)
P3	US	Ap	0-22	7.0	0.41	0.19	1.78	9.4	12.8
		Ah	22-68	6.7	0.08	0.16	1.68	10.5	14.1
		Bt1	68-120	6.7	0.34	0.14	1.49	10.6	14.0
		Bt2	120-195+	6.5	0.13	0.12	1.36	11.0	15.5
P2	MS	Ap	0-30	6.5	0.15	0.17	1.62	9.5	19.0
		A	30-75	6.8	0.11	0.14	1.54	11.0	13.5
		AB	75-130	6.6	0.14	0.13	1.50	11.5	13.0
		Bt	130-180+	6.2	0.11	0.12	1.23	10.3	11.0
P1	LS	Ap	0-20	6.3	0.2	0.22	1.77	8.0	13.0
		AB	20-86	6.6	0.19	0.22	1.67	7.6	12.0
		Bt	86-160	6.1	0.8	0.17	1.56	9.5	10.6
		C	160- 200+	6.3	0.02	0.14	1.42	10.0	11.2

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

The soil available phosphorus along the different slopes was obtained from very low to low (10.6 to 19.0 (mg/kg) (Table 4) as recommended by Cottenie, 1980 and EthioSIS, 2016. Usually the available P -Content of soils from profile depth in all pedons except P3 The higher available P found at the surface compared to the subsurface horizons could be due to the relatively higher SOC value on the top soils and the application of P-containing chemicals Inputs and manure are attributed by farmers The finding is consistent with that of Awdenegest et al (2013) who argued that more available P in the top soil layer of cropland could correlate with the addition of inputs for sustainable soil fertility management. The results showed that the available P may not be the threat nutrients for yield improvement in the area.

3.4.2 Exchangeable bases

The cation exchange capacity (CEC) of the soils varied from 23.70 to -40.70 cmol (+) kg-1 (Table 6), with the CEC of the study sites being classified in the medium to optimal range according to Landon (1991) in the cation exchange capacity category (CEC) <5, 5-15, 15-25, 25-40 and >40 cmol (+) kg-1 soil as very low, low, medium, high and very high. This could be (relative to the SOC and moderately more clay content and predominance of the 2:1 clay minerals. Also positive and significant correlation (r = 0.314) between pH and CEC of the soils at the study sites under pedons. This study is relative to that of Abebe et al., 2012, Havlin et al., 1999 and Tagbaru, 2014. Cation exchange capacity is an extremely important soil property affecting soil structural stability, nutrient availability, soil pH, and soil response to fertilizers and other improvements affected media (Hazelton and Murphy, 2007) The high CEC values indicated that the soil in the study area had sufficient nutrient holding and buffering capacities.

Exchangeable K availability was achieved between 0.033 and -1.39 cmol (+) kg-1 (Table 5), which is classified as very low to optimal as recommended by EthioSIS (2016). However, the values of exchangeable Ca, Mg and Na varied from 9.8 to 16.4, 5.05 to 8.35 and 0.1 to -0.42 cmol (+) kg-1, respectively. Values of exchangeable bases mostly improved with increasing soil depth, possibly due to wash away of exchangeable cations. Then, the high presence of calcium at all study sites compared to other cations could be due to the nature of the starting 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 (+) kg^{-1} soils, respectively. Consequently, the exchangeable K, Ca and Mg values of the surface layers of the soils are above the standards ranges. The Ca/Mg ratio of the soils was in the range of 1.81 to 2.01. As per Eckert (1987) rankings 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 scores show Mg induced Ca deficiency in the soils. The scores recommend the demand for soil management to balance the cations for optimal yield improvement, while their entire values are beyond the critical points.

The soil percentage base saturation of the study area varies in values between 39.8 and 79.9% with increasing depth, possibly reflecting an accumulation of material resulting from the leaching of basic cations from surface to subsurface. According to Hazelton and Murphy (2007), the percentage base saturation in the soils of the area was also in the sufficient to very high range. Consequently, soils in the study area could be categorized as fertile soil in line with the assessment of Landon (1991), who suggested soils with more than 60% base saturation as fertile.

Table 5. Exchangeable bases, Cation Exchange Capacity (CEC), and Percentage of base saturation (PBS) of soils in DelboAtwaro subwatershed, southern Ethiopia.

Pedon	Horizon	Depth	Exchangeable bases (cmol (+) kg^{-1}				Sum of Exchangeable bases Cmol (+) kg^{-1}	CEC cmol (+) kg^{-1}	BS (%)	Ca/Mg
			Ca	Mg	Na	K				
US	Ap	0-22	11.4	6.15	0.21	0.63	18.4	37.3	49.3	1.85
	Ah	22-68	15.6	8.25	0.13	0.83	24.8	39.3	63.1	1.89
	Bt1	68-120	16.4	8.35	0.23	0.33	25.3	37.4	67.6	1.96
	Bt2	120-195+	12.6	6.85	0.27	0.45	20.2	38.7	52.2	1.84
MS	Ap	0-30	10.4	5.65	0.40	0.52	17.0	40.2	42.3	1.84
	A	30-75	11.6	6.15	0.31	0.4	18.5	40.7	45.5	1.89
	AB	75-130	9.8	5.05	0.42	0.46	15.7	39.4	39.8	1.94
	Bt	130-180+	15.4	8.15	0.40	0.56	24.5	38.1	64.3	1.89
LS	Ap	0-20	14.6	7.25	0.35	1.1	23.3	30.4	76.6	2.01
	AB	20-86	10.2	5.65	0.10	1.39	17.3	30.9	56.0	1.81
	Bt	86-160	12.4	6.24	0.15	1.09	19.9	24.9	79.9	1.99
	C	160-200+	11.6	6.14	0.20	0.95	18.9	23.7	79.7	1.89

3.4.3 Selected extractable micronutrients

The availability of micronutrients was represented in the study area according to (Mn > Fe > Cu > Zn) throughout the landscape, with Zn being the lowest. As shown in Table 6, the extractable Mn for the study sites ranged from 105.0 to 142.0 (ppm). In acknowledgment of Karitun et al. (2013) the critical level for MnAI is 25. When the MnAI situation of the soils of the study sites was compared to the critical level, it was more than a critical level. This suggests that Mn noxiousness is one of the issues leading to the low yield production and productivity at the study sites. The score of this study is proportional to the result of Eyob Tilahun et al. (2015) and Wondosen Tena and Sheleme Beyene (2011) who reported that the amount of extractable Mn in tropical soils is generally high and the harmfulness of Mn even more common than a deficiency. The application of raw materials such as cesium carbonate, magnesium sulfate and others can improve the availability of manganese in the soil.

Extractable Fe was obtained between 99.0 and -140.0 (ppm) to a mean value of 119.33 (ppm) as shown in Table 6. It was observed that all soils in the pedons had an optimal level of extractable Fe. This result is consistent with the results of Haque et al. (2000), Abayneh (2005), Eyob et al. (2015) and Hilette et al. (2015) who found that iron was sufficient in soil samples from different areas of the country. The presence of sufficient Fe content in the soils could be due to the chemical composition of the feedstock (Vijaya Kumar et al., 2013). In addition, the soil reaction (pH) of the study area could lead to the high amount of extractable Fe since the pH of the soils in the study area is usually less than 7, which can improve the solubility of Fe. Diatta (2014) and Diatta et al. (2014) found that soil response (pH) is paramount in controlling the availability of micronutrients, while at the same time directly interfering with their solubility along with movement in the soil ecosystem.

Extractable copper varied from 10.8 to 15.6 (ppm) with an average rate of 13.26 (ppm) as shown in Table 6. It was observed that all soils in the pedons were found to be optimal in terms of extractable copper status rate according to the critical level accepted by EthioSIS (2014). Extractable Zn varied from 9.6 to 14.6 (ppm) with a mean score of 11.3 (ppm) as reported in Table 6. It was observed that all soils in the pedons maintained an optimal to sufficient range in extractable Zn status according to the critical level assumed by EthioSIS (2014). As shown in Table 6, Zn status study sites were optimal to high. The results of this study indicate that Zn was within reasonable ranges in the soils of all study sites. This could be due to soil environments such as low pH and high Zn soil parent materials. Obvious soil conditions reduce Zn availability, particularly high pH (Jones and Eck, 1973). A high rate of Zn deficiency therefore always occurs on calcareous or calcareous soils. The current study soils were neither calcareous nor calcareous and the pH values in most soils were not too high for the concentration of available Zn. According to Fisseha (1992), soil micronutrients are affected by numerous threats, among which the soil OM content, the soil reaction and the clay content are the most important.

3.4.4 Relationship between available micronutrients and some soil properties

Soil micronutrient levels are affected by numerous threats, among which soil organic carbon levels, soil response and tonal values are the most important (Fisseha, 1992). Consequently, an attempt was made to test 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 distinguish the soil issues involved in rate regulation of extractable Cu, Zn, Mn and Fe in soils. An important and positive ($p<0.05$) relationship of extractable Cu and Zn with organic carbon ($r=0.284$; $r=0.32$) was observed (Table 7). Khalifa et al. (1996), Eyob Tilahun et al. (2015) and Kumar et al. (2013). This may be due to the ability of SOC to form chelate complexes that can keep micronutrients in an available form. Also, organic carbon controls the correspondence and attraction of micronutrients with most functional groups (Jean et al., 2014).

The adverse correlation of extractable Fe and Mn with soil pH was noted (Table 7). This suggests that there is a precipitation of extractable micronutrients into insoluble waste as pH increases. The activity of Mn and Fe decreases 100-fold for each unit that increases soil pH (Lindsay, 1978). Many studies have found that soil pH is negatively correlated with Fe content (Wang et al., 2009; Sharma et al., 2004; Najafi-Ghiri et al., 2013). The availability of the micronutrients Fe and Mn decreases with increasing soil pH due to the hydrolysis reactions (by the splitting of water molecules in their hydration shells) (Sinskey, 2009). Iron, copper, zinc, and manganese correlated negatively and remarkably with silt and sand, but correlated positively with clay (Table 7).

Table 6. Micronutrients contents of the soils in DelboAtwaro subwatershed soils as influenced by topographic position and parent material

Pedon	Horizon	Depth	Micronutrients (ppm)			
			Fe	Cu	Zn	Mn
(P3) US	Ap	0-22	100	12.2	12.4	114
	Ah	22-68	105	14.6	14.6	130
	Bt1	68-120	121	10.8	10.2	142
	Bt2	120-195+	134	14.6	9.8	133
(P2) MS	Ap	0-30	129	12.4	12.4	126
	A	30-75	105	15.6	10.6	119
	AB	75-130	130	13.4	11.8	105
	Bt	130-180+	112	10.8	10.2	124
(P1) LS	Ap	0-20	99	15.2	9.8	131
	AB	20-86	122	13.6	11.4	129
	Bt	86-160	140	11.8	9.6	138
	C	160- 200+	135	14.2	12.8	125

Fe=Iron; Cu=Copper; Zn=Zinc; Mn=Manganese

3.5. Soil classification

According to FAO-WRB, all pedons had well-structured dark surface horizons greater than 25 cm thick with color values and chroma less than 3 when wet. The top layers of the pedons contained more than 0.6% OC; Base saturation (by 1 M NH4OAc, pH 7) of >50% or more through the horizons (Tables 4 and 5) that meet the criteria for Mollic diagnostic horizons.

Pedons 1, 2 and 3 had deep, well-drained soil with an effective depth of 200+cm; an underground horizon more than 30 cm thick with more than 30% clay; moderate to strong angular blocky structure, slightly plastic and sticky, brittle with shiny leaf surfaces; <0.54 silt/clay ratio that meets the criteria for a nitic subsurface horizon. The pedon had a gradually smooth and clear smooth boundary between the surface and subsurface layers; with no iron, pedestal, or vertical horizon, and there was no gley-like color pattern starting within 100 cm of the surface that met the requirements of Nitisols (FAO, 2014). In addition, the subterranean layer started at 98 cm; it had a high Fe content; dark reddish brown (2.5YR3/4 wet) for coloring; Qualification for Rhodic prefix. Therefore, the soils represented by this pedon have been classified as Rhodic Nitisols (Haplic) according to the World Reference Base for Soil Resources (FAO, 2014).

4. Conclusion

Soil utilization in a scientific way is the best option in the crop production system. In order to achieve better production and to use soil as a resource in a sustainable manner, knowledge of this resource is therefore essential. To understand this, characterization and classification were performed at the DelboAtwaro Sub-Watershed site, southern Ethiopia.

The soil at the study site showed an inconsistency in distribution due to landscape features. The soils studied were formed from volcanic rocks composed mainly of basalt parent material. The landscape of the study area had influenced soil formation, with soils on the higher slopes being developed by in situ weathering of parent material, where continuous deposition of materials from the upper slope led to the development of different soil types on the lower slopes. The main threats to increasing agricultural production at three sites in the DelboAtwaro subsea catchment on a reasonable basis are low organic carbon, total nitrogen was rated from low to medium; available phosphorus ranged from very low to low; optimal in copper and iron; very high in a manganese and exchangeable potassium was varied from very low to optimal. Magnesium-related depletions of basic cations, particularly K and to a lesser extent Ca, are expected in soils at various topographical locations. Therefore, integrated nutrient management should be used to control cation balances and build up soil organic matter as it affects the physical, chemical and biological quality of the soil.

Overall, the observed relationship between landscape features, soil properties, and soil types will help advance landscape relationships in the study area and demonstrate a less costly route to acquiring soil formations. These are crucial to making informed decisions regarding management practices for sustainable agricultural production.

Table 7. Correlation between properties of soils in study at DelboAtwaro, southern Ethiopia

Parameters	S/C	BD	pH	EC	TN	OC	C/N	Av.P	Ca	Mg	Na	K	CEC	Ca/Mg	Fe	Cu	Zn	Mn	Sa	Silt	Clay
silt/clay	1.00																				
Bulk density	-.810**	1.00																			
pH	.685*	-.761**	1.00																		
EC	0.02	0.15	-0.2	1.00																	
TN	0.31	0.07	0.08	0.27	1.00																
OC	.630*	-0.28	0.43	0.25	.847**	1.00															
C/N	-0.08	-0.27	0.19	-0.2	-.92**	-.579*	1.00														
Av.	0.40	-0.56	0.33	-0.2	-0.05	0.17	0.15	1.00													
Ca	0.18	-0.27	-0.1	0.02	-0.17	-0.18	0.11	-0.13	1.00												
Mg	0.19	-0.34	-0.1	-0.0	-0.20	-0.22	0.12	-0.08	.984**	1.00											
Na	-0.11	-0.04	-0.1	-0.3	-0.36	-0.32	0.33	0.34	-0.08	-0.11	1.00										
K	-0.22	0.55	-0.3	0.22	.737**	0.42	-.81**	-0.46	-0.14	-0.16	-0.57	1.00									
CEC	0.35	-.764**	.601*	-0.3	-0.36	-0.07	0.52	.608*	0.08	0.15	0.47	-.757**	1.00								
Ca/Mg	-0.08	0.29	-0.4	0.43	0.03	0.07	0.04	-0.34	0.44	0.27	0.16	0.06	-0.33	1.00							
Fe	-0.53	0.48	-0.4	0.21	-0.36	-0.47	0.20	0.03	-0.38	-0.39	-0.07	0.04	-0.37	-0.04	1.00						
Cu	-0.05	0.07	0.16	-0.4	0.17	0.28	-0.03	0.12	-0.23	-0.22	-0.07	0.21	-0.02	-0.08	-0.2	1.00					
Zn	0.46	-0.32	0.42	-0.4	0.06	0.33	0.08	0.21	-0.16	-0.09	-0.25	0.06	0.15	-0.41	-0.1	0.18	1.00				
Mn	-0.08	0.08	-0.3	0.34	0.13	-0.06	-0.27	0.04	.583*	0.57	-0.45	0.25	-0.34	0.24	0.20	-0.19	-0.35	1.00			
Sand	-0.39	.583*	-0.3	-0.1	0.56	0.29	-.625*	-0.43	-0.18	-0.18	-0.53	.891**	-.624*	-0.06	-0.3	0.52	0.10	0.16	1.00		
Silt	0.37	0.07	0.03	0.31	.859**	.771**	-.77**	0.18	-0.20	-0.28	-0.03	0.44	-0.30	0.21	-0.23	0.03	-0.07	0.12	0.23	1.00	
Clay	-0.08	-0.35	0.13	-0.2	-.93**	-.72**	.90**	0.12	0.23	0.29	0.30	-.797**	0.55	-0.14	0.21	-0.29	0.02	-0.2	-.68*	-.86**	1.

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

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

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors’ Contributions

All authors made a valuable and unreserved contribution as well as read and approved the final article. The authors agreed to submit the manuscript for publication in Journal of soil Science and plant nutrition and approved the manuscript for submission.

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5. References

Abayneh,E. 2005. Characteristics, genesis and classification of reddish soils from Sidamo, Ethiopia. Doctoral dissertation, University of Putra, Malaysia.

Ahn, P.M. 1993. Tropical Soils and Fertility Use. Longman Group UK limited, UK.

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

Alem, H., Kibebew, K., and Heluf, G. 2015. Characterization and classification of soils of KabeSubwatershed in south Wollo Zone, Northeastern Ethiopia. *African Journal of Soil Science,* 3(7): 134-146.

Ashaye, T.Y. 1969. “Sesquioxides status and particle size distribution in twelve Nigeria soils derived from sand stones”. *African soils,* 14: 85-96.

Ashenafi, A., Abayneh, E., Sheleme, B. 2010. Characterizing soils of DelboWegene watershed, Wolaita Zone, Southern Ethiopia for planning appropriate land management. *Journal of Soil Science and Environmental Management,* 1 (8): 184-199.

Awdenegest, M., Melku, D., Fantaw. Y. 2013. Land use effects on soil quality indicators: A case study of Abo-Wonsho Southern Ethiopia. Applied and Environmental Soil Science.Hindawi Publishing Corporation.

Basava, R.D., Naidu, M.V.S., Ramavatharama, N., Venkalah,K., Rama Rao G. and Reddy, K.S. 2005. Characterization, classification and evaluation of soils in Chandragirimandal of Chittoor District, Andhra Pradesh.*Agropedology*15:55-62.

Bremner, J.M and Mulvaney, C.S. 1982. Nitrogen total in methods of Soil Analysis.*In:* Page,A.L.(ed.),*Part 2. Chemical and microbiological properties.*SSSA, Madison, Wisconsin.

Broderson, D.W. 1994. From the surface down: An Introduction to Soil Surveys for Agronomic Use. United States Department of Agriculture, Washington, DC.

Buzuayehu,T., Gezahegn, A., Yigezu,A., Jabbar, M.A.., Paulos,D. 2002. Nature and causes of land degradation in the Oromiya Region: A review on Socio-economic and Policy Research Working Paper 36. ILRI (International Livestock Research Institute), Nairobi, Kenya.

Cools, N. and De Vos, B. 2010.Sampling and analysis of soil.Manual part, 208 pp.*In: manual on methods and criteria for harmonized sampling, assessment,*

Cottenie, A. 1980.Soil and plant testing as a basis of fertilizer recommendations.FAO soil bulletin 38/2.Food and Agriculture Organization of the United Nations, Rome, Italy.

David, M.M. 2005. "Soil Genesis and Classification of Ten Pedons Using Soil Characterization Laboratory Data and Field Soil Survey in Cades Cove, Great Smoky Mountains National Park." Master's Thesis, University of Tennessee- Knoxville. http://trace.tennessee. Edu/utk_gradthes/3269.

Dengiz, O., Saglam, M., Sarioglu, F.E., Saygin, F. and Atasoy, C. 2012. Morphological and physicochemical characteristics and classification of Vertisols developed on Deltaic Plain. *Open Journal Soil Science* 2: 20-27.

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

Dinku, D., Sheleme, B., Nand,R., Fran, W., Tekleab,G. 2014. Effects of Topography and land use on soil characteristics along the toposequence of Ele watershed in southern Ethiopia. *Catena,* 115: 47-54.

Eckert, D.J. 1987. Soil test interpretations. Basic cation saturation ratios and sufficiency levels.*Soil Science Society of America special publication*, 21: 53-64.

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

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

FAO (Food and Agriculture Organization). 1988. Salt- affected soils and their management. FAO Soil Bulletin 39. Rome, Italy.

FAO (1974). Soil map of the world. FAO, Rome.

FAO (Food and Agriculture Organization). 2006b. Plant Nutrition for Food Security: A guide for integrated nutrient management. Fertilizer and Plant Nutrition Bulletin 16, Rome, Italy.

Fisseha, I. 1992. Macro and micronutrients distribution in Ethiopian Vertisols landscapes. Ph.D. Dissertation submitted to Institute fur Bondenkunde und Standortslehre, University of Hohenheim,Germany.

Habtamu, K., Husien, O., Haimanote, B., Tegenu, E., Charles, F., Amy, S. and Tammo, S. 2009.The effect of land use on plant nutrient availability and carbon sequestration. pp 208-219. *Proceedings of the 10th conference,* March 25-27. Addis Ababa, Ethiopia.

Landon, J.R. (ed.) 1991. Booker Tropical Soil Manual: A handbook for Soil Survey and agricultural land evaluation in the tropics and subtropics. Longman Scientific and Technical publisher, New York, USA.

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

Moradi, S. 2013. Impacts of organic carbon on consistency limits in different soil textures.*International Journal of Agriculture and Crop Science,* 5(12): 1381-1388.

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

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

Mulugeta,D., Sheleme,B. 2010. Characterization and classification of soils along the Toposequence of KindoKoye Watershed in Southern Ethiopia. *East African Journal of Sciences,* 4 (2): 65-77.

Nahusenay, A., Kibebew,K., Heluf, G., Abayneh, E. 2014. Characterization and classification of soils along the toposequence at the WadlaDelanta Massif, North Central Highlands of Ethiopia. *Journal of Ecology and the Natural Environment,* 6(9): 304-320. http://dx.doi.org/10.5897/jene2014.0463.

Satyavathi, P.L.A. and Suryanarayan, M.R. 2003. Characterization and classification of shallow, medium deep and deep red and black soils of Northern Telangana zone in Andhra Pradesh. *Journal of Tropical Agriculture,* 41: 23-29.

Sims, J.T. 2000.Soil fertility evaluation. Pp.113-127. *In:* Sumner, M.E. (ed.) *Handbook of Soil Science*. CRC Press, Boca Raton.

Tekalign, T. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working document No. 13.International Livestock Research Center for Africa, Addis Ababa, Ethiopia.

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

Wakene, N., Heluf, G. 2004. The impact of different land use systems on soil quality of western Ethiopia Alfisols. International Research on Food Security: Natural Resource Management and Rural Poverty Reduction through Research for Development and Transformation. DeutcherTropentage-Berlin 5-7 October2004. pp. 1-7.

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

White, P.F., Oberthur, T. and Sovuthy, P. 1997. Soils used for rice production in Cambodia. A manual for their recognition and management. Manila (Philippines): International Rice Research Institute.

Young, A. 1976.Tropical soils and soil survey, Cambridge University Press, London, United Kingdom.