Characterization and Classification of Soils along Toposequence of Gobeya Sub-Watershed, South Wello Zone,Ethiopia

ABSTRACT

Characterizing of soil physical and chemical properties is essential for proper use of soil resources on different topographic positions and speeding up technology transfer. Detailed soil resources characterization and classification is one of the key requirements. In view of this, this study was conducted at Gobeya sub-watershed of Tehuleder District, South Wello Zone of Amhara Region of Ethiopia to characterize the spatial variability of selected soil morphological and physico-chemical properties, and to classify them according to the FAO/WRB soil classification legends. A number of auger hole points, visual observations, aerial photo and topo-map interpretation, descriptions of soil profiles and laboratory analysis were used to study the properties of the soils and for classification of the soils. A total of 12 disturbed soil samples from each genetic horizon and 7 undisturbed soil samples from the upper two horizons were collected from all profiles~~, except profile 3~~. Based on the results, the soils were ~~characterized and~~ classified as Vertic Cambisols (Humic, Hypereutric, Endoskeletic), Haplic Regosols (Hypereutric), Mollic Leptosols (Humic, Epieutric) and Haplic Cambisols (Humic, Hypereutric). Low level of available P, total N and exchangeable K could be the major chemical fertility problems in all ~~of the~~ soils ~~in~~ of the study area.

Keywords: Toposequence, Soil Profile, Soil Horizon, Soil Physico-chemical properties, Classification

1. INTRODUCTION

Agriculture, accounting for about 45% of gross domestic product (GDP) and 85% of total employment, is the dominant sector in the national economy of Ethiopia [1]. This sector is, however, beset by several natural and anthropogenic factors that adversely affect its productivity [2, 3]. Increasing population pressure expanded farming from gently sloping surfaces in the highlands to steeper slopes and marginal lands [4, 5] which in turn have brought disturbance to the ecosystems, particularly soils that are the determinant factors of agricultural production and productivity. Assessment of soil quality with respect to land use types and management practices is therefore crucial for sustainable agriculture.

In developing countries like Ethiopia where research funds are limited, the availability of pedogenic information and proper classification of soils will be greatly important in adopting well tested management technologies and landscape positions without going through the whole process of time consuming and expensive technology selection field trials as this will provide the basic information for sustainable agricultural planning. Nevertheless, sustainable soil managements that are based on the understanding of soil systems are not available for most parts of the country [6].

All soils are naturally variable with their properties changing across the landscape and vertically down the soil profile [7, 8]. Soils commonly occur in groups, each member of the group occupying a characteristic and different sequential topographical position from top to bottom of a slope, termed as toposequence. When the same sequence occurs as a mirror image on similar parent material, the two toposequences are called a catena [9]. Soil properties such as clay, sand and pH [10] and organic matter [11] correlate highly with landscape position.

In a given geographic location where diverse physiographic features like steep slopes, hilly lands and mountainous surfaces are prevalent, the role played by topographic features (slope steepness and elevation differences), climatic elements (temperature and rainfall) and vegetation cover on influencing and characterizing soil properties is immense [2].

In the Ethiopian highlands, population pressure which accounts for 85% of the country's total population as well as 67% of its livestock population, has pushed cultivation and livestock grazing to steeper slopes and fragile lands causing serious deforestation, overgrazing, soil erosion and overall land degradation. The subtropical highlands of the Gobeya Sub-watershed at Tehuledere District where the present study was conducted are not exceptions to these problems. As a consequence of land degradation, the productivity of the soils in the Ethiopian highlands including that of Gobeya area is declining at a rate of 2-3% annually [12]. The decline in soil fertility is exacerbated by soil erosion, which is aggravated by steep slopes, poor vegetation cover and continuous cropping. Thus, different points along the slope have different properties and potentials requiring different management practices.

Appropriate use of an area of land depends upon the inherent characteristics of such a land. There is therefore a need to characterize soils and classify them in a manner that will ease communication and transfer of knowledge about such soils to farmers and other stakeholders. Hence, assisting local farmers and development workers through providing basic information on soils and land resources in general so as to build the existing indigenous knowledge and experience and integrating it with modern scientific approaches is essential for increasing agricultural production as well as environmental management activities. However, such information has not been made available in Gobeya Sub-watershed hitherto. In other words, the information required for planning management practices that ensure efficient use of the soil resources on different topographic positions is scanty and/or absent. This study was, therefore, proposed to characterize the spatial variability of selected soil morphological and physico-chemical properties along the toposequence, and to classify the soils of the Gobeya Sub-Watershed along the toposequence according to the FAO/WRB soil classification legend.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was conducted at the Gobeya sub-watershed of the Logo Hayq Watershed located in Tehuledere District of South Wello Zone in Amhara Region. The Watershed is located at about 35 km north east of Dessie town and 440 km north of Addis Ababa. It is located in the ranges between 11° 16′ 37″ to 11° 18′ 49″ N latitude and 39° 43′ 27″ to 39° 44′ 38″ E longitude with altitude that ranges between 1915 to 2800 meters above sea level and it covers a total area of 504.8 ha.

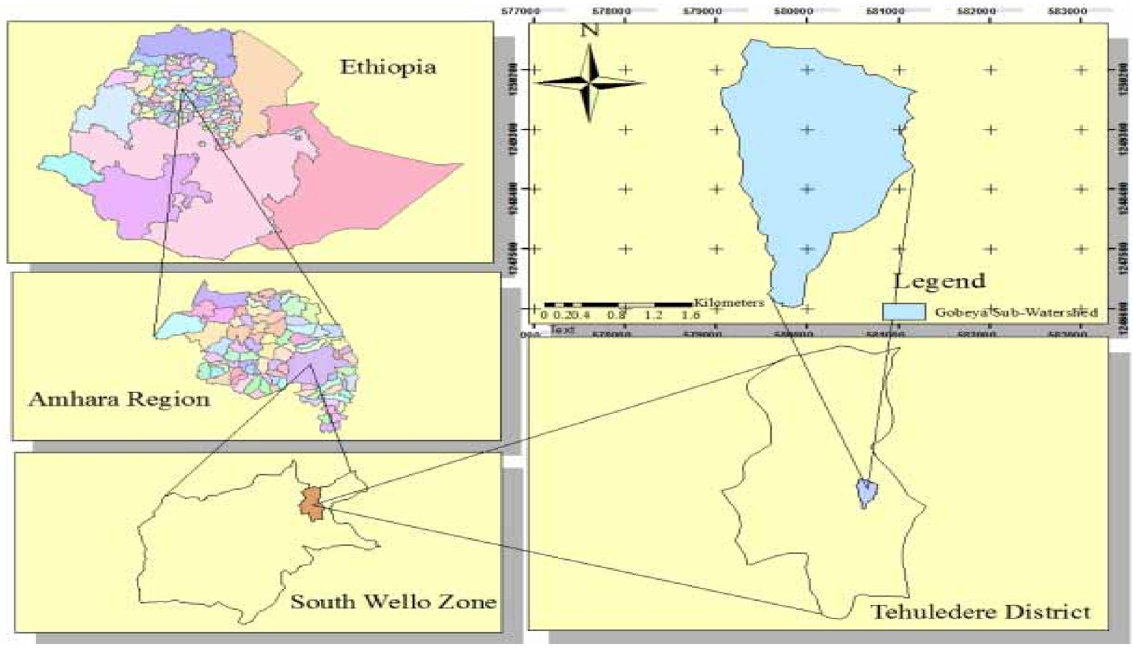

Figure 1. Location of the study area

Based on rainfall and temperature data from January 1993 to July 2013 obtained from Hayk Meteorological Station, the area is characterised by uni-modal rainfall pattern with annual average rainfall of 1259.5 mm. The highest rainfall is received in July and August (Figure 2). The mean maximum and minimum, and annual average temperatures are 26.2, 10.7 and 18.4 ^{o}C, respectively with the hottest months being June followed by May (Figure. 2).

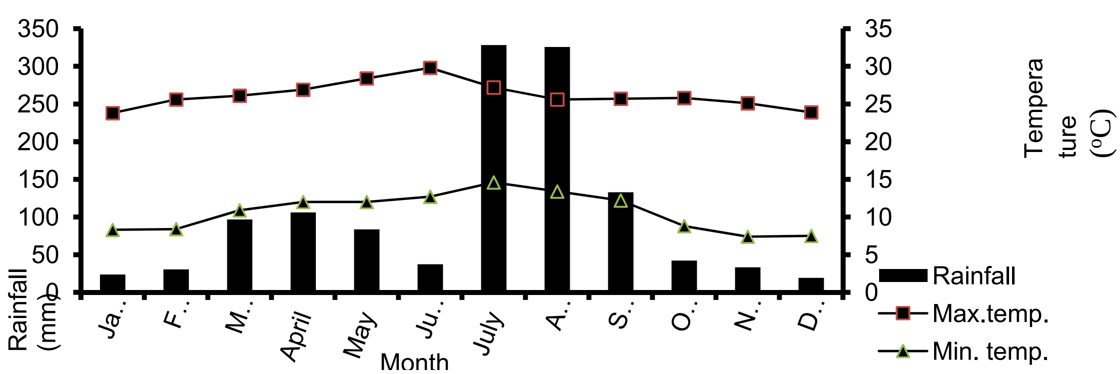

Figure 2. Monthly average rainfall (mm) and mean max. and min. Temp. (^{o}C) data of the study area from 1993 to 2013

2.2. Field Survey and Selection of Toposequence

Topographic map (1:50,000) was purchased from the Ethiopian Mapping Agency (EMA) and used to define the preliminary boundary of the Sub-watershed and select temporary profile sampling sites before the actual field survey. A reconnaissance survey was then carried out within the selected Sub-watershed to identify the major soils in the area. Free soil survey (traverse survey) method was employed to select profile excavation points as a major survey method along landform to detect variability of soils in the Sub-watershed. Based on tentative soil maps and physical observations, 99 auger samples (Figure 3) were taken from different sites up to 30 cm depth and analyzed in the field in order to observe the extent of variation of soil attributes. Based on the auger samples, visual observation of relief/landform features and land use, four representative sites were selected and one profile with 2.0 m width by 2.0 m length and 2.0 m depth was opened one each site. Slope classes were classified by using the FAO guideline, which includes 4 slope classes (Figure 3): 1-2% (very gentle sloping), 2-5% (gentle sloping), 5-10% (sloping), and 10-15% (strongly sloping). The four soil profile pits were excavated at different slope gradients on various positions of the landscape, representing summit, shoulder, footslope, and toeslope positions. Profile 4 was located on crest (summit), Profile 3 was on shoulder, and Profile 2 was on footslope, whereas Profile 1 was on a toeslope area. Profiles 3 and 4 were on grass with scattered bushes and trees vegetations; Profiles 1 and 2 were on teff and maize fields, respectively.

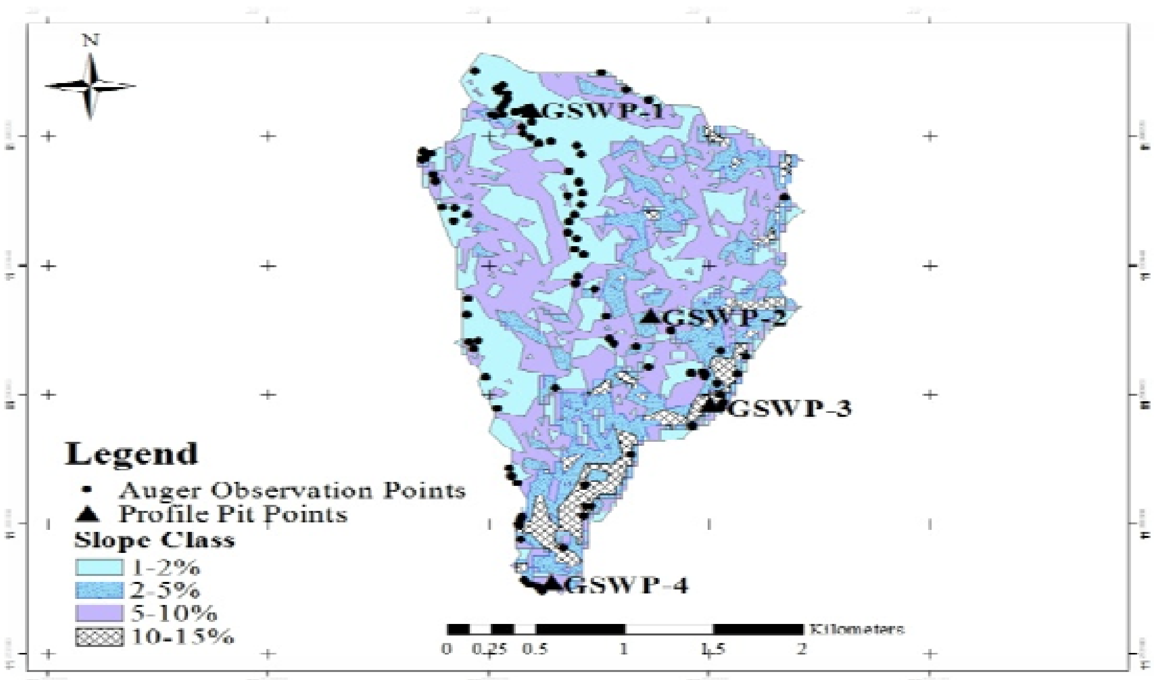

Figure 3. Distribution of profile pits and auger observation points in the study area

2.3. Soil Profile Description and Sampling

The field and environmental descriptions were done according to the FAO [13] guidelines for soil profile and site descriptions. Major morphological and physical properties along with other relevant site information were recorded on a standard profile description sheet right at the field. Finally, soil samples were collected from each genetic horizon for laboratory analysis. The opened soil profiles were demarcated/divided according to the evidence of pedogenic horizon development and described by using the procedures outlined by [13] for their morphological features on the field and the color of each layer (both in moist and dry conditions) was interpreted with the help of the Munsell color chart [14].

The auger and profile observation points were recorded by global positioning system (GPS Garmin 76s with accuracy 3) and the points were located on the 1:50,000 scale base map with the help of ArcGis 10.1 and finally indicated on the final soil map. The tentative soil map prepared during the pilot survey was adjusted in the main survey and finalized after laboratory analysis.

Totally 12 disturbed soil samples were collected depthwise from each genetic horizons or soil layers and 7 core soil samples from the first two consecutive horizons or soil layers for characterization of their physio-chemical properties that are relevant to the characterization and classification of soils in the study area.

2.4. Soil Sample Preparation and Laboratory Analysis

2.4.1. Soil sample preparations

Soil samples collected from each horizon/layer of the soil profiles were bagged, labelled and transported to Debre-Zeyit Soil laboratory for preparation and analysis of the selected soil physicochemical properties following standard laboratory procedures. In preparation for laboratory analysis, the soil samples were air dried in shade (house), grounded with pestle and mortar and made to pass through a 2 mm size sieve for the analysis of the selected soil properties except OC and total N in which case the soil samples were passed through 0.5 mm sieve to avoid coarser material. Soil bulk density and water retention at FC and PWP were determined only for the upper two horizons of each profile due to cost reasons. The bulk densities and moisture retention at FC and PWP of the soils were determined from samples collected using core ring sampler.

2.4.2. Laboratory analysis

2.4.2.1. Physical properties

The particle size distribution of the soils was analyzed by the Bouyoucos hydrometer method [15]. The bulk density (BD) of the soil was estimated from undisturbed soil samples collected using a core sampler from the upper two horizons and weighed at field moisture [16]. Total porosity was estimated using the following formula:

$$\%f = \left[1 - \frac{BD}{PD}\right] \times 100$$

where f is total porosity (%), PD is particle density which is assumed to be 2.65 g cm^{-3} and BD is bulk density (g cm^{-3})

Soil moisture retention at - 0.33 bar for field capacity (FC) from undisturbed samples and at - 15 bar for permanent wilting point (PWP) from those disturbed sub-samples used for FC determination were determined using pressure plate extraction method [17]. The plant available water was calculated as the difference between water contents at - 0.33 and - 15 bars.

2.4.2.2. Chemical properties

Soil pH was measured using pH meter method in the supernatant suspension of 1:2.5 soils to water ratio. The electrical conductivity of the soil was measured by conductivity meter after the soil samples were saturated with distilled water and was filtered by suction [18]. Organic carbon of the soils was determined following the wet digestion method [20] while percentage organic matter of the soils was determined by multiplying the percent organic carbon value by 1.724. Soil total nitrogen (TN) was analyzed by wet-oxidation procedure of the Kjeldahal method [20]. The available phosphorus was determined by the standard Olsen method [21].

Cation exchange capacity was determined at soil pH 7 after displacement by using 1N ammonium acetate method in which it was, subsequently, estimated titrimetrically by distillation of ammonium that was displaced by sodium [22]. The 1N ammonium acetate method also employed to determine exchangeable cations at pH 7. Exchangeable Ca and Mg were measured from the extract with atomic absorption spectrophotometer while exchangeable K and Na were determined from the same extracts with flame photometer [23]. Exchangeable acidity was determined by saturating the soil samples with potassium chloride (1M KCl) solution and titrated with hydrochloric acid (0.02 M HCl [23] . Percent base saturation (PBS) was calculated using the following formula:

$$\text{PBS (\%)} = \left[\frac{\text{Sum of exchangeab le bases}}{\text{CEC}} \right] \times 100$$

The cation exchange capacity of the clay fraction was estimated by dividing the CEC of the soil by the percentage of the clay and then multiplied by hundred and expressed as $cmol_C\ kg^{-1}$ clay [24]. Extractable micronutrients (Fe, Mn, Zn, and Cu) contents of the soils were extracted by DTPA method [25] and the contents in the extract were determined by atomic absorption spectrophotometer.

2.5. Soil Classification

Soil classification consisted of three steps. First, the expression, thickness and depth of layers were checked against the requirements of WRB diagnostic horizons, properties and materials, which were defined in terms of morphology and/or analytical criteria. Where a layer fulfilled the criteria of more than one diagnostic horizon, property or material, they were regarded as overlapping or coinciding [26].

Second, the described combination of diagnostic horizons, properties and materials was compared with the WRB Key in order to find the Reference Soil Group (RSG), which was the first level of WRB classification, and gone through the Key systematically, starting at the beginning and excluding one by one all RSGs for which the specified requirements were not met [26].

Third, for the second level of WRB classification, qualifiers were used. Prefix qualifiers comprise those that were typically associated to the RSG and the intergraded to other RSGs. All other qualifiers were listed as suffix qualifiers. For classification at the second level, all applying qualifiers were added to the name of the RSG. Redundant qualifiers (the characteristics of which are included in a previously set qualifier) were not added. Specifiers were used to indicate the degree of expression of qualifiers [26].

2.6. Mapping and soil mapping units

The final soil and other maps were produced from field data/mapping supported with the available aerial photographs and topographic map interpretation. All maps including topographic map of the area were produced electronically with the help of Arc GIS 10.1 software. The produced maps include location of the study area, topographic map of the study area, profile pits and auger observation points and soil map.

Based on toposequence (slope classes); interpretation of 1:50,000 aerial photos and topographic map and field survey results; the study area was divided into four soil mapping units namely soil mapping unit one (SMU-1) with slope ranges from 1-2%, soil mapping unit two (SMU-2) with slope ranges from 2-5%, soil mapping unit three (SMU-3) with slope ranges from 10-15% and soil mapping unit four (SMU-4) with slope ranges from 5 - 10% and mapped in studying the soils of Gobeya sub-watershed. The mapping units were named after the identified soil types and were classified in line with the FAO/WRB classification system.

Simple correlation analysis was carried out with the help of Statistical Analytical Software (SAS) version 9.1.3 model to reveal the magnitude and directions of relationships between selected soil physicochemical properties.

3. RESULTS AND DISCUSSION

3.1. Soil Morphological Properties

3.1.1. Soil depth

In most of the observation points, the total depth was observed to be greater than 200 cm although the identified genetic horizons had variable thickness. The described profile Profile 1 showed that the thickness of Ap (surface) horizons was 55 cm. This thickness generally increases with depth, probably indicating diminishing of differences in morphological properties with depth of the profile [27]. The thickness of identified sub-surface horizons varied from 56-200 cm. Below the Ap horizon 56-110 cm thick subsoil was identified and designated to be Ab horizon. Next to Ab horizon 111-200 cm subsoil was identified and assigned as Bw horizon.

The total depth of profile 2 was very deep (> 150 cm) on the footslope, indicating that the slope gradient could be the main factor in influencing the depth of the soils. The identified genetic horizons had variable thickness in Profile 2. Surface horizon (Ap) had about 23 cm thick. Below Ap horizon, about 69 cm thick subsoil horizon (C_1) was identified. Under C_1 horizon, about 47 cm thick another sub-soil horizon (C_2) was recognized. At last fourth horizon which had about 61 cm thick subsoil horizon was also identified.

In profile 3 soil depth of surface horizon had 24 cm. In most of the observation points of profile 4, the total depth was observed to be greater than 200 cm. The thickness of Ah horizon of Profile 4 was 40 cm. The genetic horizon underlying the topsoil was thick for 19 cm (AB), which changed to a 38 cm thick intermediate sub-surface horizon (Bw_1). The intermediate horizon changed to a 103 cm thick lower horizon, which was underlain by a deep cemented sub-soil material (Bw_2).

3.1.2. Soil color

The surface horizon of Profile 1 had very dark greyish brown (10 YR 3/2) moist, and dark brown (7.5 YR 3/2) dry color. The color of all sub-surface soils of this Profile varied only in their value from 10YR 3/2 to 10YR 2/2 (moist); while there were no variations when dry, and they showed dark brown (7.5YR 3/2). The moist and dry color of the topsoil of profile 2 was very dark greyish brown (10YR 3/2), while the moist and dry colors of sub-soil horizons ranged from dark reddish brown to very dark greyish brown (5YR 3/2 to 10 YR 3/2). The moist and dry colors of Profile 3 were dark brown (7.5YR 3/2) and Very dark grey (7.5 YR 3/1), respectively. The dark color of the profile could be attributed to the presence of higher amount of organic matter. The topsoil horizons of Profile 4 had olive brown (2.5Y 4/3) and light olive grey (5Y 6/2) moist and dry color, respectively. In general, the color of the topsoil horizon becomes darker than sub-surface horizons. The color of transition horizon AB had pale olive (5Y 6/4) and light olive brown (2.5Y 5/3) moist and dry color, respectively. The color of sub-surface soils were 5Y 6/4 (pale olive) to 5Y 7/3 (pale yellow) dry, and they had pale olive (5Y 8/2 and 5Y 6/4) moist color. The color patterns suggest that soil color become relatively lighter with depth of the profile, as a consequence of which both lateral and vertical color variability is a real phenomenon in the present soil.

3.1.3. Soil structure

The structure surface horizon of profile 1 was moderate fine subangular blocky that changed to weak very fine granular structure in its intermediate underlying horizon. The lower horizon had moderate very fine angular blocky structure. The surface horizon of profile 2 had single grained arrangement. This changed to strong coarse platy structure in all sub-surface horizons. On the other hand, surface horizon of Profile 3 had massive arrangement. The topsoil (A horizon) of profile 4 had moderate fine granular structure that changed to strong fine sub angular blocky structure in the second transitional (AB) horizon. The presence of blocky structure is an indication of initial soil development, and that the genetic development of the soil (Profile 4) is at its earliest stage. In most of the cases and as represented by Profile 4, the third horizon from the surface had strong medium angular blocky structure. This changed to strong coarse angular blocky structure. The variations in structure among horizons suggest that there was a vertical variability in the development of soil structure, and hence in the development of the representative soil profile in general.

3.1.4. Soil consistence

The surface horizon of Profile 1 had hard (dry), friable (moist), very sticky and very plastic (wet) consistence. For some of the cases, there were changes in consistency at least by one grade with depth of the profile. The horizon underlying the Ap horizon had extremely hard (dry), very friable (moist), sticky and plastic (wet) consistence. The change related to consistence characteristics may be related to a change in texture. That is, the increase in clay content with depth of a profile may result in changing the consistence of the soil at different moisture levels. The topsoil of Profile 2 had soft (dry), loose (moist), very sticky and very plastic (wet) consistence. The horizon underlying the Ap horizon (C_1 and C_2 sub-surface horizons) had hard (dry), hard (moist), slightly sticky and slightly plastic (wet) consistence. The lower underlying horizon had hard (dry), hard (moist), plastic and sticky (wet) consistence. Profile 3 had hard (dry), friable (moist), very sticky and very plastic (wet) consistence. The consistence of the surface horizon of Profile 4 was marked by soft (dry), very friable (moist), slightly sticky and slightly plastic (wet) consistence. This characteristic changed to hard (dry), firm (moist), sticky and plastic (wet) in horizons immediately underlying the topsoil. However, this change in consistence couldn't be associated with a change in texture. The intermediate horizon (i.e. the third horizon from the surface) had hard (dry), extremely firm (moist), sticky and plastic (wet) consistence. The lower underlying horizon had very hard (dry), extremely hard (moist), slightly sticky and slightly plastic (wet) consistence.

3.1.5. Horizon boundary

The boundary of Profile 1 was characterized by clear and smooth boundary in Ap and Ab horizons, which changed to abrupt and smooth in lower Bw horizon, whereas Profile 2 was characterized by clear and smooth boundary in the surface horizon, which changed to gradual and brocken in the subsoil horizons. This implies that, whereas there were clear morphological differences between overlying and sub-soil horizons, such differences become subtle with depth of the profile. The wavy boundary characteristics indicate the existence of differences in weathering intensity within Profile 3. In all of the horizons, the boundary topography was described to be irregular but changing from clear to gradual from surface to sub-surface horizons with depth in Profile 4. The gradual boundaries in the lower horizons reflect absence of distinct morphological differences between the subsequent subsoil horizons of such soils. This may reconfirm early stage of soil development of the profile in particular and in identified mapping unit in general.

Table 1. Morphological properties of soils of the study area

Profile	Horizon	Depth (cm)	Color		Structure	Moist and wet Consistence	Horizon boundary
			Moist	Dry			
1	Ap	0-55	10YR 3/2	7.5YR 3/2	MO,FI,SB	FR,ST,PL	C,S
	Ab	55-110	10YR 3/2	7.5YR 3/2	WE,VF, GR	VFR,SST, SPL	C,S
	Bw	111-200	10YR 2/2	7.5YR 3/2	MO,VF, AB	VFR,ST,PL	A,S
2	Ap	0-23	10YR 3/2	10YR 3/2	Massive	LO,VST,VPL	C,S
	C_1	23-92	5YR 3/2	5YR 3/2	ST,CO,PL	HA,SST.SPL	G,B
	C_2	92-139	5YR 3/2	5YR 3/2	ST,CO,PL	HA,SST,SPL	G,B
	Cg	139-200	7.5YR 4/1	7.5YR 5/1	ST,CO,PL	HA,PL,ST	G,B
3	Ah	0-24	7.5YR 3/1	7.5YR 3/2	Massive	FR,VST,VPL	C,W
4	Ah	0-40	2.5Y 4/3	5Y 6/2	MO,ME,MA	VFR,SST,SPL	C, I
	AB	40-59	5Y 6/4	2.5Y 5/3	ST,FI,AB	FI,ST,PL	G, I
	Bw_1	59-97	5Y 6/4	5Y 8/2	ST,ME,AB	EFI,ST,PL	G, I
	Bw_2	97-200	5Y 6/4	5Y 7/3	ST, CO,AB	EFI,ST,PL	G, I

Where, MO = moderate, ME = medium, MA = massive, FI = fine, very firm SB = sub-angular blocky, PL = plastic, PL = platy, VPL = very plastic, F = fine, VF = very fine, SST = slightly sticky, AB = angular blocky, WE = weak, GR = granular, FR = friable, VFR = very friable, ST = sticky, VST = very sticky, VFR = very friable, C = clear, S = smooth, A = abrupt, CO = coarse, G = gradual, B = broken, I = irregular, W = wavy

3.2. Soil Physical Properties

3.2.1. Particle size distribution

The texture of Profile 1 is sandy clay loam both in top soil horizon and in the subsoil horizons. The particle size analysis indicates that, the proportions of clay, silt and sand showed an irregular variation with depth of this profile (Table 2). The irregular variation in amounts of clay, silt and sand could implicate unequal weathering of materials among the horizons in the profile. The silt/clay ratio of the plough layer was found to be much higher than the sub-surface soils. The higher silt/clay ratio in the surface horizon and it decline with depth shows the presence of clay migration from the upper to the lower horizon (Table 2).

The texture of Profile 2 is sandy clay loam in the surface horizon, whereas the sub-surface horizons showed sandy, sandy loam and sandy clay loam texture from upper sub-surface horizon to the deeper lower horizon, respectively. The proportions of sand and clay increased in the sub-soil horizons, whereas the proportion of silt showed an even variation in all the horizons with the exception of the lower sub-soil horizon (140-200 cm) which showed higher silt content (Table 2). The increase in clay content with depth of sub-surface horizons may be attributed to a vertical movement of finer clay materials as well as its transformations from other particle sizes; whereas the decrease in sand content could indicate its destruction through weathering process and transformations to finer materials. On the other hand, the regular allocation in amounts of silt could indicate equal weathering of materials among the horizons of the profile. Lower silt/clay ratio was identified in the sub-surface horizon. However, it increased unsystematically down the profile. Higher silt/clay ratio was recorded from the lower horizon. Lower silt/clay ratio in the sub-surface horizon also indicates better nutrient reserve and water retention capacity than the surface, overlying and underlying sub-soil horizons.

Profile 3 is clay loam in texture. The amount of clay in this profile was 34%, whereas the contents of sand and silt were recorded as 30% and 36%, respectively with silt to clay ratio of 1.06.

The textural classes of all horizons except the surface horizon of Profile 4, which is sandy loam, are sandy clay loam. Content of clay increased consistently down the profile even though it showed constant values for the two consecutive sub-surface horizons. The content of sand and silt showed irregular variation with depth of the profile. The silt/clay ratio of the surface horizon was lower than two middle sub-surface horizons, but higher than the deeper lower sub-soil horizon.

3.1.1. Bulk density and total porosity

The bulk density of Profile 1 showed an increasing pattern with depth of the profile. It varied from 1.24 g cm^{-3} in the first lower underlying horizon to 1.4 g cm^{-3} in the surface horizon. On the other hand, the total porosity in Profile 1 increased from surface (47%) to the first sub-surface (53%) horizon (Table 2). In Profile 1 of the present study, values of bulk densities could not be generally related to variation in contents of organic carbon as in other soils of the study area as well as elsewhere [28, 24, 29, 27]. Accordingly, whereas contents of organic carbon decreased with depth of the profiles, bulk density values decreased in the similar pattern. This suggests that attributes other than organic matter such as particle size distribution, effects of cultivation and micro-structure characteristics may be form the main factors in affecting and differentiating bulk density values.

Values of bulk density of the first two horizons of Profile 2 showed a decreasing pattern with depth of the profile. It varied from 1.4 g cm^{-3} in the surface horizon to 1.24 cm^{-3} in the upper sub-surface horizon. The bulk density value of Profile 3 was 1.04 gm cm^{-3}. This low value of bulk density could reflect the presence of higher organic matter level [29, 9, 30]. The total porosity of this profile was recorded as 60.75%.

The values of bulk density of Profile 4 in the study area showed increasing pattern from surface to the first upper sub-surface horizon and with in the upper two horizons, and it varied from 0.88 g cm^{-3} to 1.55 g cm^{-3}. In Profile 4 of the present study, values of bulk densities could be generally related to variation in contents of organic carbon. Accordingly, whereas contents of organic carbon decreased with depth of the profiles, bulk density values increased. Total porosity of Profile 4 varied from 41.5% in the upper sub-surface to 66.8% in the surface horizon. It varied inversely following the variation in bulk density values.

3.1.2. Soil moisture retention and available water holding capacity

In most of cases, there was no clear pattern of variation in field capacity (FC), permanent wilting point (PWP), and available water holding capacity (AWC) among the soils of the Sub-watershed (Solomon, 2006). Analysis on moisture retention for the top soil horizon of Profile 1 showed that the FC was

37.57% and the PWP was 27.3%, giving an AWC of 102.7 mm m^{-1}. Surface horizon and the upper sub-surface horizon of Profile 2 showed that the FC was 36.4 and 39.0%, and PWP 24.27 and 24.96%, giving an AWC of 121.3 and 140.4 mm m^{-1}, respectively. By and large, the higher and the lower moisture contents (at FC and PWP) corresponded with the higher and lower clay contents of the soil, respectively except excluding upper sub-surface horizon of Profile 2 (23-92 cm) that contained high moistures at FC, PWP and AWC. This is probably due to the higher matric potential (suction) of the clay particles that hold the water tightly [31].

In surface horizon of Profile 3 the AWC was 96.1 mm m^{-1} and it had moisture retention at field capacity (FC) and permanent wilting point (PWP) of 39.91 and 30.3% respectively. As determined for the surface horizon of Profile 4, FC and PWP values were found to be 57.17% and 40.47%, respectively, giving an AWC of 167 mm m^{-1}. The first upper sub-surface horizon of Profile 4 had higher FC and PWP than the surface horizon which showed 25.29% (FC) and 18.56% (PWP), giving 67.2 mm m^{-1} (AWC) (Table 2).

The amounts of AWC that a soil can retain vary with the soil texture, OM content, rooting depth and structure of the soil [32]. In this study, it also showed association with OM content, rooting depth and clay content of the soil. Generally, the available water holding capacity of the soil in the study area was found to be low in surface horizons of Profiles 3 and 4 as well as sub-surface horizon Profile 1, and medium in surface horizon of Profile 1 as well as sub surface horizons of Profiles 2 and 4 [33] who rated the value of AWC (in mm of water per m of soil) as low (<100), medium (100-200), and high (>200) (Table 2).

able 2. Particles size distribution, bulk density, water retention at FC and PWP and AWC of soils of the study area.

Profile	Depth (cm)	Particle size distribution			TC	Silt/ clay	BD (g cm^{-3})	TP (%)	Water retention (%)		AWC (mm m^{-1})
		Sand (%)	Silt (%)	Clay (%)					FC (%)	PWP (%)	
1	0-55	52	26	22	SCL	1.18	1.40	47.2	37.57	27.3	102.7
	55-110	64	16	20	SCL	0.80	1.24	53.2	28.21	20.1	81.1
	110-200	52	22	26	SCL	0.85					
2	0-23	58	16	26	SCL	0.61	1.18	55.5	36.4	24.27	121.3
	23-92	84	6	10	S	0.6.0	1.40	47.2	39.0	24.96	140.4
	92-139	80	6	14	SL	0.43					
	1139-200	52	20	28	SCL	0.71					
3	0-24	30	36	34	CL	1.06	1.04	60.8	39.91	30.3	96.1
4	0-40	70	14	16	SL	0.88	0.88	66.8	57.17	40.47	167
	40- 59	52	28	20	SCL	1.40	1.55	41.5	25.28	18.56	67.2
	59- 97	50	30	20	SCL	1.50					
	97-200	58	17	25	SCL	0.60					

Where CL = clay loam, S = sandy, SL = sandy loam, SCL = sandy clay loam, TC = textual class, TP = total porosity

3.2. Soil Chemical Properties

3.2.1. Soil reaction

The pH of soils in the study area ranged from 6.3 to 7.4 which were rated as slightly acidic to mildly alkaline with mainly of neutral reaction (6.6-7.3) [34]. The pH value of Profile 1 revealed an increasing trend with depth, ranging between 6.5 in the surface to 7.3 in the sub-surface horizon (Table 3). Increased in soil pH in Profile 1 with soil depth may indicate a presence of vertical movements of exchangeable bases and less H^+ ions are released from decomposition of organic matter, which is caused by decreased organic matter content with depth [35]. The pH of Profile 2 showed an irregular pattern with depth of the representative profile (Table 3). It showed decreasing pattern from surface to the next upper sub-surface horizon, and then after showed increasing pattern in all three identified sub-surface horizons.

The pH value of Profile 3 was described as slightly acidic (6.5). This is due to the higher buffering capacity attributed to the relatively higher organic matter content of the areas. The pH values regularly decreased with depth of Profile 4 in the upper three horizons, and then after showed constant value in the deeper lower sub-soil horizon, ranging from 6.6 in the surface horizon to 6.3 in the underlying lower horizons (Table 3). The decrease in pH values could due to seasonal soil water saturation that may have caused bases removal from the horizon and contributed to the lowering of pH value [27].

3.2.2. Electrical conductivity

Due to the moderately acidic to neutral nature of most soils of the study area, the electrical conductivity (EC) values were below 1 dS m^{-1}. The relatively higher value of electrical conductivity of the extract was recorded in the surface horizon of Profile 3 which was 0.5 dS m^{-1} (Table 3). Electrical conductivity values in all profiles were rated as very low [36]. Generally, the EC values measured throughout the depths of the soils in the study area indicated that the concentrations of soluble salts are below the levels at which growth and productivity of most agricultural crops are affected due to soil salinity [37, 24].

3.2.3. Soil organic carbon

The organic carbon of soils were in the range between 0.86 and 3.34, and was generally between low and high [38] who rated the values of OC as extremely very low (<0.5%), low (0.5-1.5%), medium (1.5-3%) and high (>3%). The organic carbon contents of Profile 1 showed an irregular variation with depth of the profile. The content of organic carbon was low for a horizon with relatively high sand percentage. However organic carbon content was relatively high in surface horizon. Studies made in Ethiopia [39, 40] showed that the level of soil organic carbon are related to land use history, and other generally expected to be low in cultivated soils as compared to the same fallow land. The content of organic carbon varied from 1.23% in the surface to 0.86% in the lower sub-soil horizons, and showed irregular decreasing pattern with depth of profile 2. The organic carbon content in of profile 3 of surface horizon was 3.34% which was rated as high (Table 3) [38].

As it is generally true for most other similar soils in the other parts of Ethiopia [41, 42], organic carbon content of Profile 4 regularly decreased with depth, which ranged from 0.94% in the lower underlying to 1.50% in the surface horizons (Table 3). The relatively higher content of organic carbon in the surface horizon of Profiles 3 and 4 could be ascribed to the presence of sufficient grass and grass roots for decomposition.

3.2.4. Total nitrogen and carbon to nitrogen ratio

The content of total nitrogen revealed an erratic distribution with depth of the profile in line with variations in the level of organic carbon. It varied from 0.04% in the buried to 0.15% in the surface horizon of Profile 1. In general, the level of total nitrogen ranged from low to medium throughout the Profile 1 [38]. Total nitrogen followed the same pattern of variation as that of organic carbon content, and ranged between 0.05% in the surface to 0.02% in the underlying sub-surface horizons of Profile

2. In the surface horizon of Profile 3 the level of total nitrogen was 0.23% which was rated as high [38] (Table 3).

In Profile 4 the content of total nitrogen was generally very low, considering the ratings given in [38], and decreased regularly with depth even though the lower sub-surface horizons showed constant value. It varied between 0.02% in the underlying to 0.04% in the surface horizons. This decrease generally parallels to a decrease in contents of organic matter, suggesting that the main source of total nitrogen was organic matter.

The level of carbon to nitrogen ratio of Profile 1 varied from 11.08% in the surface to 33.4% in the underlying sub-surface horizon, whereas it varied from 24.6% in the surface to 43.5% in the sub-surface horizon of Profile 2 and it showed an irregular increase with depth of the profile. The carbon/nitrogen ratio measures the relative nitrogen content of organic materials. In Profile 3 the calculated carbon to nitrogen ratio was recorded as 14.52%, whereas it varied from 37.5 to 50% in Profile 4.

If C/N ratio of organic material is less than 25% (surface horizons of Profiles 1, 2 and 3 of the present study area), decomposition may proceed at the maximum rate possible under environmental conditions [43]; if greater than 25% (all sub-surface horizons of Profiles 1 and 2 as well as all horizons of Profile 4 of the present study area), decomposition slows unless nitrogen is added. Nitrogen will be tied up in organisms decomposing the organic material, and will not be available to any crops sown (nitrogen immobilization occurs).

Table 3. Soil reaction (pH), Electrical conductivity, organic carbon, total nitrogen, carbon to nitrogen ratio and available phosphorous of the soils

Profile	Horizon	Depth (cm)	pH (1:2.5, soil:water)	EC (dS m^{-1})	OC (%)	TN (%)	C:N ratio	Av.P (mg kg^{-1})
1	Ap	0-55 cm	6.5	0.01	1.66	0.15	11.08	Trace
	Ab	55-110 cm	7.1	0.03	1.21	0.04	33.28	6.00
	Bw	110-200 cm	7.3	0.03	1.28	0.05	25.69	6.00
2	Ap	0-23	7.3	0.04	1.23	0.05	24.6	2.00
	C_1	23-92	7.2	0.01	0.87	0.02	43.5	8.00
	C_2	92-139	7.3	0.03	0.87	0.02	43.5	Trace
	Cg	139-200	7.4	0.02	0.86	0.02	43.0	Trace
3	Ah	0-24 cm	6.5	0.05	3.34	0.23	14.52	2.00
4	Ah	0-40	6.6	0.02	1.50	0.04	37.5	4.00
	AB	40- 59	6.5	0.02	1.47	0.03	49.0	Trace
	Bw_1	59-97	6.3	0.02	1.00	0.02	50.0	6.00
	Bw_2	97-200	6.3	0.02	0.94	0.02	47.0	4.00

3.2.5. Available phosphorous

According to [44], the available P contents of the soils ranged from very low to medium (Table 3). The authors rated Olsen P as < 3 mg kg^{-1} as very low, 4-7 mg kg^{-1} as low, 8-11 mg kg^{-1} as Medium, and > 12 mg kg^{-1} as high. The level of available P was rated as low throughout Profile 1, and showed uniform variation (6 mg kg^{-1}) with depth of the profiles with the exception of the surface horizon which was trace (very low) in amount. The level of available P showed increasing pattern from the surface to the next sub-surface horizon (varied from 2 mg kg^{-1} (very low) to 8 mg kg^{-1} (medium) (Table 3), and then totally absent in the underlying sub-soil horizons of Profile 2. The increasing of available P down the profile is attributed to the decrease in clay content.

In the surface horizon of Profile 3 the amount of available phosphorous was recorded as 2 mg kg^{-1}, which was rated as very low as indicated by [44] (Table 3). Phosphorus fixation tends to be more pronounced and ease of phosphorus release tends to be lowest in those soils with higher clay content [8].The available phosphorous content ranged from very low to low as rated in the same authors throughout the horizons of Profile 4 and showed an irregular variation with depth. It varied between trace and 6 mg kg^{-1}. The low P content of the soils could be related to P fixation by Ca and

Mg. As represented by all profiles, crop cultivation in these soils would be limited by low P status in addition to other limiting factors mentioned earlier, as a result of which application and management of P may be required.

In fact, low content of P is a common characteristic of soils characterized by tropical humid climates as in the present study area [45]. It is also suggested that the existence of low contents of available P is a common characteristic of most Ethiopian soils. Consequently, low available P of the soils could form one of the major soil fertility limiting factors in the study area [46]. Therefore, to increase any economical agricultural production would require raising of available P through various P management practices, such as fertilization and/or organic manure application [47].

3.2.6. Exchangeable bases

Exchangeable calcium followed by magnesium formed the dominant cation in the exchange complex throughout the horizons of the all representative profiles (Table 4). The two cations together occupied 74 to 99% of the exchange site throughout Profile 1. However, exchangeable calcium and magnesium contained 59 to 89.9% of the total surface exchange site throughout the horizons of Profile 2. These two cations also occupied 80% and 61.9% to 70.6% of the exchange site throughout the Profiles 3 and 4 respectively, but the proportions showed an irregular pattern with depth of Profiles 1, 2 and 4, probably indicating different leaching intensity within the profiles (Table 4). According to FAO ratings [13], exchangeable Ca and Mg were rated as high and very high with the exception of surface horizon of Profile 4, which showed medium Ca content. As described by [13] exchangeable K was rated as very low in all profiles excluding surface horizons of Profile 2, whereas exchangeable Na in Profiles 1, 3, and 4 as well as surface horizon of Profile 2 was rated as low and very low, but it ranged from medium to high in sub surface horizons of Profile 2 [13].

Exchangeable calcium alone consisted of 55 to 72% and 35.8 to 40.7% of the exchange site of Profiles 1and 4 respectively, and it occupied 59.5% of the exchange site in Profile 3. In absolute terms, contents of exchangeable calcium varied from 24.96 to 34.39 $cmol_C\ kg^{-1}$, and exchangeable magnesium varied between 9.44 and 10.41 $cmol_C\ kg^{-1}$ throughout Profile 2. Contents of exchangeable calcium and magnesium accounted for 29.92 $cmol_C\ kg^{-1}$ and 10.39 $cmol_C\ kg^{-1}$, respectively in Profile 3.

Exchangeable K and Na showed uneven distribution with depth of almost all profiles. In all profiles these monovalent cations together saturated less than 1% of the exchange site. From these data, it may be pointed out that, whereas toxicity from Na is unlikely to occur but K deficiency is expected in the cultivated soils according to [24] ratings. It may also partly indicate an existence of different sources of parent materials for the profile that were located in landscape positions where it could receive depositional materials originating from various parent rocks. `Moreover, the exchangeable K was nearly 0.17% of the total exchangeable base (the minimum ratio is 2 to 3%), this value also show very low level of exchangeable K [48]. Other profiles had also nearly equivalent values as that of Profile 1. Therefore, it is possible to judge that the level of exchangeable K was very low in soils of the Gobeya sub-watershed.

3.2.7. Cation exchange capacity and percent base saturation

The CEC of the soils in both surface and sub-surface layers ranged from 21.95 $cmol_C\ kg^{-1}$ (profile 4) to 63.16 $cmol_C\ kg^{-1}$ (profile 2) and was generally between medium and very high (very high) according to [24]. The high amount of CEC in the soils of the study area may due to the presence of active Clay mineralogy. The cation exchange capacity (CEC) of Profile 1 ranged from 36.2 $cmol_C\ kg^{-1}$ in the sub-surface horizon to 48 .94 $cmol_C\ kg^{-1}$ in the surface horizon. CEC varied from 40.66 to 63.16 $cmol_C\ kg^{-1}$ in Profile 2, and varied from 21.95 $cmol_C\ kg^{-1}$ to 49.39 $cmol_C\ kg^{-1}$ in Profiles 4, respectively. In both profiles CEC showed irregular variation with depth of the profiles. Relatively lower value of CEC (21.95 $cmol_C\ kg^{-1}$) in Profile 4 was recorded for horizons where all exchangeable cations were found to be low. The content of CEC in Profile 3 of surface horizon was 50.2 $cmol_C\ kg^{-1}$ and the CEC-clay was 69.5 $cmol_C\ kg^{-1}$. The CEC-clay varied from 199 to 451.14 $cmol_C\ kg^{-1}$, and showed unsystematic variation with depth of the Profile 2 (Table 4).

Generally, the CEC-clay indicating the presence of appreciable amounts of expandable smectite type of clay mineralogy (2:1) and/or mixed clay mineralogy at surface and sub-surface layers of the soils (Table 4). The existence of high CEC-clay fractions at sub-surface horizons of Profile 2 could also be due to the possible contribution of pseudo-silt sized clay particles to CEC [41]. Wide variation in the extent of CEC-clay values among the subsurface horizons of all profiles may indicate the presence and deposition of various materials that could weather to different clay mineralogy. Within this broad range of CEC-clay values, the occurrence of mixed clay mineralogy is expected.

The PBS of Profile 1 ranged from 75% on the surface to 86% in the underlying sub-surface horizon. It varied from 61% to 92%, and showed unsystematic variation with depth of Profile 2. Percent base saturation of Profile 3 was estimated to be 80.7%, but it varied from 62% in the underlying to 71% in the surface horizons, and showed unsystematic variations with depth of Profile 4 (Table 4).

The PBS values in both surface and sub-surface horizons ranged from high (60-80%) to very high (> 80%) based on the rating of [49]. According to the same author level of PBS indicates the intensity of leaching or extent of leaching in the sense of depletion of the exchangeable bases. Accordingly, the PBS of soils of the study area could be characterized as very weakly leached (50-70%) and weakly leached (70-100%). The percent base saturation of the soils ranged from 61% to 92% in Profile 2. The very high PBS of the profiles indicates the presence of $CaCO_3$, which would be dissolved during CEC determination using 1M NH_4AOc ammonium acetate of pH 7, and contributes to the values exchangeable Ca. Therefore, it would not be possible to make generalization on PBS of the soils based on these values.

3.2.8. Exchangeable acidity

Exchangeable acidity refers to the sum of the concentrations of hydrogen and aluminium ions in the soil exchange complex. The amount of exchangeable acidity varied from 0.16 $cmol_C$ kg^{-1} to 0.22 $cmol_C$ kg^{-1} in Profile 1 and 0.16 $cmol_C$ kg^{-1} to 0.25 $cmol_C$ kg^{-1} in Profile 2. It was recorded as 0.26 $cmol_C$ kg^{-1} in the surface horizons of Profile 3.

The exchangeable acidity of Profile 4 ranged from 0.22 $cmol_C$ kg^{-1} to 0.39 $cmol_C$ kg^{-1}. It increased irregularly throughout this profile. The relatively higher exchangeable acidity (0.39 $cmol_C$ kg^{-1}) was observed at the deeper lower sub-surface horizon (97-200 cm) of Profile 2. The sources of acidity of such slightly acidic soils in the study area may be release of organic acids during decomposition of organic matter and steepness of the topography, which causes removal of basic cations by erosion and leaching (Table 4).

Table 4. Exchangeable cations and exchange properties of soils

Profile	Horizon	Depth (cm)	Na	K	Ca	Mg	TEB	EA	CEC	CEC-clay	PBS (%)
			$cmol_C$ kg^{-1}								
1	Ap	0-55	0.17	0.07	27.0	9.53	36.77	0.16	48.94	222	75
	Ab	56-110	0.16	0.06	23.40	8.66	32.28	0.17	36.2	181	86
	Bw	111-200	0.23	0.09	27.01	11.65	38.98	0.22	46.87	180	83
2	Ap	0-23	0.76	0.24	34.39	9.48	44.87	0.22	55.22	212	81
	C_1	24-92	0.96	0.05	27.12	9.44	37.57	0.18	40.66	406	92
	C_2	93-139	1.16	0.15	27.12	10.16	38.59	0.16	63.16	451	61
	Cg	140-200	1.14	0.09	24.96	10.41	36.6	0.25	55.72	199	65
3	Ah	0-24	0.06	0.16	29.92	10.39	40.54	0.26	50.23	69	80
4	Ah	0-40	0.06	0.03	8.95	6.56	15.6	0.26	21.95	137	71
	AB	40-59	0.17	0.02	17.92	12.52	30.63	0.22	48.66	243	63
	Bw_1	59-97	0.23	0.04	17.70	13.70	31.67	0.27	49.39	247	64
	Bw_2	97-200	0.17	0.03	15.74	10.75	26.69	0.39	42.78	171	62

Where, TEB = Total exchangeable bases; EA = Exchangeable acidity; CEC = Cation exchange capacity; PBS = Percent base saturation

3.2.9. Extractable micronutrients

At low pH values, the solubility of the micronutrient cations is at a maximum and as the pH is raised their solubility and availability to plants decrease [8]. Relatively higher Fe (20.58 mg kg^{-1}) content was registered from the sub-surface horizon (59-97 cm) of Profile 4 of the summit area (Table 5). In general, extractable Fe showed unsystematic increase with depth of Profiles 1 and 4, but it showed unsystematic decrease with depth of Profile 2. The concentration of extractable Mn decreased systematically with depth, and it varied from 15.5 mg kg^{-1} in the surface to 14.1 mg kg^{-1}in the lower deeper sub-surface horizon of Profile 1, however varied from 13.8 mg kg^{-1}in the surface to 23.5 mg kg^{-1} in the underlying horizon (93-139 cm) in Profile 2 (Table 5). It was indicated that the critical or threshold levels of available Fe and Mn for crop production are 2.5-4.5 mg kg^{-1} and 1-50 mg kg^{-1}, respectively [50]. Therefore, the results observed in this study revealed that the average mean values of available Fe and Mn were in adequate range for the production of most crop plants.

The trend of extractable Zn and Cu concentration increased regularly with depth of Profile 1, but they decreased unsystematically with depth in Profile 2. Extractable Zn in Profile 1 varied from 0.16 mg kg^{-1}in the surface to 0.30 mg kg^{-1} in the lower deeper sub-surface horizon of Profile 1, and it varied from 0.12 mg kg^{-1}in the surface to trace level in the lower sub-surface horizon (93-139 cm). Extractable Cu varied from 0.68 mg kg^{-1} to 0.49 mg kg^{-1} in Profile 1, and varied from 0.38 mg $kg^{-1}$to 0.03 mg kg^{-1} in Profile 2.The extractable Fe, Mn, Zn, and Cu contents of the surface horizon of Profile 3 of the shoulder area were 13.66, 19.9, 0.50, and 1.39 mg kg^{-1}, respectively.

The concentration of extractable Zn increased systematically with depth and it varied from 0.29 mg kg^{-1} in the surface to 1.95 mg kg^{-1}in the lower deeper sub-surface horizon, whereas the concentration of extractable Mn and Cu concentration decreased irregularly with depth in Profile 4. In this profile extractable Mn varied from 1.0 mg kg^{-1}in the underlying to 12.9 mg kg^{-1}in the surface horizon, whereas the extractable Cu varied from 0.04 mg kg^{-1} in the lower deeper horizon to 0.49 mg kg^{-1} in the first sub-surface horizon.

According to the ratings indicated in [44], extractable Fe in all profiles were rated as high with the exception of surface and subsurface horizons of Profile 2 which were rated as medium, whereas extractable Mn was rated as medium exclusively of sub-surface horizon of Profile 2, which was rated as high. As described in the same author extractable Zn of Profiles 1 as well as surface horizon of Profile 4 were rated as low and very low, however it rated as medium and high in surface horizon of Profile 3 and 4, and all sub-surface horizons of Profile 4, respectively. Moreover, extractable Cu of all representative profiles ranged as low and very low.

Table 5. Extractable micronutrients of soils of the study area

Profile	Horizon	Depth (cm)	Micronutrient (mg kg^{-1}) Fe	Mn	Zn	Cu
1	Ap	0-55	8.43	15.5	0.16	0.68
	Ab	55-110	9.68	14.4	0.26	0.84
	Bw	110-200	7.81	14.1	0.30	0.91
2	Ap	0-23	3.67	13.0	0.12	0.38
	C_1	24-92	2.34	14.8	0.06	0.03
	C_2	93-139	6.00	23.5	Trace	0.09
	Cg	140-200	2.85	13.8	0.01	0.31
3	Ah	0-24	13.66	19.9	0.50	1.39
4	Ah	0-40	16.18	12.9	0.29	0.30
	AB	40-59	13.87	1.0	1.15	0.49
	Bw_1	59-97	20.58	1.9	1.44	0.22
	Bw_2	97-200	14.62	1.9	1.95	0.04

3.3. Soil Classifications

From the morphological and physicochemical characteristics discussed, the soils of Profile 1 can be classified as Cambisols according to FAO/WRB classification guideline. According to these set of criteria, the second horizon (Ab) could be identified as and qualify for a Cambic horizon. Therefore, the profile was classified as Cambisols at the reference group level. This profile has cracks that open and close periodically and are 1 cm or more wide; which may qualify to recognize it as Vertic prefix qualifiers. Profile 1 showed a base saturation of 50 percent or more throughout between 20 and 100 cm from the soil surface and 80 percent or more in some layers within 100 cm of the soil surface, and it fulfilled the criteria of Hypereutric suffix qualifiers. According to FAO/WRB, a soil having the following organic carbon contents in the fine earth fraction as a weighted average in Ferralsols and Nitisols, 1.4 percent or more to a depth of 100 cm from the mineral soil surface; in Leptosols, 2 percent or more to a depth of 25 cm from the mineral soil surface; in other soils, 1 percent or more to a depth of 50 cm from the mineral soil surface. So Cambisols (Profile 1) qualify for Humic suffix qualifier. Moreover, the presence of 40 percent or more (by volume) gravel or other coarse fragments averaged over a depth between 50 and 100 cm from the soil surface, indicates endoskeletic suffix qualifiers. As a result, these soils were identified and classified as Vertic Cambisols (Humic, Hypereutric, Endoskeletic) which are mapped as CMvr (hu,he,skn) (CM, cambisols; vr; vertic; hu, Humic; skn, Endoskeletic; he, Hypereutric). The mapping symbols used here and in the other soils discussed in this work are as suggested in FAO/WRB, and will not be discussed any more.

Taking into consideration the characteristics of the soil, Profile 2 was classified as Regosols. As described in FAO/WRB, Regosols form a taxonomic remnant group containing all soils that could not be accommodated in any of the other RSGs. In practice, Regosols are very weakly developed mineral soils in unconsolidated materials that do not have a mollic or umbric horizon, are not very shallow or very rich in gravels (Leptosols), sandy (Arenosols) or with fluvic materials (Fluvisols). Regosols are extensive in eroding lands, particularly in arid and semi-arid areas and in mountainous terrain [26]. Profile 2 of the study area showed a base saturation (by 1 M NH4OAc) of 50 percent or more throughout between 20 and 100 cm from the soil surface and 80 percent or more in some layer within 100 cm of the soil surface, and it fulfilled the criteria of Hypereutric suffix qualifiers. According to the identified morphological and physicochemical properties of the soils, Profile 2 meets the requirement of "Haplic" prefix qualifier. Haplic is a kind of prefix qualifier having a typical expression of certain features and only used if none of the preceding qualifiers applied in the process of classification [26]. Therefore, these soils were identified and classified as Haplic Regosols (Hypereutric) which were mapped as RGha [26] (Figure 4).

Considering the morphological and physicochemical characteristics of soils of the shoulder area, Profile 3 was classified as Leptosols. Leptosols are soils either limited in depth by continuous hard rock within 25 cm from the soil surface; or having mollic horizon with a thickness between 10 and 25 cm directly overlying material with a calcium carbonate equivalent of more than 40 percent; containing more than 10 percent (by weight) fine earth from the soil surface to a depth of 75 cm; and having no diagnostic horizon other than mollic, ocric, umbric or yermic horizon [26]. Therefore, Profile 3 was limited in the depth by lithic and paralithic contact within 25 cm from the soil surface and qualified for classification under Mollic Leptosols reference group, and classified accordingly. Moreover, it had very dark brown color, well aerated, 3.34% OC, massive in structure, and PBS more than 50% (Table 4). Considering these and other soil properties, the surface horizon of these soils met the requirement for Mollic Leptosols soil unit of the FAO/WRB soil classification system. A soil having the following organic carbon contents in the fine earth fraction as a weighted average in Ferralsols and Nitisols, 1.4 percent or more to a depth of 100 cm from the mineral soil surface; in Leptosols, 2 percent or more to a depth of 25 cm from the mineral soil surface; in other soils, 1 percent or more to a depth of 50 cm from the mineral soil surface [26]. So Leptosols (Profile 3) qualify for Humic suffix qualifier. Leptosols having a base saturation of 50 percent or more in a layer, 5 cm or more thick, directly above continuous rock and it can be categorized under Epieutric soil property. Hence, this profile was classified as Mollic Leptosols (Epieutric, Humic) and mapped as LPmo (ee, hu) (Figure 4).

The soil described at the summit area the soils of Profile 4 can be classified as Cambisols according to the FAO/WRB soil classification guideline. According to these set of criteria, sub-surface horizons could be identified as and qualify for a Cambic horizon. Therefore, the profile was classified as Cambisols at the reference group level. The profile has a base saturation of 50% or more throughout the whole profile; which may qualify to recognize it as Hypereutric at the second level of the employed classification procedure. Furthermore, Profile 4 showed a character of humic (hu) suffix qualifier at the third level of classification. Similar to Profile 2, this profile meets the requirement of Haplic prefix qualifier. As a result these soils were identified and classified as Haplic Cambisols, which were mapped as CMha (hu, he) (CM, Cambisols; ha, Haplic he; Hypereutric; hu, Humic) (Figure 4).

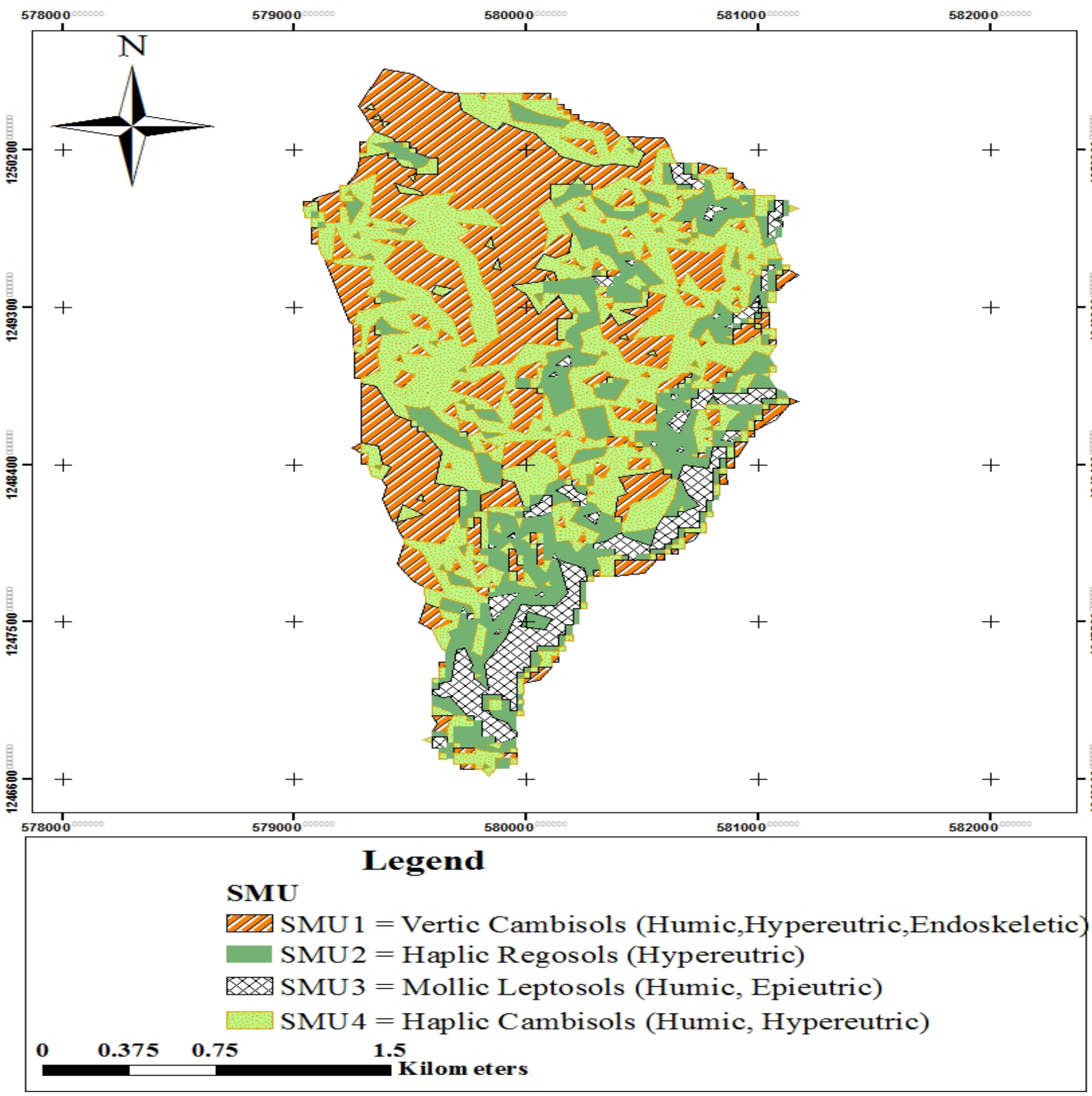

Figure 4. Soil map of the study area

3.4. Simple Linear Correlation Analysis

Simple linear correlation analysis was carried out in order to explore the magnitude and direction of relationships among the soil physicochemical properties along the toposequence of the study area. The results showed that certain attributes of soil showed significant relation with each other, whereas others did not show any significant form of relationships among themselves. Soil reaction (pH) was highly significantly and positively correlated with Na and Ca (r = 0.73**). Similarly pH was also highly significantly and positively correlated with PBS (r= 0.72**). However, pH was highly significantly but negatively correlated with OC. The contents of total N and organic carbon were significantly and positively correlated with each other. This is an indication of the direct dependence of total nitrogen content on the available content of soil organic matter. Therefore, in the management of total nitrogen, it may be imperative to maintain and increase the level of soil organic matter.

Exchangeable Ca was positively and highly significantly correlated with exchangeable Na and K and PBS. Exchangeable Ca was also positively and significantly correlated with CEC indicating their respective major contributions to the CEC of the soil in the study area. FC and PWP were positively and highly significantly correlated with each other (r = 0.98**) and they were negatively and significantly correlated with bulk density of the soil.

4. CONCLUSIONS

~~This indicates a consideration of soil characteristics in the fertility and other management aspects of the soils of the study area. Thus, in introducing new agricultural technologies in mountainous environment like the present study area, the local variations in soils should be considered for a sustainable agricultural development.~~ Based on the results of characterization, the soils were classified as Vertic Cambisols (Humic, Hypereutric, Endoskeletic), Haplic Regosols (Hypereutric), Mollic Leptosols (Humic, Epieutric) and Haplic Cambisols (Humic, Hypereutric). Low level of available P, total N, and exchangeable K could be the major chemical fertility problems in almost all of the soils in the study area. Generally, the differences observed in morphological, physical and chemical properties among soils of the watershed area indicate the presence of different factors that affect the development of the soil in the area. ~~Thus, in mountainous areas like the present study area it is necessary to consider an existence of frequent local variability in soil types within a short distance for successful introduction and adoption of agro-technologies on sustainable basis.~~

COMPETING INTERESTS

Authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between all authors. Author SM designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors KK and MM managed the analyses of the study and managed the literature searches. All authors read and approved the final manuscript.

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