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Characterization and Classification of Soils Along the Toposequence of Medo Sub-watershed at Wondo Genet District, Ethiopia

Abreham Yacob*, Ashenafi Nigussie

Department of Natural Resource Management, Wondo Genet Agriculture Research Center, Shashemene, Ethiopia

Email address:
abrehamW1@gmail.com (A. Yacob)
*Corresponding author

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Abstract: Soil characterization and classification study under topographic position is essential to recognize the effects of slope on soil physicochemical, and morphological properties and to draw promising management practices. In view of this, the present study was implemented to characterize and classify the soils along the toposequence of Medo sub-watershed using the World Reference Base for Soil Resources. First, topographic positions were categorized as upper, middle, and lower slopes position. One representative pedon was opened per each slope position and the profiles were described in situ. Soil morphological properties were influenced by topographic position. Sandy clay loam was the dominant soil textural classes in the surface soils. In all pedons, soil bulk density ranged from 0.8 - 1.2 g cm^{-3}. The soil pH. ranged from 5.43 – 5.81 in the surface to subsurface layers of the three pedons. Soil organic carbon contents were ranged from 1.46 - 2.23 in the upper, middle and lower slope positions, respectively. Total nitrogen contents of the soils were varied from 0.14 to 0.22 and rated as medium to high. The soils present base saturation was categorized as very high (> 80%) in all pedons, respectively. The upper, middle and lower pedons had Mollic epipedon in the surface horizon but they had different sub-surface horizons. The middle and lower pedons had Argic and Cambic sub-surface horizons, respectively. The upper, middle and lower slope pedons had Vitric, Leptic and Cambic principal qualifiers, respectively while Arenic, Arenic and Aric supplemental qualifiers for upper, middle and lower pedons, respectively. Therefore, the studied soils were classified as Vitric Andosols (Arenic), Leptic Retisols (Arenic) and Cambic Phaeozems (Aric) for upper, middle and lower slope positions, respectively. In conclusion, topography remarkably affects soil properties, therefore, site-specific soil management is vital to maintain and improve soil organic matter and essential plant nutrients.

Keywords: Pedon, Soils Horizons, Soil Properties, World Reference Base

1. Introduction

Soil is a natural finite resource base that sustains life on earth. It is a three-phase dynamic system that performs many functions including ecosystem services and agricultural systems. It provides essential requirements for human and animal life such as food, fodder, and fuel [52]. Soil is a dynamic natural resource that results from soil-forming factors. Topography is one of the major soils forming factor that influences the way soils to develop. The landscape's position affects runoff, drainage, soil temperature, soil erosion, soil depth, and thus soil formation. Different soil properties encountered along landscapes will influence plant production, litter production, and decomposition patterns, all of which will affect the soil's carbon and nitrogen content. Landscape position has been found to be substantially linked with clay content and depth distribution, sand content, and pH [65].

In Ethiopia, there have been several efforts to relate soil properties to landscape position for many landscapes positions and identified different soil types [5, 66]. Similarly, other authors reported that major soil characteristics such as particle size distribution, pH, OC, TN, Avail. P, exchangeable cations, and CEC vary with slope positions [18, 42, 44]. All of these investigations revealed that topographic positions had a substantial relationship with soil characteristics.

Information on soil characteristics and distribution are indispensable for proper planning and implementation of sound management practices which enables to restore degraded lands and fertility status [8, 18]. Soil information can be acquired through systematic field observation, evaluation and identification, as they provide information related to potentials and constraints of the land [37, 60]. Since, soils have a wide range of morphological, physical, chemical, and biological characteristics. Their characterization and classification are very important to get information of the soils.

Soil characterization is a scientific way of gathering soil information that allows recognizing the physical, chemical, and mineralogical properties of the soils [54]. It is a major building block for understanding the soil environment [48]. Furthermore, soil characterization records allow for the ideal classification of the soil to serve as a basis for a more detailed assessment of the soil [54]. Soil classification is vital to reflect real diversity of soils to make decisions about adequate or sustainable land use. It also aids in the organization of our knowledge and the transfer of experience and technology from one location to another [4, 15]. For generations, Ethiopian agriculture, which is the backbone of the country's economy Shimeles [57], has been heavily reliant on natural resources [9]. Soil degradation is highly widespread, and inadequate soil fertility is one of the major obstacles to agricultural production and productivity. Hence, understanding the soil properties and their distribution over an area is crucial to plan and implement site-specific soil management practices for efficient utilization of limited soil resources. However, this valuable soil resource information is not yet properly investigated and documented, particularly at watershed levels, owing to limited research funds Idoga et al. [28]. Furthermore, in Ethiopia, soil characterization and classification studied so far, mostly at regional and small-scale, which are inadequate to provide basic soil data that can help to manage soils according to the local variability (i.e., watershed or farm scale) [25].

Currently, the idea of watershed-based holistic development has emerged and considered as one of the viable options in rain-fed agricultural areas which leads to better agricultural output in a sustainable manner Madhan, (2008). However, the soil morphological, physical, and chemical characteristics at Medo sub-watershed were not yet thoroughly studied. Moreover, the soil fertility in the selected sub-watershed has been declining, owing to soil erosion, which is forced by steep slopes, poor vegetation cover and continuous cultivation. Therefore, soil characterization and classification study along the slope positions at Medo sub-watershed levels is important to investigate the effects of topographic position on soil properties.

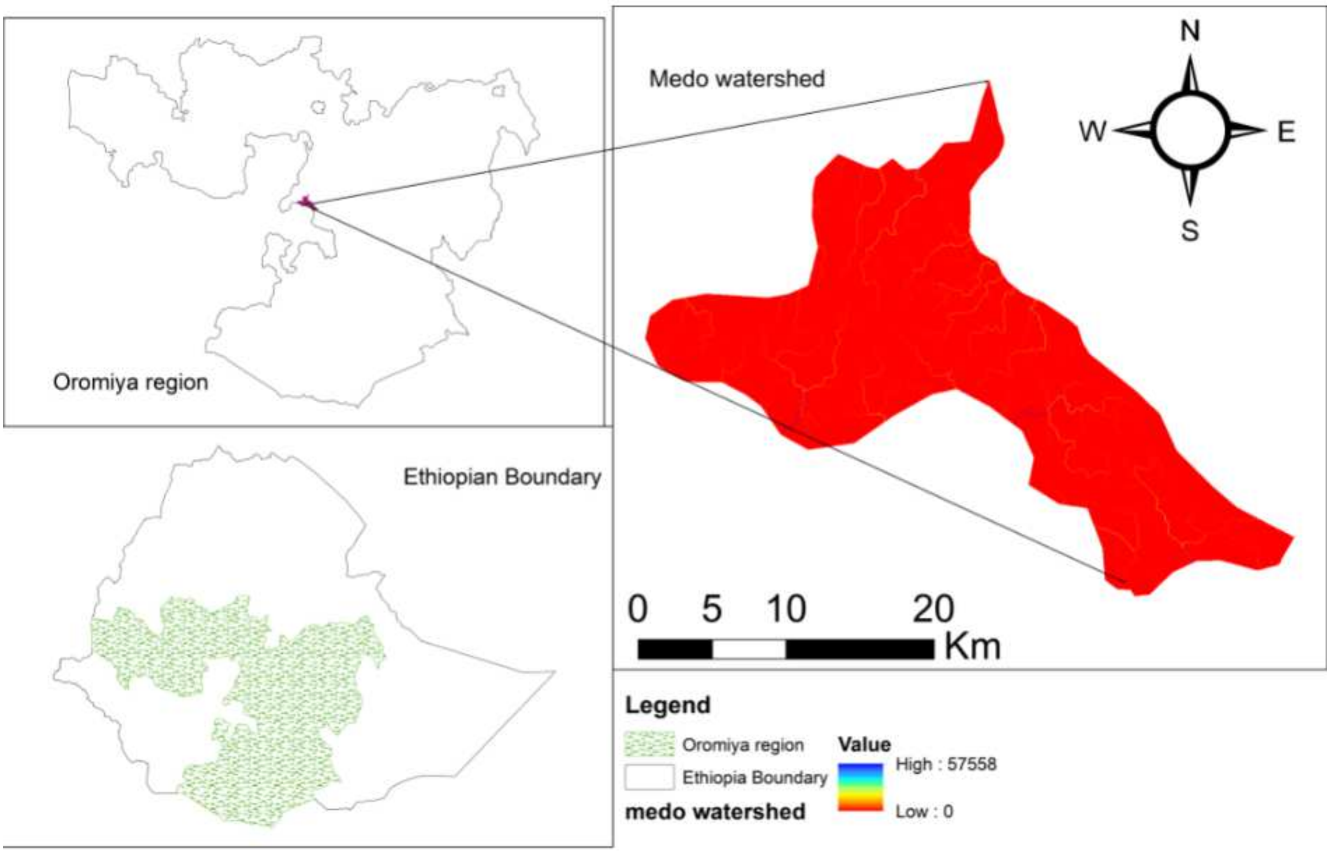

Figure 1. *Locational Map of the Study area. Source. Arc GIS 10.3.*

2. Materials and Methods

2.1. Description of the Study Area

The research was carried out in Medo sub watershed Wondo district of the West Arsi Zone of Oromia Regional State, Ethiopia. The area is located around 12 kilometers northeast of Shashemane town and 250 km south of Addis Ababa. Geographically, it is between (38°35'E - 38°38'E longitude and 7°05'N - 7°06'N, between (38°35'E - 38°38'E longitude and 7°05'N - 7°06'N, latitude with altitudinal ranges ranging from 1700 to 2100 meters above sea level. The area is primarily distinguished by bimodal rainfall patterns. The average annual rainfall is 1121 mm, and the average annual lowest and maximum temperatures varied from 11.5 to 26.21°C. The study area is characterized by varied land features including mountains, flat land and agricultural fields. The area is dominated by 35.1% plain lowlands, 37% hilly and 27.9% of mountainous topography. It occupies around 504.42 hectares. The district's population is projected to be male 54143 and female 55016, for a total population of 109159.

An investigation survey was conducted in Wondo woreda and Medo sub-watershed, the chosen Sub-watershed to record important information such as soils, topography, water/hydrological, vegetation, land use and land management, and socioeconomic condition of the people. The Ethiopian Mapping Agency (1:50,000 topographic maps) was used to conduct physical observations of the designated sub-watershed, and general site information was collected. The free-soil survey (traverse survey) approach was used to identify profile excavation locations along the landform, as reported by Dent and Young [17]. Along the terrain, three mapping units were defined based on slope position: upper-slope, middle-slope, and lower-slope.

2.2. Soil Profile Opening and Sampling

Three representative Pedon's, on each in slope categories, was excavated representing upper slope, middle slope and Lower slope positions along the toposequence with 2m width by 2m length and 2m depth. The newly opened representative soil profiles and horizons were described and designated according to guidelines of soil description [21]. On standard soil site and soil profile description sheets, all key morphological and physical parameters, as well as other pertinent site information, were documented in the field. Soil samples were collected from each genetic horizon in order to characterize and classify their physicochemical features. Additionally, surface soil samples were collected from a depth of 0-20 cm along the toposequence. To make composite soil sample, taken from each depth. Thus, from each depth sixteen composite samples representing three each in toposequence were prepared to check the influence of toposequence on soil properties.

2.3. Soil Morphological Distribution

Soil morphological characteristics were described following the Guidelines for soil description FAO [21]. The color, texture, consistency, structure, plant rooting patterns and other soil features were examined to determine which horizons are present and at what depth their boundaries occur. Each genetic horizon received both disturbed and undisturbed soil samples. The color of the soil was then determined using the Munsell color chart Munsell, [43]. The sequence, grade, size, and type (shape) of aggregates were used to characterize the soil structure, whilst the depth and distinctness of horizon borders were used to define the horizon boundaries. The consistency of the soil was determined in dry, moist, and wet moisture conditions.

2.4. Soil Physical Properties

Soil physical properties were analyzed including particle size distribution, by using Bouyoucos hydrometric method [14]. The undisturbed soil samples were collected for the determination of bulk density (BD) using a core sampler. The bulk densities of the soils were determined using the core sampler method from undisturbed soil samples. The procedure described by WRB [29] was used to determine the soil particle size distribution using the hydrometer method, and from this result, the soil textural classes were determined.

2.5. Soil Chemical Properties

Soil pH was determined electrochemically by means of pH meter as described by Jankson [30] in suspensions of 1:2.5 soil to water ratio. Electrical conductivity was measured by conductivity meter on saturated soil paste extracts obtained by applying suction [46]. The wet digestion method developed by Walkley and Black [64] was used to determine the organic carbon of the soils. The Kjeldahl digestion, distillation, and titration method [10] was used to determine total nitrogen, while the standard Olsen extraction method [47] was used to determine available phosphorus. Cation exchange capacity was determined by 1 N neutral ammonium acetate method in which it was, subsequently, estimated by distillation of ammonium that was displaced by sodium [14]. The leachate of a 1 molar ammonium acetate (NH_4OAc) solution at pH 7 was used to determine the exchangeable base (Ca, Mg, K, and Na) in the soil. A flame photometer was used to read K and Na, while an atomic absorption spectrophotometer was used to read exchangeable Ca and Mg [50]. Then, percent base saturation (PBS) was calculated from the sum of exchangeable bases as a percent of the sum of CEC.

$$PBS = \frac{Sum\ of\ exchangeable\ bases}{CEC} * 100$$

Available Micronutrients Fe, Mn, Zn, and Cu were extracted from the soil samples with Diethylene Triamine Penta acetic Acid (DTPA) as described by Lindsay and Norvell [36]. All the micronutrients extracted were measured by atomic absorption spectrophotometer.

2.6. Soil Classification

The soils of the study area were finally classified into different units based on morphological, physical, and chemical properties, according to the [21] classification system.

3. Results and Discussion

3.1. Soil Morphological Features

All of the Pedon's profile depths ranged from moderate to deep (128 to 200cm) (Table 1). The parent materials, with the exception of the lowest pedon, limited the upper and middle slope locations. The upper slope (US) and middle slope (MS) Pedon's horizons were distinguished by an A, B, BC, and R sequence, whereas the lower slope (LS) pedon had six horizons (A-BA-B-C). The A horizon on upper and lower slope positions were formed as a result of the assimilation of humified organic elements from grass and plant wastes, respectively. The toposequence' B horizons the parent material's in-situ weathering results in the upper, middle, and lower slope positions [18]. The upper slope the top (0-32 cm) and the middle slope top (0-30 cm) and A horizons of pedon were thinner than the lower tope (0-43 cm) Pedon's [18, 42]. This could be attributed by runoff, which deposited soil materials from the upper and middle slopes on the lower slope landscape. The middle slope condition at the lower slope may have resulted from the accumulation of soil deposits eroded from the upper and middle slope position.

The soil color (moist) for the Middle slope (MS) Ap, A2, B1, B2, and BC horizons ranged from dark reddish-brown (7.5YR/3/1), very dark brown (10YR 3/2), yellow dark grey (7.5YR/4/3), dark reddish-brown (10YR 3/4), and dark yellow-brown (10R/3/3). They had a variety of colors ranging from 7.5YR to 10YR, as well as values/chromas ranging from 3/2 to 3/4. They had a variety of colors ranging from 5YR to 10R, as well as a range of values/chromas ranging from 3/6 to 5/4. (Table 1). Lower pedon wet colors ranged from black (7.5YR/2.5/1), dark red (5YR/2.5/1), dark brown (7.5YR 3/2), reddish brown (5YR 4/3), dark reddish brown (5YR/3/2) to light yellow-brown (10YR 6/4) for Ap, A2, BA, Bt1, Bt2, and BC horizons. They come in a variety of colors ranging from 5YR to 10YR, with values/chromas ranging from 2.5/1 to 6/4 (Table 1). According to Sharma *et al*. [53], chroma values greater than two indicate a deeper water table in these soils, while values greater than three indicate a low organic matter content. Soil color variation was observed across and between pedons, indicating that OM content, parent material, and drainage conditions differed [5].

The surface soils of the three pedons were distinguished from the subsurface soils by a dark reddish-brown and dark red wet hue, which was most likely due to the presence of more organic matter. Similarly, Teshome *et al*. [60] demonstrated that organic matter content has a significant impact on soil color, with the color darkening as the organic matter concentration increases. As soil depth increased, the color of all pedons became redder, as did the value and chroma (Table 1). These subsurface reddish and brownish hues indicate that the soil is well-drained and aerated [17]. This could be due to the accumulation of sesquioxides in the subsurface layer, which are frequently responsible for the visible reddish soil hue. Mottling (red, yellow, or brown splotches) was absent in all pedon strata, indicating that the soil pores had not been filled with water for long periods of time [53].

3.2. Soil Structure

Within each Pedon's defined horizons and among Pedon's of the Medo sub-watershed, there was significant diversity in grade, size, and form features (Table 1). As a result, the surface layer structure of the pedon changed from weak, fine, granular in the upper slope pedon to moderate, medium/fine, granular in the middle and lower slope Pedon. It ranged from moderate, medium, and sub angular blocky in the upper and middle slope Pedon's to weak, medium, and angular blocky in the lower slope Pedon's in the subsurface horizons (Table 1). Except for the pedon on the upper slope, both the middle and lower slopes are surrounded by cultivated land, exposing the surface layers of the two pedons to the effects of soil management techniques, especially the pressure of soil tillage. Because of their higher clay content, the subsurface layers of the two pedons (middle and lower slope pedons) demonstrated superior structural development along the profile than their respective surface horizons Ashenafi *et al*. [11]; Alemayehu and Sheleme, [6]. Tobiasova *et al.* [61] also discovered that soil organic matter and particle size distribution have the greatest influence on aggregate dynamics.

3.3. Soil Consistency

The result revealed that under the study area, the exception of the middle slope pedon, the surface layers of the upper and lower slope positions was very friable moist study area, whereas the surface layer of the middle pedon was friable. The presence of comparatively higher organic matter content in the layers could explain the friable and extremely friable consistency observed in the surface layers. However, a slightly sticky/slightly plastic wet consistency was observed on the surface layers of the three pedons (Table 1). Variations in moist and wet consistencies within and across pedons are most likely explained by differences in particle size distribution, specifically clay concentration, OM, and clay particle composition in upper, middle and lower slope profiles respectively. This result is agreed, Moradi [41] who pointed out that the soil consistency differed depending on soil texture. Wakene and Heluf, [65] also suggested that the soil consistency is an inherent property, the presence of high OM in the surface horizon amends it the result of approval with, different writers.

The horizon border between surface and subsurface horizons was visible in all pedons, with smooth topography (Table 1). The topography was smooth and wave-like, despite the fact that the horizon limits between subsurface horizons were progressive. Smooth topography was discovered in the lower slope Pedon's final successive subsurface horizons (Table 1). This result is agreed, Cools and De Vos, [16], Differences in horizon borders between soil pedons may indicate variations in soil formation processes, as well as partially reflecting anthropogenic effects.

Biological activities with the horizon on upper topographic positions were characterized by very fine few channels to medium root, medium, common and clear and smooth Boundaries in surface soil and the horizon on middle topographic positions were characterized by medium to common channels, medium root and earthworm pathways were higher in the surface layers, and the horizon on lower topographic positions were characterized by very fine channels and fine to medium roots and smooth boundaries surface layers, and decreased with depth, which could be related to decreasing root biomass, aeration, nutrients, and management impacts down the soil profiles. The roots in the Pedon's various horizons ranged in size from extremely fine to coarse, as well as in quantity from few to many. Cools and De Vos [16] also suggested that the variation in nature of the horizon boundaries within a pedon and among pedons may indicate the existence of variations in processes that formed the soils and, in some cases, they reflect anthropogenic impacts.

Table 1. *Morphological features of the soils along the top sequences at Medo sub watershed.*

Horizon	Depth (cm)	Color (moist)	Structure	Consistence		Horizon boundary
				Moist	Wet	
Upper slop position (US)						
A	0-21	5YR / 3/2	WE, F, GR	VFR	SS/SP	C, S
A2	21-32	10YR 3/2	WE, M, GR	VFR	SS/SP	C, S
B1	32-50	7.5YR/4/3	MO, M, SAB	VFR	SS/SP	G, S
B2	50-70	2.5YR 4/3	MO, M, SAB	FR	S/P	G, S
BC	70-142	10YR 3/3	MO, C, SAB	FR	S/P	-
R	142+	-	-	-	-	-
Middle Slope position (MS)						
Ap	0-12	7.5YR/3/1	MO, M, GR	FR	SS/SP	C, S
A2	12-30	7.5YR/4/4	WE, C, SG	LO	SS/SP	C, S
B1	30-65	10R3/3	MO, M, SAB	FI	S/P	G, S
B2	65-107	10R/4/3	MO, M, AB	FI	S/P	G, S
BC	107-128	10R/3/6	MO, C, SAB	VFI	SS/SP	-
R	128+	-	-	-	-	-
Lower Slope position (LS)						
Ap	0-20	7.5YR/2.3/1	MO, F, GR	VFR	SS/SP	C, S
A2	20-43	5YR/2.5/1	WE, F, GR	VFR	SS/SP	C, S
BA	43-71	10R/3/2	MO, M, AB	FR	SS/SP	C, S
Bt1	71-107	10R/3/3	WE, M, SAB	FR	SS/SP	C, S
Bt2	107-136	5YR/3/2	WE, F, SAB	VFR	S/P	C, S
C	136-200	10YR/7/4	WE, VF, GR	LO	NS/NP	-

*WE = Week; FM = Fine and medium; GR = Granular; AB = Angular blocky; SAB = Sub angular blocky; FR =Friable; VFR = Very friable; FI = Firm; VFI = Very firm; SS/SP = Slightly sticky and slightly plastic; S/P= Sticky and plastic; G-S = Gradual and smooth; C--S = Clear and smooth; MO = Moderate; M = Medium; LO = Loose VW = Very weak; F=fine, C, clear, SG= slightly gradual, NS/NP = No sticky No plastic.

3.4. Soil Physical Properties

3.4.1. Soil Texture

The particle size distributions of the study area revealed a difference in the proportion of the three separates and their distribution with soil depth under each of the three slope positions upper, middle and lower slope positions, respectively (Table 2). The Sand, silt, and clay particle percentages in the three Pedon's surface soils ranged from sand (63 to 74), silt (1 to 6), and clay (23 to 39) percent, upper, middle and lower slope positions respectively, whereas the subsurface layers ranged from sand (61 to 78), silt (8 to 12), and clay (19 to 41%), respectively.

As a result, of the investigated upper, middle and lower slope profiles. soil's sand, silt, and clay concentrations ranged from high to low and low to moderate, respectively (Table 2). In all slope locations, the results indicated that the textural class of surface soils was sandy clay loam and sandy loam textural classes (Table 2). This indicates that slope positions had little influence on soil textural class and also indicates the similarity of the soil's source material. In terms of slope positions, the upper, middle, and lower slope positions had the highest mean value of sand, silt, and clay contents in surface soils, while the lower, middle and upper slope positions had the lowest mean sand, silt, and clay contents in subsurface soil (Table 2). The percentage of clay was in sub-surface horizon of the middle and lower slope pedons is high, whereas the percentage of sand and silt lower in the subsurface horizon. Mulugeta and Sheleme [42] also suggested that the percentage of clay in the profile increases with depth, indicating pedogenic eluviation-illuviation processes. The removal of finer particles by selective erosion or transfer of finer particles into the subsurface soil may be responsible for the highest sand content at the surface soil of the three slope positions. This result is consistent with the result of khan *et al*. [33].

Clay content was higher in the subsurface soils of cultivated land (middle and lower slope positions) than in the upper slope position (grassland). This could be attributed to extensive and continuous cultivation, which could have resulted from clay translocation from surface soil caused by intensive and continuous cultivation. Similarly, to Teshome *et al*. [59], the reason for low clay in surface soil of cultivated fields may be due to erosion selectively removing clay from the surface [3].

Both the middle and lower slope pedons showed a vertical increase in clay content. Despite this, clay cutans, or clay skins were observed in the B-horizons during the field description of the profiles. As a result, the clay buildup in the lower Pedon's subsurface horizons could have been caused by the predominant in situ synthesis of clay from the weathering of primary minerals in B layers Rust, (1983); Chadwick and Grahm, (2000). However, vertical migration of clay down the profile was not detected in the upper slope pedon; rather, a declining trend was observed in the current investigation (Table 2). The silt: clay ratio of the soils was less than one in all studied pedons and recognized horizons, indicating that the soils were weathered to an advanced state (Abayneh, 2005).

3.4.2. Bulk Density

Soil bulk density values of the soil ranged from 0.8-0.8, 0.8, 1, and 1.2 at upper slope and 1, 0.9, 1.1, 1.1, and 1.3 lower slope 0.95, 1, 1.1, 1.1, 1.1, and 1.2 mgm^{-3} in upper middle and lower slope positions, respectively. (Table 2). The bulk density value of the surface horizon ranged from 0.8 to 1.00 mgm^{-3} recorded in upper and middle profiles, respectively. Whereas, the bulk density value of upper and middle profiles showed irregular variation with depth, whereas lower profile showed systematically consistent variation. Even though it showed under the study area inconsistent variation with depth of the profiles. The bulk density values in all profiles were increased with depth. This is due to the presence of high organic matter content and abundant root systems resulting in well-structured and porous surface soil, whereas subsurface horizons had high bulk density values as per the lower distribution of organic matter content, rare abundance of roots and poor aggregation of soil. The results agreed with Adhanom and Teshome [4]; Esayas, [19], the bulk density of soils increased with the depth of the profiles, which could be due to changes in organic matter content, porosity, compaction and the weight of the overlying soil.

Soils with a high or low bulk density, according to Patil and Prasad (2004), have poor soil physical characteristics and are not beneficial for agriculture. The current study's findings revealed variable bulk density values across soil depth in the three pedons (Table 2). The three pedons' surface horizons ranged from 0.8 to 1.0 gm cm^{-3}, whereas the subsurface horizons ranged from 0.8 to 1.3 gm cm^{-3}. In general, surface soils of the detected strata had lower bulk density than subsurface layers, which is lower than the typical range for mineral soils (1.3-1.4 gm cm^{-3}) as reported by Bohn *et al* [12]. In the current study, soil bulk density rose with profile depth, owing to a reduction in soil OM content (Table 2). Several writers, including Achalu *et al.* [3], and Wakene [63], found that surface soils have lower bulk density than deeper layers.

Table 2. *Particle size distribution and bulk density of the soils in Medo sub-watershed.*

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	Silt: Clay	BD (g cm^{-3})
Upper Slope position (UP)							
Ah	0-21	63	6	31	Sandy clay loam	0.19	0.8
A2	21-32	57	4	39	Sandy clay	0.10	0.8
B1	32-50	61	12	27	Sandy clay loam	0.44	0.8
B2	50-70	71	10	19	Sandy loam	0.53	1.0
BC	70-142	74	7	19	Sandy loam	0.37	1.2
R	142+	-	-	-	-	-	-
Middle Slope position (MP)							
Ap	0-12	70	1	29	Sandy clay loam	0.03	1.0
A2	12-30	74	3	23	Sandy clay loam	0.13	0.9
B1	30-65	53	6	41	Sandy clay	0.15	1.1
B2	65-107	63	2	35	Sandy clay	0.06	1.1
BC	107-128	61	2	37	Sandy clay	0.05	1.3
R	128+	-	-	-	-	-	-
Lower Slope position (LP)							
Ap	0-10	74	1	25	Sandy clay loam	0.04	0.95
A2	10-43	63	6	31	Sandy clay loam	0.19	1.0
BA	43-71	64	3	33	Sandy clay loam	0.09	1.1
Bt1	71-107	61	6	33	Sandy clay loam	0.18	1.1
Bt2	107-136	61	8	31	Sandy clay loam	0.16	1.1
C	136-200	78	9	13	Sandy loam	0.69	1.2

In terms of slope locations, middle and lower slope pedons had higher mean bulk density than upper slope pedons, which may be attributed to cultivation. Tilling soils (cultivation) usually decrease pore space and hence increase bulk density, which explains why cropped soils have greater bulk densities than uncultivated soils. Bulk density is an indirect measure of pore space that is largely influenced by texture and structure, demonstrating that as solid space and clay content rise, so doe's bulk density.

3.5. Soil Chemical Properties

Soil pH and electrical conductivity

According to Jones [32], the soil pH (H_2O) at the surface layers (A- horizon) of the pedons was found to be mildly acidic, with values ranging from 5.43 to 5.81. (Table 3). The upper slope landscape had the lowest pH value in surface soil when compared to the middle and lower slope landscapes; this was probably owing to the removal of bases cations from the top slope gradient to the middle and lower slope gradients (Table 3). This small increase in soil pH down the slope position might be attributed to soil material washing [39, 57]. This conclusion is consistent with Mulugeta and Sheleme's [42] findings, which showed that soil pH rose as the slope gradient decreased. In all of the soil profiles from the various landscape sites, soil pH increased in general as profile depth increased, which may be attributed to the removal of basic cations from the overlying horizon via leaching and crop absorption.

The soil EC values of the study area ranged from (2.34–2.16), (2.02-1.84) and (2.78 -2.06 dSm^{-1}) in upper, middle and lower topographic profiles, respectively (Table 3). The EC values of soil measured at the upper profile were (2.16, 2.34), (1.71, and 2.62 dSm^{-1}) in horizon A, A2, B1, B2 and BC respectively. The value of EC measured at the middle profile were, (2.02, 1.84), (1.53, 1.61 and 1.92 dSm^{-1}) in horizon Ap, A2, B1, B2, and BC, respectively. The value of EC measured at the middle profile were, (2.78, 2.06), (1.25, 1.33), (1.22 and 0.73 dSm^{-1}) in horizon Ap, A1, BA, Bt1, Bt2, and C, respectively. The highest (2.78 dSm^{-1}) EC value was observed at surface horizon Ap of Lower profile and the lowest (0.73 dSm^{-1}) EC value was found at the surface horizon of the lower profile.

The EC value of soil studied in the area showed consistent variation with depth of lower profile and inconsistent variation with depth of upper and middle profiles. Despite the inconsistent variation with depth of the profiles, the EC values throughout the profiles at all slope positions were increased with depth, which could be due to continuous leaching and soil erosion aggravated by over cultivation and removal of crop residues. from these studies it could be associated with the increase in concentrations of exchangeable base (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) and pH down the topographic positions. The EC values the studied soil ranged from 0.73 – 2.78 dSm^{-1}. Thus, the EC values of the soil in all profiles were rated as salt-free according to Ethiosis [20].

3.5.1. Organic Carbon, Total Nitrogen, C:N Ratio and Available Phosphorus Concentrations

Organic carbon (OC) contents in pedons ranged from extremely low to medium [20]. The OC concentration in the surface soils of the three pedons was determined to be in the middle range according to Tekalign [58] and Ethiosis [20] ratings (Table 3). The OC concentration of the three pedons' surface soils ranged from top slope profile recorded (1.97%), (2.11%) and (2.23%) upper, middle and lower slope in surface soil positions respectively. In general, the OC increases with decreasing slope gradient, with the maximum OC found in the lower slope pedon, which may be ascribed to the movement of organic materials from higher slope positions to lower slope positions, and thus higher organic material accumulation. Similarly, Dinku et al. [18] found that slope location has a significant impact on the quantity of surface organic carbon buildup. Furthermore, Kravchenko and Bullock [34] discovered a negative and substantial relationship between organic matter and slope locations or slopes.

In all studied Pedon's, OC demonstrated a declining trend alongside the profile depth when the depth of the particular pedon was considered (Table 3). The surface layers had higher OC concentrations than the deeper layers. This was attributed to the presence of plant material, as well as root and biological activity, on the surface soils as opposed to the subsurface soils. Similarly, prior research found that the topsoil had a greater OC than the subsurface [1, 17].

Total nitrogen (TN) in the surface soils of the three Pedon's, like OC, was significantly impacted by slope position, and with the highest and lowest amounts of TN detected in lower and upper slope pedons, respectively (Table 3). This indicates that soil organic matter accounts for the majority of total nitrogen in the soil (OM). Furthermore, the soil TN distribution inside the particular Pedon's horizon showed a declining tendency in comparison to soil depth, and this accompanied a similar pattern to that of OC, indicating that the OM was the primary source of TN. This is consistent with the findings of Alemayehu *et al*. [7], and Mulugeta and Sheleme [42], who found that TN concentration dropped as profile depth increased.

The C:N ratio of the soils ranged from (8.6 to 19.75) and declined with soil depth in general, except the lower slope pedon (Table 3). The C:N ratio in the surface soils varied from (10.14 to 13.18) in the lower and middle slopes, respectively, suggesting optimal microbial activity for mineralization of organic residues Landon [35]. Surface soils on the lower slope exhibited the lowest C:N ratio when compared to the middle and upper slope pedons, owing to the presence of comparatively greater organic matter.

According to Havlin *et al*. [26], the available P content in the investigated pedons ranged from 1.19 mg kg^{-1} in the bottom horizon of the upper pedon to 15.92 mg kg^{-1} in the A horizon of lower slope (Table 3). The available phosphorus in the pedons' surface soils ranged from 6.07 mg kg^{-1} in the middle slope to 15.19 mg kg^{-1} in the lower slope's A horizon. In general, the distribution of accessible P increases from upper to lower slope toposequence. This is because the slope position is related to soil characteristics, which are regulated by erosion processes. Kravchenko and Bullock [34] discovered that slope was adversely associated with organic matter and accessible P in more than half of their research locations. The relative maximum accessible P contents in the surface layers of lower and upper slope pedons declined with depth in tandem with the OC contents. The decrease in available P down the profile in these pedons might possibly be attributable to lower layers that fix phosphorus having less OM and more clay. Because of in presence of clay illuviation in the high to low slope gradient in upper, middle and lower slope respectively in accordance with this conclusion, Alemayehu *et al.* [7] found that available P dropped as profile depth increased.

Table 3. *Soil chemical properties in soil of the Medo Watershed.*

Horizon	Depth (cm)	pH (H_2O)	TN (%)	EC	OC (%)	C/N	Avai P (mg kg^{-1})
Upper Slope (US)							
A	0-21	5.43	0.17	2.34	1.97	11.59	10.56
A2	21-32	5.52	0.14	2.16	1.46	10.43	6.25
B1	32-50	5.82	0.12	2.62	1.22	10.17	4.21
B2	50-70	5.75	0.09	2.31	0.92	10.22	3.35
BC	70-142	5.68	0.1	1.71	0.91	9.10	1.19
R	142+	-	-	-	-	-	-
Middle Slope (MS)							
Ap	0-12	5.76	0.16	2.02	2.11	13.18	6.08
A2	12-30	5.69	0.13	1.84	1.58	12.15	7.42
B1	30-65	5.25	0.13	1.53	1.41	10.85	5.54
B2	65-107	5.31	0.12	1.61	1.08	9.00	4.36
BC	107-128	5.39	0.1	1.92	0.86	8.60	3.76
R	128+	-	-	-	-	-	-
Lower slope (LS)							
Ap	0-10	5.81	0.22	2.78	2.23	10.14	15.92
A1	10-43	5.90	0.13	2.06	1.63	12.54	11.46
BA	43-71	5.92	0.09	1.25	1.6	17.78	6.40
Bt1	71-107	5.81	0.08	1.33	1.58	19.75	3.89
Bt2	107-136	5.54	0.06	1.22	1.04	17.33	3.85
C	136-200	5.48	0.05	0.73	0.87	17.40	2.46

3.5.2. Cation Exchange Capacity and Exchangeable Bases

According to Hazelton and Murphy's [27] rating of (6, 6-12, 12-25, 25-40), and >40 $cmol_c kg^{-1}$ soil, CEC of the soils classified as very low, low, medium, high, and very high. As a result, the soils' cation exchange capacity (CEC) ranged from (8.56 to 17.62) cmolckg^{-1} across the surface and subsurface layers, indicating a low to medium CEC. The lower slope pedon had the highest CEC value, followed by the middle slope, and the top slope pedon had the lowest (Table 4). From upper to lower slope toposequence, the distribution of CEC increases. This was due to the relationship between slope location and soil properties. Kravchenko and Bullock [34] discovered that when the slope position changed from upper to lower, CEC increased. The CEC values of the pedons were incongruent with profile depth (Table 4). However, CEC of the soils increased with profile depth in general, owing to an increase in clay content and basic cations caused by leaching.

Slope positions, like CEC, had a significant impact on total exchangeable bases and base cations, with the lowest obtained at the lower slope (LS) pedon and the highest obtained at the US and MS positions (US and MS) (Table 4). This could be explained by the movement of soil components from higher elevations and accumulations at lower elevations. The topographic position difference could be attributed to soil particle removal from upper slope positions by soil erosion and subsequent buildup in lower topographic positions. This study's findings were consistent with those of Shimeles *et al*. [57], who suggested that topographic location could influence exchangeable cations.

According to Bohn *et al.* [12], In infertile agricultural soils, the exchangeable cation order was $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$, and any deviation from this order may cause an ion-imbalance problem for plants. The results of this study's analytical results revealed that all of the pedons studied had the same order of basic cation concentration. The concentration of exchangeable calcium in the exchange complex was higher than the concentrations of the other cations in all pedons. This was most likely due to its higher adsorption to soil colloids than other cations, particularly Na, due to its higher charge and lower hydrated radius [24].

The exchangeable Ca^{2+} content of surface soil ranged from 6.0 $cmol_c kg^{-1}$ in upper pedon to 10 $cmol_c kg^{-1}$ in lower pedon, while the exchangeable Mg^{2+} content ranged from 1.2 $cmol_c kg^{-1}$ in higher pedon to 1.86 $cmol_c kg^{-1}$ in middle pedon. According to the FAO [21] assessment, both exchangeable Ca^{2+} and Mg^{2+} were discovered in medium ranges. In all pedons, the subsurface horizons had more exchangeable Ca^{2+} and Mg^{2+} than the surface horizon, which could be attributed to leaching from the overlaying horizons. With increasing soil depth, the exchangeable cation content of all pedons increased marginally (Table 4). The minor increase in basic cations along the profile depths could be due to soil material leaching from the surface to the subsurface horizons [11].

Topographic location had significant effects on exchangeable Ca^{2+} and Mg^{2+} concentrations; the maximum was found at the lower slope position. The increments down the slope could be the result of soil particle removal from upper slope locations via soil erosion and subsequent accumulation in lower slope positions. This finding is similar to that of Ashenafi *et al*. [11], who discovered an increase in cations with soil depth as a result of leaching in the Delbo Wegene watershed in southern Ethiopia.

Soil potassium levels were classified as (>1.2), (0.6-1.2), (0.30.6), (0.2-0.3), and (0.2) as very high, high, medium, low, and very low, respectively, by FAO [21]. The exchangeable K content of the surface soil ranged from 0.72 $cmol_c kg^{-1}$ in the middle pedon to 1.19 $cmol_c kg^{-1}$ in the bottom pedon (Table

4). The surface soils of the three pedons were found to have higher exchangeable K levels, implying that the nutrient is less limiting for plants. Except for the top pedon, the exchangeable K content of the soils increased with soil depth (Table 4), which could be attributed to increased clay content in the subsurface layer that holds the cation. The slope location also has a significant impact on the exchangeable K. The highest exchangeable K was discovered in the lower Pedon's surface horizon, and the higher and lower slope positions had higher K content in the surface horizons than the middle slope position (Table 4).

Surface soil exchangeable Na content ranged from 0.36 $cmol_c kg^{-1}$ in the upper and lower pedons to 0.39 $cmol_c kg^{-1}$ in the middle pedon. In general, the concentrations of exchangeable sodium (Na) and potassium (K) in the soil exchangeable complexes were lower than those of Ca and Mg (Table 4), which may be attributed to the higher intensity of reactivity of divalent cations on the exchange complexes.

According to FAO [21], agricultural soils with a percent base saturation (PBS) greater than 50% are considered more fertile and conducive to crop development, whereas soils with less than 50% are considered less fertile. The percent base saturation (PBS) values in the three pedons' surface and sub-surface horizons ranged from high (60-80%) to extremely high (> 80%), Similarly, Hazelton and Murphy [27] defined PBS in terms of the amount of exchangeable base leaching or depletion. As a result, the PBS of the soils in the research area can be classified as poorly leached (50-70%) or very weakly leached (less than 50%). PBS, unlike CEC, was unaffected by toposequence; however, there may be a tendency for increment as we move from upper to lower slope locations.

Knowing the calcium to magnesium ratio is critical for assessing the potential influence of calcium on magnesium (Mg) absorption by plant roots. The surface horizon of the investigated soils revealed a Ca: Mg ratio less than 10:1 ranging from 4.30 in the middle pedon to 5.52 in the bottom pedon. According to Havlin *et al.* [26], the Ca: Mg ratio should be between 10:1 and 15:1 in order to avoid Mg deficiency.

Table 4. *Exchangeable bases, cation exchange capacity, percent base saturation, and Ca: Mg ratio of the soils at the Medo Watershed.*

Horizon	Depth (cm)	Exchangeable bases and CEC ($cmol_c kg^{-1}$)						PBS	Ca: Mg
		Ca	Mg	K	Na	TBS	CEC		
Upper Slope (US)									
Ah	0-21	6.00	1.20	1.14	0.36	8.90	10.68	83.3	5.0
A2	21-32	4.59	1.27	1.15	0.44	7.45	12.72	58.6	3.61
B1	32-50	4.74	1.20	0.54	0.26	6.74	7.14	94.4	3.95
B2	50-70	5.73	0.60	0.31	0.21	6.85	7.06	97.0	9.55
BC	70-142	7.01	1.01	0.49	0.10	8.61	8.76	98.2	6.94
R	142+	-	-	-	-	-	-	-	-
Middle Slope (MS)									
Ap	0-12	8.00	1.86	0.72	0.39	10.97	12.88	85.2	4.30
A2	12-30	4.24	2.21	1.00	0.44	7.89	8.56	92.2	1.92
B1	30-65	8.13	2.26	1.08	0.41	11.88	12.78	92.9	3.59
B2	65-107	8.76	2.46	0.87	0.22	12.31	12.92	95.3	3.56
BC	107-128	7.29	2.44	1.05	0.13	10.91	11.69	93.3	2.99
R	128+	-	-	-	-	-	-	-	-
Lower Slope (LS)									
Ap	0-10	10.00	1.81	1.19	0.36	13.36	13.5	98.9	5.52
A2	10-43	10.25	2.32	2.02	0.40	14.99	17.62	85.1	4.42
BA	43-71	10.40	2.31	1.78	0.67	15.16	16.86	89.9	4.50
Bt1	71-107	9.15	1.46	1.42	0.85	12.88	13.36	96.4	6.27
Bt2	107-136	10.99	1.55	1.45	0.92	14.91	15.96	93.4	7.09
C	136-200	11.04	1.42	1.78	0.59	14.82	17	87.2	7.77

TEB = Total exchangeable bases; CEC = Cation exchange capacity; PBS = Percent base saturation;

3.5.3. Available Micronutrient Contents

The contents of available micronutrients varied with topographic location along the toposequence and soil depth (Table 5). The contents dropped uniformly down the slope and with soil depth along the toposequence. The concentrations of available micronutrients in surface soil samples from the pedons were comparable to those in the corresponding pedons' surface horizons. The amount of Fe and Mn available varied depending on topographic location along the toposequence and depth within each pedon. In general, the amount of available Fe and Mn decreased with soil depth in all pedons (Table 5). Havlin *et al.* [26] state that the concentrations of Fe and Mn in all soils have been determined to be adequate.

The A horizon of the lower topographic position had the highest available Zn concentration (4.45 mg kg^{-1}) followed by the A horizon of the middle topographic position (2.0 mg kg^{-1}) and the third upper topographic position (0.71 mg kg^{-1}) (Table 5). Furthermore, as reported by Havlin *et al.* [26] available Zn content decreased with soil depth, and its concentration in the surface layers around the pits was sufficient [26].

The A horizon of the lower topographic position had the highest concentration of available Cu (16.50 mg kg^{-1}) followed by the A horizon of the middle topographic position (9.33 mg kg^{-1}) and the A horizon of the third topographic position (7.61 mg kg^{-1}) (Table 5). Both available Zu and Cu increased as one moved down the slope in the current study, indicating that surface erosion is a major cause and that erosion control should be implemented. Furthermore, the availability of copper and zinc decreased as one moved deeper into the strata. This could be due to the link between available Cu and organic carbon concentration. These findings were consistent with those of Mulugeta and Sheleme, [42] and Wakene [63]. According to Havlin *et al.* [26] the concentration of available Cu in all layers of Medo sub-watershed soils was adequate [22].

Table 5. *Available micronutrient contents in soil profiles of the Medo Watershed.*

Horizon	Depth (cm)	Available micronutrient (mg kg^{-1})			
		Fe	Mn	Zn	Cu
Upper slop position (UP)					
Ah	0-21	64.56	24.50	0.71	7.61
A2	21-32	40.39	23.39	0.44	2.06
B1	32-50	14.00	22.29	0.67	11.33
B2	50-70	10.61	18.28	0.61	3.39
BC	70-142	6.39	13.44	0.06	0.83
R	142+	-	-	-	-
Middle slop position (MP)					
Ap	0-12	12.78	74.72	2.00	9.33
A2	12-30	11.82	39.72	1.28	2.26
B1	30-65	4.78	28.28	1.61	1.00
B2	65-107	4.67	16.22	1.78	0.06
BC	107-128	5.39	11.28	2.00	0.50
R	128+	-	-	-	-
Lower slop position (LP)					
Ap	0-10	16.11	89.94	4.45	16.50
A2	10-43	11.72	79.11	3.94	8.17
BA	43-71	11.61	67.67	3.50	3.83
Bt1	71-107	9.83	5.89	2.67	2.78
Bt2	107-136	8.11	5.21	3.17	4.22
C	136-200	5.22	5.72	3.38	1.89

3.6. Classification of the Soils According to WRB

The studied soils were classified; according to World Reference Base Legend IUSS Working Group [29]. The morphological, physical and chemical characteristics of the soils were used for classification purposes. The upper topographic position had texture of sandy clay loam and sandy loam at the surface horizon; a clay increment did not Observed. Granular and sub-angular blocky dominant the structure at the surface and sub-surface horizons, respectively. Furthermore, the surface horizon had thick profile depth, dark reddish-brown color with a Munsell color value of ≤ 3 moist, and chroma of ≤ 3 moist, medium organic carbons and a high percent base saturation. The surface horizon characteristics thus exhibit a Mollic epipedon. Moreover, a Mollic/vitric property was observed in the Andic properties of the surface horizons. Therefore, the soils are classified as Andosols according WRB soil classification system IUSS Working Group [29]. The profile had Mollic vitric property to be classified as Mollic vitric principal qualifier. However, the sub-surface horizon had greater clay increment over that of the upper layer horizon. Furthermore, loam sand or finer and greater than 8% clay, indication of clay illuviation but doesn't form part of natric horizon. These properties signify the Argic horizon. Moreover, sandy loam textural class was the dominant throughout the profile, and thus qualify Clayic supplemental qualifier. Therefore, the soil is classified as Vitric Andosols (Clayic).

The surface soil at the middle topographic position had dark red moist color, moderate, medium and granular structure, friable consistency, sandy clay loam in textural class, slightly acidic in soil reaction, and medium in OC, and CEC and high in PBS (> 50%). The surface horizon characteristics thus exhibit a Mollic epipedon. However, the sub-surface horizon had greater clay increment over that of the upper layer horizon. Furthermore, loam sand or finer and greater than 8% clay, indication of clay illuviation but doesn't form part of natric horizon. These properties signify the Argic horizon. Therefore, the soils are classified as Retisols according WRB soil classification system IUSS Working Group [29]. The profile had continuous rock or hard materials starting < 100 cm from the soil surface this qualify Leptic principal qualifier property. Moreover, sandy loam textural class was the dominant throughout the profile, and thus qualify Clayic supplemental qualifier. Therefore, the soil is classified as Leptic Retisols (Clayic).

The surface soil at lower topographic position had texture of sandy clay loam at the surface horizon; a slight clay increment was observed but not greater than 8%. The surface horizon had thick profile depth, black color with a Munsell color value of ≤ 3 moist, and chroma of ≤ 3 moist. The granular and sub-angular blocky structures were the dominant at the surface and sub-surface horizons, respectively. Moreover, medium and high in organic carbons and percent base saturation, respectively. Hence, the surface horizon characteristics showed a Mollic epipedon. However, most of the subsurface layers showed structural development without indications of carbonate buildup, existences of rock structure in more than 50 percent of the volume of the fine earth fraction, and a thickness greater than 15 cm. Hence, the sub-surface horizons qualify properties Cambic horizon. Therefore, the soils are classified as Phaeozems according WRB soil classification system IUSS Working Group [29]. The profile had a cambic horizon not consisting of albic material and starting < 50 cm from the soil surface this qualify Cambic principal qualifier. Moreover, sandy loam textural class was the dominant throughout the profile, and thus qualify Aric supplemental qualifier. Therefore, the soil is classified as Cambic Phaeozems (Aric).

4. Conclusions

Soil color and particle size distributions were influenced by topographic positions with the upper topographic position being dark reddish-brown and sandy clay loam and sandy loam textured, whereas the lower topographic position soils being black and sandy clay loam textured. Similarly, topographic positions were impacted soil parameters such as pH, organic carbon, total nitrogen, available P, exchangeable bases, CEC, and available micronutrients. The upper topographic position profile had the lowest pH value in surface soil when compared to the middle and lower slope positions. Similarly, OC, TN, and available P were increased while slope gradient decreased, with the maximum OC, TN and available P found at the lower slope pedon. Slope positions had significant impacts on CEC, exchangeable bases and present base saturation, with the LS obtained at the lower slope (LS) pedon and the highest obtained at the US and MS slope positions (US and MS). The percent base saturation (PBS) values in the three pedons' surface and sub-surface horizons ranged from high (60-80 percent) to extremely high (> 80 percent). The concentrations of available micronutrients varied with topographic locations and soil depth. The contents dropped uniformly down the slope and with soil depth along the toposequence. The significant variations in the physicochemical properties of the studied soils indicate slope positions soil management needs of each soil type to maintain soil organic matter and essential plant nutrients. However, further research is required into the areas, particularly in terms of soil-landscape and land management connections, as well as selecting appropriate agricultural technology depending on soil type to provide a solid conclusion for sustainable agricultural output.

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