Effect of Landscape Positions on Soil Properties in an Agricultural Land A Transect Study in the Main Rift Valley Area of Ethiopia

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Abstract

This study addressed the effects of landscape positions on morphological, physicochemical properties of soils in the Main Rift Valley of Ethiopia. Three landscape positions: upper, middle and lower; and three profile horizons: A, B and buried Ab were considered along a transect line. Nine soil profiles; three in each landscape position, were opened, described and samples collected from each of the observed diagnostic horizon and analyzed. The average thickness of the A- horizon was 34 cm in the upper, 10 cm in the middle and 50 cm in the lower landscape positions. Gravels and high sand fractions (average, 41.4%) dominated the B-horizons, indicating the low rate of weathering. The clay fractions and soil bulk density ($p<0.001$), available water capacity (AWC) ($p=0.050$), soil organic carbon (SOC) and total N ($p= 0.004$ and 0.025, respectively), Available P ($p=0.004$), Exchangeable Ca^{2+} ($p=0.019$) and CEC ($p=0.010$) varied significantly with horizons. Landscape positions also influenced the textural fractions of clay, bulk density, AWC, SOC, total N, available P, exchangeable Ca^{2+} and CEC. However, the SOC concentration across the profiles were low due to the combination of lower inputs because of less biomass return on harvested land, increased aeration by tillage and crop residue collection for fire. The low available P might be due to the high P-fixation behavior of andosols. Continuous cultivation without appropriate soil management practices has resulted in more complex and non-systematic patterns of soil nutrient distribution. Thus, landscape level management practices are required to replenish soil nutrients for sustainable agriculture.

Key words: Soil fertility; Soil Catena; Topographic gradient; Andosols; Ethiopia
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INTRODUCTION

Knowledge on the morphology, physical and chemical characteristics of the soils of a given landscape is vital to enhance sustainable environmental management and crop productivity (Assen and Yilma, 2010). The distribution of soils and their characteristics, among other forming factors, is affected by topography (Jenny, 1980). Topography influences soil properties through its effects on geomorphological, hydrological and biogeochemical processes (Webster et al., 2011). It determines both the vertical redistribution of elements within soil profiles through leaching and laterally along slope gradients (Laekemariam et al., 2016).

Consequently, some studies relate variations in soil properties to topographic attributes (e.g., Yimer et al., 2006; Dessalegn et al., 2014). Also, land use and soil management practices affect soil quality and spatial variability (Yimer et al., 2007). Fisher and Binkley (2000) observed a strong relationship between topographical position and soil properties due to the down slope transport of water and nutrients. Some morphological properties such as solum and Pedon thicknesses, clay content, organic carbon, CEC and exchangeable cations varied on various slope positions (Brubaker et al., 1993; Dessalegn et al., 2014; Negasa et al., 2017). McKenzie and Ryan (1999) found 78% of total P, 54% of total C and between 26 and 64% variations in soil moisture due to terrain attributes. Topographic attributes are also central to many ecological characteristics through their influence on both soil moisture and soil chemistry and thereby affecting plant communities and their distribution on the landscape (Yimer et al., 2006).

Several studies have been made to characterize soils of the Ethiopian highlands (e.g., Lundgren, 1971; Assen and Yilma, 2010). Yimer et al. (2006) reported soil property variations along topographic and elevation gradients over the wide ranges of mountain slopes and topographic aspects in the south eastern highlands of the country. Other studies in Ethiopia also revealed trends of variation in many of the soil properties, which are associated with soil-topography processes and land use histories (Lemenih et al., 2005; Negasa et al., 2017). The soil–landscape relationship has been used as a model to explain the soil genesis (Huggett, 1998) and as attribute for site index assessment (Hägglund and Lundmark, 1977). Present day physico-chemical models used in soil management also require detailed information on the spatial distribution of soil properties (Pennock and De

Jong, 1990). Giesler et al. (1998) described the strong spatial variability of the soil chemistry at landscape scales induced by topographic variation. Various reports (e.g. Nyssen et al., 2015; Zhao et al., 2015) also indicated that SOC, TN, avail. P, depth to seasonal water table and hydrological conditions varied with topography and slope positions. The characteristics and predictable soil-landscape position associations occur as a result of the influence of topography on pedogenesis processes (Yimer et al., 2006). The distribution of physical and chemical soil properties are of interest because of their direct and indirect influences on productivity, which has implications for site-specific fertility management.

The spatial distribution of soils in the Main Rift Valley area of Ethiopia (MRVE) is poorly described (Erikson and Stern, 1987) and only little work has been done on the soil geography of the MRVE (Lundgren, 1971; Fritzsche et al., 2007). Thus, a systematic description of present soil properties in relation to the current landscape and agricultural practice is critically required (Lemenih et al., 2005; Fritzsche et al., 2007; Yimer and Abdelkadir, 2011). Moreover, understanding the dynamics and distribution of the soil characteristics as influenced by landscape features is critical for assessing the effect of future land use changes on soil use and management (Agbenin and Tiessen, 1995).

Sustainable management practices that are based on the understanding of the soil-landscape systems are not available for most parts of Ethiopia (Assen and Yilma, 2010). More specifically, there has been no detailed information concerning the soil-topographic relationships and characteristics of soils developed from volcanic ash (pumic materials) on cultivated landscape in MRVE. It has become a special and interesting area for analysis of soil properties in relation to cultivation and landscape position studies. Knowing the physical and chemical qualities of the soil would help the smallholder farmers to avoid blanket fertilizer application (Elias, 2017) for all soil types and determine the potentials and limitations of soils for agricultural productions. The study area is one of the most intensively cultivated areas in the country due to high population pressure. There is, therefore, a need to assess the relationship between landscape position and soil properties for sound management of land resources and enhance sustainable crop productivity in the rift valley area of the country. The objective of the present study was to assess the effect of landscape positions on selected morphological, physical and chemical properties of cultivated soil (andosols) in the MRVE. The outcome of the present study may provide appropriate information to researchers and development practitioners for sustainable management of cultivated andosols across different landscape positions.

MATERIALS AND METHODS

Description of the study area

This study was undertaken at Lango sub-catchment which is part of the MRVE. The Lango sub catchment (study area) lies to the northeast of Hawassa town at about 15 km south of Shashemene town, south central Ethiopia. It is located between 7° 03' 30" N - 7° 07' 40" N and 38° 34' 44" E - 38° 39' 00" E (Fig. 1). Very steep mountain chains, hills, and gently undulating slopes are dominant topographic features.

The study area has a sub-humid tropical climate with a highly variable mean annual rainfall ranging from 1200 to 1244 mm (Kebede et al., 2013). The study area and the surrounding environs are characterized by a bi-modal precipitation distribution pattern with the main precipitation (66% of mean annual total) occurring from June to September/October and small rain (34% of mean annual total) from March to May while November to February are dry months (Kebede et al., 2013). The mean annual temperature is 26.6 °C. The major land uses and land cover of the study area include cultivation, grazing, forestlands, rock outcrops and marshy areas.

The cultivation lands are mainly used for rotational cultivation of maize (*Zea mays*) and *tef* (*Eragrostis tef*) with sweet potato (*Ipomoea batatus*) and free grazing in crop fields commonly practiced after harvest. Crop residues after harvest have been left in fields and used as animal feeds. Animal dungs and residues are not usually collected for cooking. Montane forest species such as *Celtis africana, Cordia africana, Croton macrostachys, Albizia gumifera, Podocarpus gracilor, Milletia* sp. and *Phonix* spp. are the most dominant tree species (Eriksson and Stern, 1978).

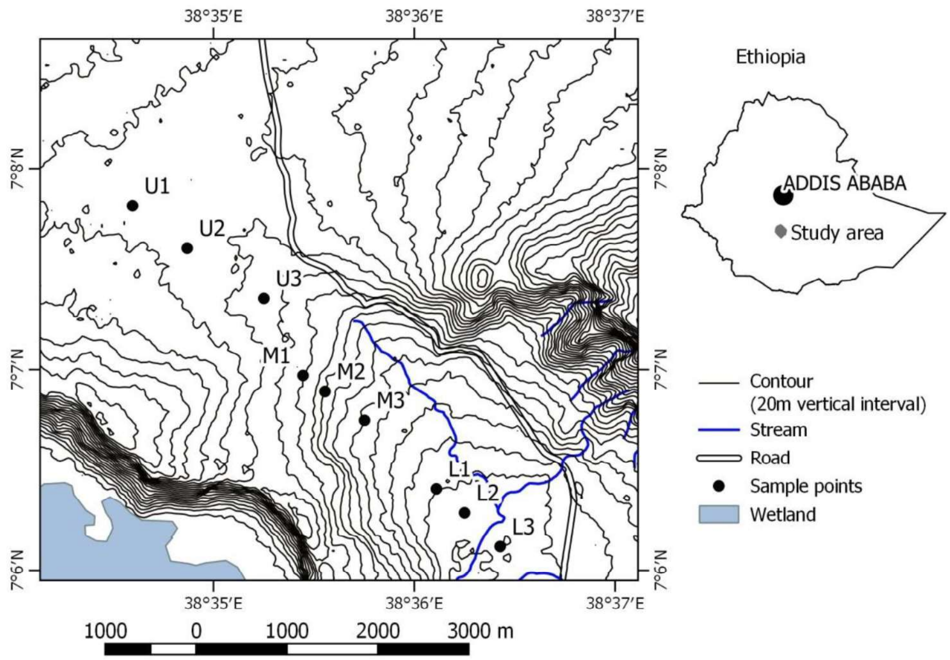

Figure 1. Location map of the study area with representative soil profiles (source for contour: "The STRM 30DEM 1 Arc second data product was retrieved from the online Data Pool, courtesy of the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota, https://lpdaac.usgs.gov/data_access/data_pool

Geologically, the Rift Valley area of Ethiopia, generally, consists of rocks of volcanic origin such as alkaline (basalts), acidic (rhyolites and ignimbrites, pumice, volcanic ash) and tuff, riverine and lacustrine alluvium (Makin et al., 1975; Fritzsche et al., 2007). The soil type in the MRVE is closely related to parent material (pumice/volcanic ash), its degree of weathering (Makin et al., 1975) and topography. The mainly explosive activities of numerous eruptions taking place during the Quaternary period have distributed volcanic materials (pumice/volcanic ash) over larger parts of the study area. These volcanic materials are known to be highly susceptible to climatic weathering and provide favorable physical and chemical conditions for plant growth and subsequent development of andosols (Barois et al., 1998). Andosols formation depends essentially on the rapid chemical weathering of porous, permeable, fine grained parent materials containing 'volcanic glass' in the presence of organic matter (Barois et al., 1998; FAO-ISRIC, 2001).

Methods

Since intensive soil-surveys are very expensive, a smaller sub catchment, the Lango sub-catchment (ca. 2500 ha) was chosen as a reference for the surrounding pumic (volcanic ash parent material) dominated agricultural landscape. A stratified purposive sampling procedure (Agbenin and Tiessen, 1995) was adopted where three landscape positions [upper, middle and lower] assuming to represent changes in geomorphology and soil characteristics on agricultural landscapes were selected (Fig. 1). At each agricultural landscape position, three representative profiles were opened in each landscape position. The profiles were characterized by genetic horizons and described according to the standard soil profile description and classification procedures (FAO, 2006). A total of twenty nine disturbed soil samples were collected from recognized genetic horizons, air-dried, gently crushed to pass a 2-mm sieve, and used for the analysis of selected soil characteristics. Twenty-nine separate core soil samples were also collected for soil bulk density determination. Additional samples from six of the A-horizons, two from each landscape position, were also collected for andic property determination.

The pipette method was used in the analysis of soil particle size classes (Soil Survey Staff, 1996). The USDA particle size classification was adopted to determine the percentages of sand (2.0-0.05 mm), silt (0.05-0.002mm) and clay (<0.002mm). Bulk density was determined from core samples after drying the samples at 105 °C for 24hours (Landon 1991). The soil moisture constants, the field capacity (FC at 1/3 bar pressure) and permanent wilting point (PWP, at 15-bar pressure)] was determined from the undisturbed soil samples and available water content (AWC) was found by subtracting

PWP from FC (Landon, 1991). The SOC (%) concentration was determined according to the Walkley and Black method (Schnitzer, 1982) and total nitrogen (TN, %) was analyzed using the Kjeldahal procedure (Bremner and Mulvaney, 1982). Calcium and magnesium were determined by atomic absorption spectrophotometer (AAS) while sodium and potassium were determined by the flame emission spectrophotometer (Black et al., 1965). The base saturation was obtained by dividing sum of exchangeable bases by CEC soil expressed as percentages. Available P was analyzed according to the method described by Olsen et al. (1954). Soil pH was measured with a combination electrode in a 1:2.5 soil to water suspension. Cation exchange capacity (CEC) was determined titrimetrically by distillation of ammonium displaced by sodium (Chapman, 1965). All soil samples were analyzed at Water Works Design, Addis Ababa.

Statistical analysis
The obtained analytical data were grouped and summarized according to the landscape positions and recognized genetic soil horizons. Statistical differences were tested using two-way analysis of variance (ANOVA) following the general linear model (GLM) procedure of SPSS Version 16.0 for Windows. Tukey's honest significance difference (HSD) test was used for mean separation when the analysis of variance showed statistically significant differences ($p < 0.05$).

RESULTS AND DISCUSSION

Morphological and physical characteristics of soils as influenced by landscape position and horizon
The morphology of the surface horizons of andosols of the study area was marked by black (10YR 2/1, moist) to very dark brown (7.5YR 2.5/2, moist). As expected on young volcanic deposits, soil textural fractions are generally coarser ranging from sandy loam - loam to silt loam textures; moderate fine to medium granular structure; none sticky/none plastic to slightly sticky/ slightly plastic (wet), friable (moist), soft (dry) and smeary consistency. For most profiles, the average thickness of the A- horizon along the transect was highly variable ranging from about 34 cm in the upper to 10 cm in the middle and 50 cm in the lower landscape positions (Fig. 2). On the middle positions, nearly all soil profiles have become shallow depths. This was resulted from the interplay between pulverization during cultivation and slope steepness accelerating rainwater erosion, and mixed with the underlying coarser C-horizon. Similarly, Dessalegn et al. (2014) indicated that differences in the detachment and transportation of particle-sizes, whereby transport of course-size particles (sand) is low whilst that of fine- and medium-size particles are high resulting in significant variations in the distribution of textural fractions along the landscape.

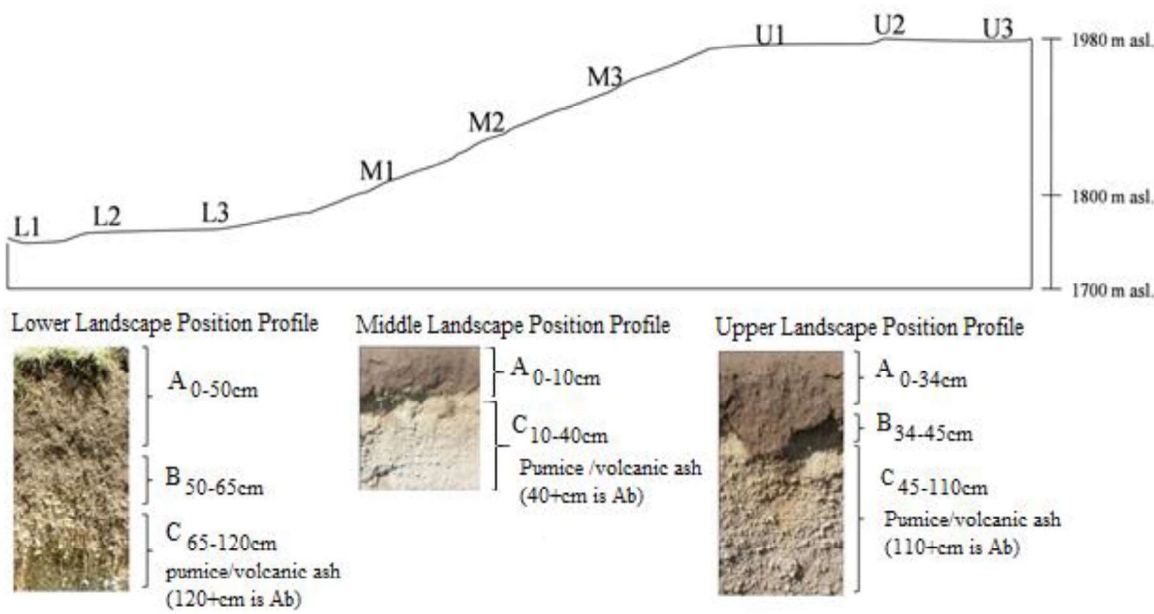

Figure 2. Sketch showing the soil-landscape relation in the study area

Gravels and high sand fractions (average, 41.4%) dominated the B-horizons, indicating the low rate of weathering. The presence of higher proportion of sand fractions and higher silt:clay (si/c) ratio of more than 1.0 in the A- and B - horizons across the landscapes (Tables 1 and 2) indicated the soils were less weathered and rich in weatherable minerals (Tegene, 1995). It was only in the buried Ab-horizon the ratio showed lower mean value (0.69±0.07; Table 2) than the overlying horizons, which is an indication of higher clay fraction concentration due to weathering of parent materials before buried by volcanic ashes. The range of Si/C ratio for highly weathered soils is less than 0.15 (Brady and Weil, 2002). The clay fractions varied significantly with horizons ($p < 0.001$) and landscape positions ($p = 0.008$, Table 1). The low clay fraction throughout the overlying horizons (A and B) reflects the young age of andosols while the oldest buried horizon have a considerably higher clay fraction (39.6±1.41; Table 2) than the overlying younger horizons.

The clay fractions varied significantly with horizons ($p < 0.001$) and landscape positions ($p = 0.008$, Table 1) which could be probably attributed to the effects of long term weathering of clay rich minerals before volcanic eruption took place and movement of fine fractions from the overlying horizons. The higher clay fraction (37.1±3.27, Table 2) at the lower landscape position compared with others could also be attributed to selective removal of fine earth fractions during water erosion leaving behind the coarser ones. Hoyos and Comerford (2005) reported that clay content and surface thickness increased from the middle to the lower landscape positions.

Landscape position ($p = 0.001$), horizon ($p < 0.001$, Table 1) and their combined effects ($p = 0.033$) have significantly affected the values of soil bulk density (BD). The values of soil bulk density were found to be higher (1.12±0.06 g cm^{-3}) in the middle and lower in the upper and lower landscape positions (0.90±0.05 and 0.90±0.03, respectively; Table 2). Similarly, it was lower in the sourface A-horizon (0.89±0.03) compared with the other hrizons. The significantly higher BD value in the middle position could be related to the abundance of coarser fragments and compaction due to animal trampling. The lower BD values in the upper and lower landscape positions and at the A-horizon could be ascribed to the relatively higher clay fractions and SOC concentrations in the respective landscapes and soil horizons (Selassie et al., 2015).

Table 1. Two-way ANOVA for soil textural fractions (sand, silt and clay, %), bulk density (Bd, g cm^{-3}), silt to clay ratios (Si:C), percent pore space (% P) and Available water content (AWC) (%) of soils in the study area

Source of Variation	df	Sand		Silt		Clay		Bd		Si:C		%P		AW C	
		MS	*p*	MS	*p*	MS	*p*	MS	*p*	MS	*p*	MS	*p*	MS	*p*
Position (P)	8	48439.53	0.05	93.12	0.031	74.09	0.008	0.092	0.001	0.281	0.365	38.423	0.140	676.448	<0.001
Horizon (H)	2	218.55	0.004	31.68	0.266	788.64	<0.001	0.111	<0.001	1.761	0.006	86.609	0.019	151.446	0.050
P × H	4	152.02	0.096	20.10	0.483	101.53	0.187	0.029	0.033	0.482	0.164	28.247	0.214	21.050	0.774
Error	20	66.63		22.371		59.28		0.009		0.265		17.704		47.166	

Table 2. Soil physical properties at different landscape positions and soil horizons (Mean ± SE)

Properties	Positions			Horizons		
	Upper	Middle	Lower	A	B	AB
Sand	41.9±2.46[ab]	47.4±4.50[a]	30.2±3.32[b]	44.8±3.22[a]	45.8±4.15[a]	33.6±1.72[b]
Silt	29.6±1.59[b]	27.1±1.55[b]	32.7±1.44[a]	30.5±1.40[a]	30.7±1.32[a]	26.8±2.27[a]
Clay	28.5±3.39[a]	25.5±4.10[a]	37.1±3.27[b]	24.7±2.27[a]	23.5±4.20[a]	39.6±1.41[b]
Bd	0.90±0.05[b]	1.12±0.06[a]	0.90±0.03[b]	0.89±0.03[b]	1.06±0.05[a]	1.09±0.05[a]
Si/C	1.02±0.14[a]	1.27±0.22[a]	1.31±0.24[a]	1.35±0.12[a]	1.55±0.31[a]	0.69±0.07[b]
%pore	55.77±1.83[a]	56.98±1.97[a]	59.97±1.03[a]	60.51±1.36[a]	56.88±1.43[ab]	54.68±1.63[b]
AWC	43.57±1.73[b]	38.24±2.54[b]	55.60±2.52[a]	50.45±2.73[a]	31.38±3.74[b]	56.93±2.87[a]

Means followed by the same letter(s) across rows are not significantly different (p = 0.05) with respect to landscape positions and horizons.

The available water content (AWC) varied significantly with landscape position ($p < 0.001$) and horizons ($p = 0.050$, Table 1). AWC was the highest in the lower landscape position (55.6±2.52) and at the buried Ab-horizon (56.93±2.87) followed by the A-horizon (Table 2). The AWC showed a non-systematic pattern of distribution both with landscape positions and horizons ascribed to variations in the combined effects of soil organic carbon (SOC) and clay fractions distribution. This result is in accordance with Hoyos and Comerford (2005) findings ascertaining characteristics such as high SOC and clay contents have a positive effect on higher water holding capacity of andosols. The A- horizons of andosols have excellent structure and porosity (≥55%) that make them resistant to erosion. Such conditions further permit good aeration and high moisture holding capacities. Frei (1978) reported the ability of andosols for supplying sufficient water at least for 100 days in the dry seasons.

Chemical soil properties of soils as influenced by landscape position and horizons

Soil pH (H_2O)

The soil pH showed significant variation with landscape positions ($p = 0.035$) and horizons ($p = 0.017$; Table 3). It was high in the lower landscape position (6.50±0.11) and at the buried Ab-horizon (6.70±0.22). The soil pH showed a steady increase with depth throughout the profiles (Table 4). The increase in soil pH at the lower slope position could be attributed to the accumulation of bases that are presumed to have been moved laterally by erosion and vertically through leaching effects across the profiles in each landscape position. Ovalles and Collins (1986) have reported high correlation of soil pH with landscape position. Generally, the pH of andosols in the study area remained within the acceptable range for most crops even though its lower end is moderately acidic for some crops according to the explanation of Landon (1991).

Table 3. Two-way ANOA for SOC, TN, C/N ratios and available P and pH of soils of the study area

Source of variation	df	SOC		TN		C/N		Avail. P		pH	
		MS	*p*	MS	*p*	MS	*p*	MS	*p*	MS	*p*
Position (P)	2	2.334	0.015	0.022	0.028	0.579	0.930	13.341	0.037	1.168	0.035
Horizon (H)	2	3.350	0.004	0.023	0.025	5.088	0.536	36.426	0.004	1.484	0.017
P × H	4	1.124	0.072	0.005	0.400	2.065	0.899	1.440	0.876	0.131	0.775
Error	20	0.444		0.005		7.910		4.832		0.29	

Soil Organic Carbon (SOC, %,), total nitrogen (TN, %) and C/N ratio

There were significant differences in SOC and TN with landscape positions (p = 0.015 and 0.028, respectively). SOC was high in the lower landscape position (2.28±0.28) and low in the middle position (1.12±0.14, Tables 3 and 4). Similarly, Guzman and Al-Kaisi (2011) have observed the greatest SOC concentrations at the lower landscape positions, followed by the upper and the least at the middle positions, which was attributed to SOC distribution and losses due to soil erosion and deposition effects by slope position. Total N followed the SOC trend and was found to be higher (0.9±0.03, Table 4) at the lower than in the middle and upper landscape positions.

There were also significant differences in SOC and TN with soil horizons (p = 0.004 and 0.025, respectively, Table 3). The mean SOC was found to be higher in the surface horizon (2.48±0.29) compared with the B and Ab- horizons (Table 4), showing a decreasing trend with depth. Because of the high inputs (e.g. crop residues after harvest and root biomass) at the surface, SOC level generally declines with depth (Li and Zhao, 2001). However, residue mulching may not always improve SOC in all soils because positive effects depend on the quality and quantity of residue applied, management duration, tillage system, site-specific soil properties and climate (Blanco-Canqui and Lal, 2007). In the study area, animal excreta and crop residues were not widely used for fuel. On the other hand, in some areas of Ethiopia, where the tree cover has been removed, up to 90 per cent of the animal dung is used as fuel (Yimer and Abdelkadir, 2011).

Table 4. Mean SOC (%), TN (%), C/N ratios, Avail. P (ppm), pH (H_2O), exchangeable (Exc.) cations (cmolc kg^{-1}soil), CEC (cmolc kg^{-1} soil) and percent base saturation (PBS, %) (Mean ± SE)

Properties	Positions			Horizons		
	Upper	Middle	Lower	A	B	Ab
SOC	1.89±0.36 ^{ab}	1.12±0.14 ^{b}	2.28±0.28^{a}	2.48±0.29 ^{a}	1.49±0.23 ^{b}	1.27±0.25 ^{b}
Tot. N	0.16±0.03^{b}	0.20±0.01^{b}	0.90 ±0.03 ^{a}	0.21±0.03 ^{a}	0.13±0.03 ^{ab}	0.11±0.02 ^{b}
C/N	12.60±1.01 ^{a}	12.4±0.80 ^{a}	12.2±0.66 ^{a}	12.08±0.54 ^{a}	11.86±0.79 ^{a}	13.22±1.34 ^{a}
Avail. P	3.45±0.84 ^{ab}	1.85±0.77 ^{b}	4.52±0.86 ^{a}	5.40±0.89 ^{a}	1.98±0.45 ^{b}	2.04±0.43 ^{b}
pH (H_2O)	6.30±0.16 ^{ab}	5.9±0.31 ^{a}	6.50±0.11 ^{a}	6.03±0.13 ^{b}	6.15±0.23 ^{ab}	6.70±0.22 ^{a}
Exc. Na	0.54±0.05 ^{a}	0.61±0.12 ^{a}	0.55±0.07 ^{a}	0.50±0.04 ^{a}	0.59±0.13 ^{a}	0.62±0.06 ^{a}
Exc. K	0.97±0.11 ^{a}	0.94±0.16 ^{a}	1.01±0.13 ^{a}	1.02±0.12 ^{a}	0.85±0.16 ^{a}	1.04±0.14 ^{a}
Exc.Ca	12.40±1.13 ^{c}	7.17±0.85 ^{b}	15.93±1.04 ^{a}	14.31±1.60 ^{a}	12.17±1.52 ^{b}	9.77±0.78 ^{b}
Exc. Mg	2.38±0.25^{ab}	2.02±0.17 ^{b}	3.99±0.65 ^{a}	2.50±0.32 ^{a}	2.41±0.31 ^{a}	3.19±0.64 ^{a}
CEC	23.28±3.09 ^{a}	20.91±0.69 ^{a}	24.20±1.11 ^{a}	25.85±1.78 ^{a}	20.83±1.15 ^{ab}	20.16±0.91 ^{b}
PBS	68.60±5.30 ^{b}	56.25±6.65 ^{b}	91.36±2.41 ^{a}	72.75±7.15 ^{a}	76.63±6.85 ^{a}	72.78±5.65 ^{a}

Means followed by the same letter(s) across rows are not significantly different (p = 0.05) with respect to landscape positions and horizons.

However, the SOC concentration across landscape positions and horizons was generally found to be low according to Landon (1991) rating for agricultural soils. The generally lower SOC and total N contents in the studied landscapes could mainly be attributed to the high rates of oxidation of soil organic matter due to tillage and to the loss of topsoil by water erosion (Selassie et al., 2015; Elias, 2017). Stable isotopic studies show that N is becoming limited in dry lands of Ethiopia (e.g., the rift valley areas) due to substantial losses via volatilization in that ^{15}N is closely related to aridity (e.g. Terwilliger et al., 2008). In addition, a combination of lower SOC inputs because of less biomass carbon return on harvested land, increased aeration by tillage and crop residue collecting partly causes the reduction of SOC and TN in cultivated soils (Girma, 1998). Since SOC mediates many of the chemical, physical and biological processes of soil, the extensive degradation of large areas and subsequent loss of SOC, would undoubtedly alter the capacity of the soil to perform successfully.

The C/N ratio did not show any variation with landscape positions (p = 0.930) and horizons (p = 0.536, Table 3).

Across the landscape positions and horizons, the C/N ratios ranged between 11.9:1 and 13.2:1 (Table 4), the median for most soils being near 12:1 (Brady and Weil, 2002). The narrow variations in C/N ratios across landscape positions and horizons suggest less variability in the degree of humification of organic matter. Ratios of above 11.0 show the stability of the clay humus complexes while the lower values suggest advanced stages of humification (Wada, 1985). According to Assen and Yilma (2010) a C/N ratio of about 10:1 suggests relatively better decomposition rate, serving as index of improved nitrogen availability to plants and possibilities to incorporate crop residues to the soil without having any adverse effect of nitrogen immobilization. In the buried horizon, the C/N ratio was slightly higher than the rest of the horizons that might be due to the long time accumulated undecomposed material rich in carbon in to the soil before the volcanic eruption took place in the MRVE.

Available phosphorus (Avail. P; ppm) Exchangeable Bases, CEC (cmolc$^{(+)}$/kg soils) and Percentage Base Saturation (PBS)

Available phosphorus showed significant variation with landscape positions and horizons ($p = 0.037$ and $p = 0.004$, respectively; Tables 4 and 5); higher in the lower position and A-horizons (5.40±0.89) than the rest of positions and horizons. Such increase in available P with downward landscape positions and horizons as suggested by Weinert and Mazurek (1984) could be related to the faster process of mineralization and mobilizing of phosphorous favored by the oxidation due to the relatively higher temperature and frequent pulverization of farmlands. Also higher mean annual precipitation may have had an influence on leaching and indirectly through promoting biomass production giving more organic materials for mineralization. Prüeß et al. (1992) argued that the amounts of SOC distribution in the soil and landscape positions are the main factors of controlling available P and other soil fertility parameters. However, compared to the ratings for some tropical soils (Landon, 1991); the contents of available P are generally low to medium, which could be related to the P-fixation by Al and Fe (Zewdie, 1999). Consequently, low available P in the soils became one of the major soil fertility limiting factors to crop production in the study area and elsewhere where there is a similar soil type and landscape characteristic.

Among the exchangeable complexes, exchangeable Ca^{2+} showed variation with landscape positions ($p < 0.001$) and horizons ($p = 0.019$, Tables 4 and 5). It was higher in the lower position (15.93±1.04) followed by the upper compared with the middle landscape position. The middle landscape tended to lose significant Ca^{2+} because the topsoil is constantly eroded. The A-horizons have higher Ca^{2+} followed by the B-horizons compared with the Ab. Exchangeable calcium in a soil has an important relation to soil pH and to the availability of several nutrient elements (Thompson and Troeh, 1993). Throughout the studied horizons, Ca^{2+} remained to be high but declined with depth, attributed to the parallel decline in SOC with soil depth.

Table 5. Two-way ANOVA for base cations (exc. Na, K, Ca and Mg), CEC and Percent Base Saturations (PBS, %)

Source of variation	df	Exc. Na		Exc. K		Exc. Ca		Exc. Mg		CEC		PBS	
		MS	*p*	MS	*p*	MS	*p*	MS	*p*	MS	*p*	MS	*p*
Position (P)	2	0.017	0.729	0.023	0.891	152.066	<0.001	7.861	0.009	29.668	0.266	2840.647	<0.001
Horizon (H)	2	0.035	0.536	0.106	0.589	32.429	0.019	1.232	0.409	124.261	0.010	83.259	0.630
P × H	4	0.090	0.199	0.146	0.568	16.170	0.082	0.963	0.581	14.727	0.600	500.950	0.051
Error	20	0.054		0.195		6.678		1.316		20.974		175.908	

The second principal base cation in the exchange complex of andosols of the study area was Mg^{2+}, which significantly varied with landscape positions ($p = 0.009$). It was higher in the lower (3.99±0.65) than in the upper and middle landscape positions (Tables 4 and 5). Though not significant, Mg^{2+} also showed an increasing tendency with horizon and became higher in the Ab-horizon. The high concentrations of Mg^{2+} in the subsurface horizons compared to the surface horizon soils may be due to the effect of weathering and leaching of elements over time. The concentration of Ca^{2+} and Mg^{2+} generally follow the pH trend, in agreement with the findings of Young and Hammer (2000). The range in Mg^{2+} contents of the studied soils across the landscape positions and horizons were higher than the critical level of 0.5 cmol kg^{-1} reported for both tropical and temperate soils (Landon, 1991). Although the variation was not significant, exchangeable Na^{+} showed an increasing trend with horizons with a recorded value of 0.62 cmolc kg^{-1} soil. Exchangeable potassium (K^{+}) is within a range of 0.94 to 1.01 and 0.85 to 1.04 $cmol_c$ kg^{-1} soil, respectively, with landscape positions and horizons. Exchangeable K^{+} didn't show systematic pattern of variability with landscape positions and horizons.

The variation in CEC was significant with horizon ($p = 0.010$, Table 5), but not with landscape positions ($p = 0.266$). The highest CEC (25.85±1.78 $cmol_c$ kg^{-1} soil) was recorded in the A-horizon followed by the B-and the lowest (20.16±0.91) at the Ab-horizon (Table 4). Although the differences were not significant, CEC was higher in the lower landscape compared with the middle and upper positions. According to the Landon's (1991) ratings, the investigated soils have a medium level (25-40) of CEC for agricultural crop productions. The medium to high CEC values may be attributed to the predominance of high surface area clay minerals such as allophane and imegolite (Wada, 1985; Southard and Southard, 1989; Tegene, 1995). CEC of a soil is determined by the relative amount and/or of two main colloidal substances; humus and clay (Gao and Change, 1996).

The percent base saturation (PBS) varied with landscape position ($p < 0.001$; Table 5) with the highest at the lower landscape position (91.36±2.41) which could be attributed to the exchange sites with less amounts of organic matter (carbon) and more base cations leading to higher base saturation. The investigated soil across the landscapes and horizons had high PBS of greater than 56 percent. Except the soil profiles at the middle landscape position, the rest had high (greater than 60%) base saturation values and were generally considered fertile according to Landon (1991) ratings.

CONCLUSIONS

The studied soil in the Main Rift Valley area of Ethiopia showed marked variations in most of their physical and chemical properties with landscape positions and horizons. Most of the soil nutrients considered in the study was generally low due to lower organic matter inputs, which in turn were associated with less biomass return on harvested land, increased aeration by tillage, soil erosion and high P-fixation behaviors of andosols. Continuous intensive cultivation without appropriate soil management practices have also contributed for lower levels of soil nutrient distribution across the landscape positions. The lower levels of soil fertility indicators across the landscape reveal the need for improved land and water management strategies. Thus, based on the current study, emphases should be placed on promoting site-specific sustainable land management practices for soil nutrient improvement and thereby better agricultural productivity. Otherwise, the soils are likely to undergo accelerated degradation and rapid productivity losses.

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