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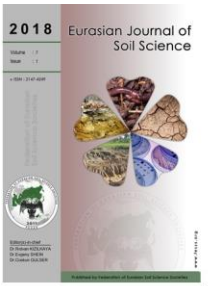

Characterization and classification of soils of Yikalo Subwatershed in Lay Gayint District, Northwestern Highlands of Ethiopia

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Abstract

Soil resource information is vital for sound land use planning and sustainable fertility management. This study was carried out with the objective of characterizing and classifying soils of Yikalo Subwatershed at Lay Gayint district, Northwestern Ethiopia. Representative soil pedons were opened along topographic positions and described on genetic horizon basis in the field for their morphological characteristics and analyzed in the laboratory for selected physical and chemical soil properties. The soils were classified following the FAO (2014). The results revealed the presence of variations in the selected morphological properties within a pedon and along the topographic positions. Soils differed in reaction from 4.57 to 6.42. On the surface horizons of the soil pedons, available P content varied from 0.21 to 3.25 mg kg^{-1}, while exchangeable acidity ranged from 0.17 to 3.65 cmol$_c$ kg^{-1} soil. There was no consistent trend for cation exchange capacity (CEC) and PBS (percent base saturation) with soil depth and topographic positions. The soils in Yikalo Subwatershed were classified as Hyperdystric Cambisols (Humic), Haplic Alisols (Humic), Cambic Umbrisols (Colluvic), Haplic Luvisols (Epidystric), and Pellic Vertisols (Mesotrophic). Optimum rates of organic and inorganic amendments should be applied to reduce the level of soil acidity, and improve the fertility level of the soils for better crop production and productivity.

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Introduction

Soil is slowly renewable dynamic natural resource that determines the ultimate sustainability of any agricultural system. Water movement, water quality, land use, and vegetation productivity all have relationships with soil. Soils provide food, fodder and fuel for meeting the basic human and animal needs (Schoonover and Crim, 2015). However, due to the increasing rate of population demanding food, the nutrients have been depleted and the productive capacity of soils has diminished through changes in soil characteristics. This demands systematic evaluation of soil resources with respect to their extent, distribution, characteristics, and use potential, which is very important for developing an effective land use system for augmenting agricultural production on a sustainable basis (Pulakeshi et al., 2014).

The main task of soil classification is to reflect real diversity of soils to make decisions about adequate or sustainable land use. An in-depth study of the soil characteristics and classification will provide baseline information on the physical, chemical, and mineralogical properties of the soil for precision agriculture, land use planning, and management (Ukut et al., 2014). Classification of soils is also useful to facilitate technology

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transfer and information exchange among soil scientists, decision makers, planners, researchers, and agricultural extension advisors (Assen and Yilma, 2010).

The process of developing a soil map forces one to understand the fundamentals of soils, how they were formed, occur across the landscape or the globe, and how they might respond to use and management. Soil mapping also aims to unravel deficiencies in our understanding of soil properties and processes both in time and space (Hartemink et al., 2012). Hence, the Ethiopian Soil Information System (EthioSIS) led by the Ethiopian government has recently developed soil fertility map for fertilizer recommendations in various regions of the country and, in collaboration with capacity building for scaling up of evidence based best practices in agricultural production in Ethiopia (CASCAPE) project, has published soil maps in selected thirty districts of the country. Major soil types identified in five districts of the Amhara region include Luvisols, Nitisols, Leptosols and Vertisols (Mekonnen, 2015). The existing few soil maps in the country are dominantly smaller scale maps of scattered areas with limited analytical data, which could not help for necessary interpretations and making site-specific land use decisions. Thus, it is imperative to undertake detailed soil survey and mapping for a better understanding of soil resources so that soil patterns and distribution could be predicted and mapped more precisely.

One of the critical constraints hampering agriculture in Ethiopia is unavailability of site-specific information on soil and land characteristics. Adequate information on soil and land characteristics is required for maintaining soil productivity and realization of land use planning. In view of this, soil characterization and classification has been carried out across different parts of Ethiopia (Negassa and Gebrekidan, 2003; Ashenafi et al., 2010; Mulugeta and Sheleme, 2010; Yitbarek et al., 2016) in the western and southern part of Ethiopia. Most of the studies reported depletion of cation exchange capacity (CEC), organic carbon (OC), and total nitrogen (TN) (Ashenafi et al., 2010; Yitbarek et al., 2016). Available soil phosphorus (P) was found to be deficient in most soils of cultivated lands (Mekonnen, 2015; Melese et al., 2015). More recently, variations of soil properties such as TN, organic matter (OM), and CEC with topographic positions and soil depth in some areas of north and south Wollo of the Amhara region have been reported (Nahusenay et al., 2014; Alem et al., 2015). Different soil units such as Acrisols, Cambisols, Fluvisols, Leptosols, Luvisols, Nitisols, Vertisols and Umbrisols with various qualifiers have been identified in the country (Ashenafi et al., 2010; Mulugeta and Sheleme, 2010; Nahusenay et al., 2014; Alem et al., 2015; Yitbarek et al., 2016). However, the studies are limited as compared to the large land mass, landform complexity, and soil variability of the country. This necessitates characterization and classification of soils at a larger scale to produce meaningful soil maps for soil management.

The alarming increase in population in the highlands of Ethiopia is putting persistent pressure on land resources, leading to the removal of soils on slopes and tilling soil without proper soil management practices put in place. This has serious management implications, because the more intensively cultivated upland soils deteriorate rapidly due to erosion and fertility depletion. Investigation of the relationship between landscape and soil properties enhances the effort to improve the fertility and productivity of land. Hence, topography based soil studies play a significant role in the process that dictates the distribution and use of soils on the landscape (Esu et al., 2008). It is widely reported that topography affects soil types and properties at a watershed level (Shimelis et al., 2007; Sheleme, 2011).

Undulating topography and large variations in slope are the characteristic features of Yikalo subwatershed which result in large variations in soil types. The soils have not been characterized and classified for sound land management at Lay Gayint district where agriculture has been widely practiced for thousands of years. Farmers continue to use the land with limited input to improve soil fertility. Moreover, the prevailing land use system and management interventions are not supported with information that shows the potentials and constraints of soil resources. On the other hand, land degradation due to the use of incompatible land management practices has continued unabated. As a consequence, the production and productivity of the smallholder farmers' subsistence farming is declining from time to time. This decline in production and productivity has threatened the food and nutrition security of the community in the study area. Given the population size, which is increasing from time to time at a rate that is not commensurate with the carrying capacity of the land resources in the study area, there is no opportunity for extensification. In order to use the limited land resources more efficiently, site-specific management recommendations based on site-specific information are very much required. Therefore, there is a dire need to characterize soils to pinpoint their constraints and potentials, and classify and map to depict their geographical distribution in the study area. This study was therefore, initiated to characterize the morphological, physical and chemical properties of soils, and classify and map the soils of Yikalo subwatershed.

Material and Methods

Location and topography

The study was conducted at Lay Gayint district of South Gondar Zone of the Amhara National Regional State (ANRS), Ethiopia (Figure 1). The district lies within the geographical grid coordinates of 11°32’-12°16’ N and 38°12’-38°19’ E, and covers an estimated area of 1548 km^2. It is one of the districts of the ANRS where food and nutrition insecurity is a chronic problem for the majority of the rural population. It is located at about 175 km from Bahir Dar, the capital of the ANRS, in the northeast direction, along the Woreta-Woldia highway.

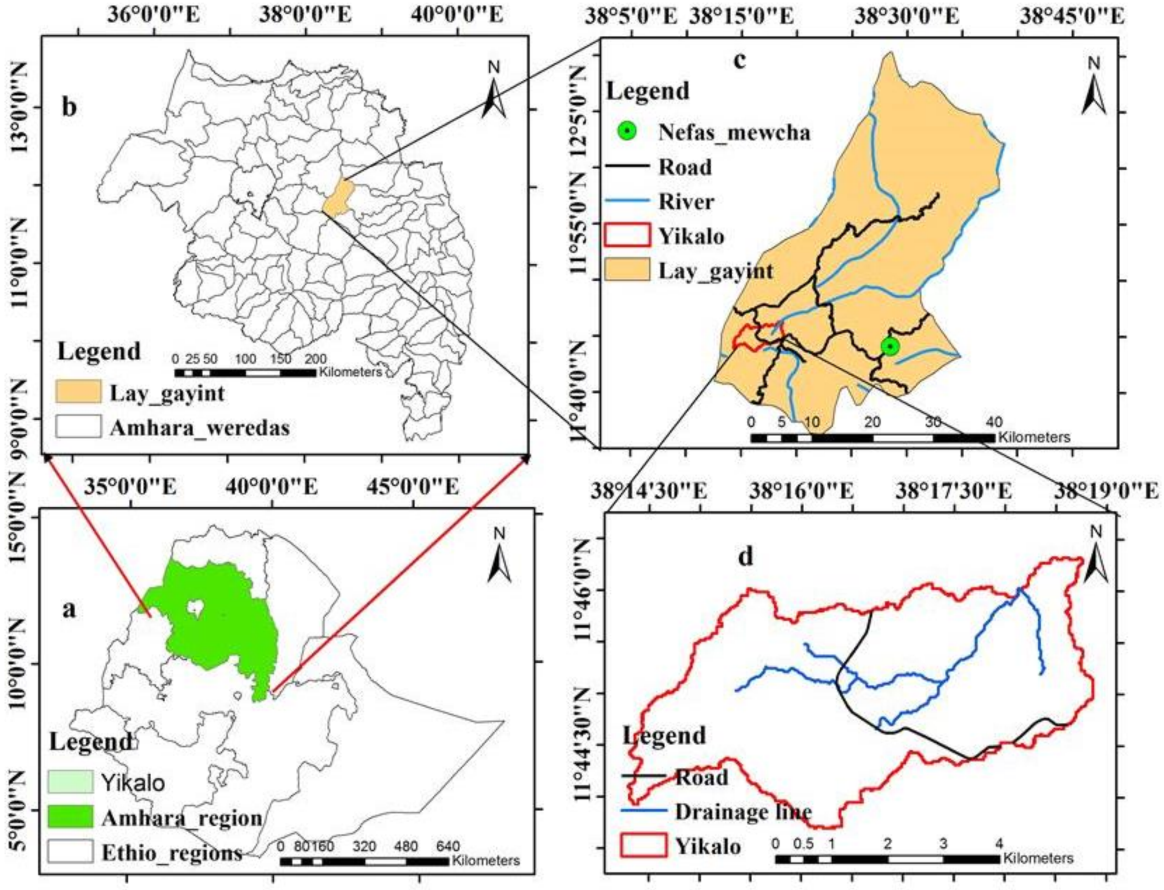

Figure 1. Location map of the study area: (a) ANRS in Ethiopia (b) Lay Gayint district in ANRS (c) Yikalo sub-watershed in Lay Gayint district (d) Drainage lines in Yikalo sub-watershed

The topography of the district is mostly characterized by a chain of mountains, hills, and valleys extending from Tekeze Gorge (1500 m a.s.l.) to the summit of Guna Mountain (4235 m a.s.l.). It is characterized by plain (10%), undulating (70%), mountainous (15%), and gorge and valley (5%) topographic features. The major land use patterns of the study area comprise of cultivated land (44%), grazing land (14%), forest/bush land (5%), water body (2%), infrastructure and settlement (6%), and unproductive land (29%) (Addisu and Menberu, 2015).

Agro-ecology and climate

Agro-ecologically, the district is divided into four elevation and temperature zones, namely: lowland (*kolla*) (12.5%), midland (*woina-dega*) (39.42%), highland (*dega*) (45.39%), and *wurch* (very cold or alpine) (2.71%). Based on a 20 years climate data (1997-2016) obtained from the Ethiopian National Meteorological Service Agency (ENMSA, 2017), Lay Gayint district receives a mean annual rainfall of 1020 mm. The main rainy season, which represents the long rainy season (*meher*) occurs between June and September, while the small rainy season (*belg*) occurs between March and May. The mean minimum and maximum air temperatures of the district are 6.9 and 21.9 ^{0}C, respectively (Figure 2). The coldest month is November, while the warmest month in February. Deforestation, overgrazing, poor quality soil, lack of compatible soil and water conservation measures, and erratic rainfall have contributed to the prevalence of drought in the district.

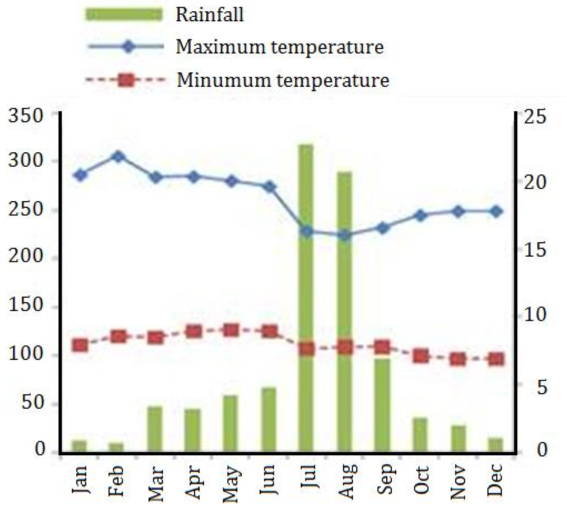

Figure 2. Mean monthly rainfall and mean monthly maximum and minimum temperatures (1997-2016) of Lay Gayint district

Geology and soils

Yikalo subcatchment is part of the Guna volcanic massif, which is one of the huge volcanic centers in the northwestern Ethiopian plateau. It is found between Seimen and Choke Miocene- Pliocene shield volcanoes, east of Lake Tana. The stratigraphy of Guna includes trap basalt, rhyolite lava flow, and pyroclastic flow deposits erupted during Cenozoic Tertiary period in the Pliocene (Adise, 2006). Based on the general soil survey of FAO (1981), the soils in Lay Gayint district include Cambisols, Luvisols, Leptosols and Regosols.

Land use/ farming system and vegetation cover

Most of the people in the district are engaged in mixed crop-livestock agriculture. Crop production is entirely rain-fed, except in some very specific and small areas where vegetables are grown using traditional small-scale irrigation. The most commonly produced crops in the study area are annual crops such as *Triticum aestivum* L., *Eragrostis tef* (Zuccagni), *Zea mays* L., *Sorghum bicolor* L., *Hordeum vulgare* L., *Cicer arietinum* L., *Vicia faba* L., *Phaseolus vulgaris* L., and *Solanum tuberosum* L. The natural vegetation in the study area consists of some tree species that are remnants of a once dense evergreen forest occurring on slopes and sparse grass complex in various spots. *Juniperus procera, Olea africana and Hajenia abyssinica* are the dominant species.

Traditionally, farmers around the study area maintain the fertility status of the soil through applications of compost, farmyard manure (FYM) and crop rotation practices. They also add inorganic fertilizers such as urea, diammonium phosphate (DAP), and blended fertilizers have been introduced recently. Soil and water conservation activities, though inadequate in quality and area coverage, soil bund, stone bund, checkdams, and hillside terraces could be mentioned. The agricultural activity in the area is not productive enough because of the recurrent natural calamities. Natural resources are deteriorating and soil erosion is marked by the presence of expanding gullies. Rapid population growth has resulted in shrinking the farmland sizes and grazing lands. Land degradation, moisture shortage, ground and surface water depletion, increasing infertility of soil and natural hazards like drought, landslide, incidence of crop pests and weed and livestock diseases, coupled with cultural and attitudinal factors are among the major problems in the study area. All these, in turn, have made the district one of the food and nutrition insecure areas of the ANRS.

Soil survey

Before the start of the study, physical observation with the help of 1:50000 topographic maps, obtained from the Ethiopian Mapping Agency, were conducted and general soil site information was recorded. The boundaries of the watershed were determined from the 30 m-resolution digital elevation model (DEM), and the soil mapping units were determined based on slope positions, and after taking 115 auger pit observation points (Figure 3). Accordingly, four mapping units namely: Upper-slope, Middle-slope, Lower-slope, and Toe-slope were identified along the landscape (Figure 3). The free survey method described by Dent and Young (1981) was followed. The depth of auger points was 0-20 and 20-40 cm. The hand held GPS (global positioning system) was used to record location of the pits, augers, and the boundaries of the different mapping units.

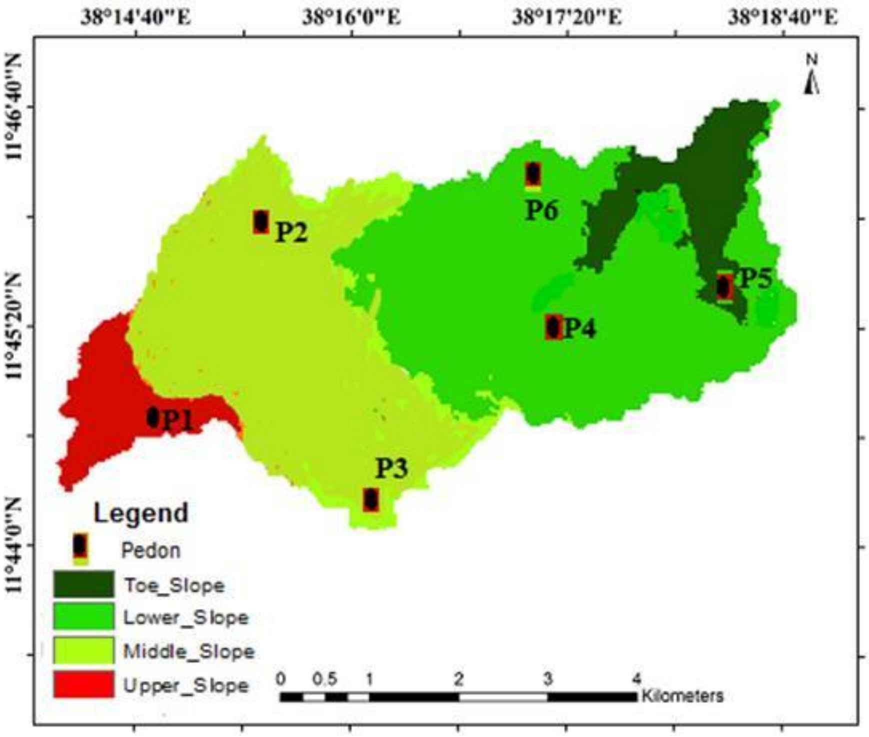

Figure 3. Slope positions and pedon points in Yikalo subwatershed

Soil pedon description, sampling, and sample preparation

The middle and lower slope positions, each consisted of two representative pedons. The upper and toe slope positions, each had one representative pedon. These representative soil pedons were opened and described *in situ* (Tables 1and 2). For each identified mapping unit, 1 m width x 2 m length x 2 m depth pit was opened for soil morphological examination and soil sample collection for laboratory analysis. After cleaning away loose debris from pit face, color, texture, consistence, structure, plant rooting patterns, and other soil features were examined to determine which horizons are present and at what depth their boundaries occur. A soil description was then done using a standard format developed following the Guidelines for Soil Description (FAO, 2006). Both disturbed and undisturbed soil samples were collected from each genetic horizon. Soil color was determined using the Revised Munsell Soil Color Chart (Munsell Soil Color Chart, 1994). Soil structure was described in terms of the sequence: grade, size, and type (shape) of aggregates whereas horizon boundaries were described in terms of depth, distinctness, and topography. The soil consistence was identified at dry, moist and wet moisture conditions. Core samples were collected at different points across each horizon for determination of bulk density. A cylindrical metal core with volume of 100 cm^3 was pressed in to the soil until it is completely filled. The soil was trimmed at both ends with a knife and covered with a cap, labeled and packed in box. The soil samples collected from the study area were bagged, labeled and transported to the laboratory for preparation and analysis of selected soil properties following standard laboratory procedures. In preparation for laboratory analysis, the soil samples were air dried, crushed, and made to pass through a 2 mm sieve size for the analysis of soil pH, texture, available P, exchangeable bases, exchangeable acidity, and CEC, whereas, for analysis of OC and total N, samples were made to pass through 0.5 mm sieve size.

Laboratory analysis of soil physical and chemical properties

Soil texture was determined using the Bouyoucos hydrometer method (Day, 1965). Bulk density (BD) was determined from the weight of undisturbed (core) soil samples, which were first weighed at field moisture content and then dried in an oven at 105 ^{o}C to constant weight (Baruah and Barthakur, 1997). The bulk density was calculated from the mass of oven dry soil and the volume of the core. The average soil particle density (PD) (2.65 g cm^{-3}) was used for estimating total porosity. The moisture content at field capacity (FC) and permanent wilting point (PWP) was measured at the soil water potentials of -1/3 and -15 bars, respectively, using the pressure plate apparatus technique (Richards, 1965). The results were converted into volume percent (Vol %) by multiplying the gravimetric water content with the ratio of soil bulk density to the density of water. The available water content (AWC) was obtained by subtracting water content at PWP from FC and finally converted to mm/ m of soil depth by multiplying it by 1000.

The pH of the soil was measured potentiometrically in the supernatant suspension of a 1:2.5 soil to water ratio using a pH meter as described by Chopra and Kanwar (1976). Organic carbon was determined using the wet oxidation method (Walkley and Black, 1934) whereby the carbon was oxidized under standard conditions with potassium dichromate in sulfuric acid solution. Total N was determined by the micro-Kjeldahl method (Jackson, 1967) while available P was extracted using the sodium bicarbonate solution following the procedure described by Olsen et al. (1954). The exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, and Na^+) in the soil were extracted with 1 M ammonium acetate (NH_4OAc) solution at pH 7.0 (Jackson, 1967). Exchangeable Ca^{2+} and Mg^{2+} in the leachate were determined by atomic absorption spectrophotometer, while exchangeable K^+ and Na^+ were determined by flame photometry (Rowell, 1994). The potential cation exchange capacity (CEC) of the soil was determined from the NH_4^+ saturated samples that were subsequently replaced by K^+ using KCl solution. The excess salt was removed by washing with ethanol and the ammonium that was displaced by K^+ was measured using the micro-Kjeldahl procedure (Chapman, 1965) and reported as CEC. Total exchangeable acidity was determined by saturating the soil samples with 1 M KCl solution and was titrated with 0.02 M NaOH as described by Rowell (1994). From the same extract, exchangeable Al^{3+} in the soil samples was determined by application of 1 M NaF, which forms a complex with Al^{3+} and releases NaOH and then NaOH was back titrated with a standard solution of 0.02 M HCl (Sahlemedhin and Taye, 2000). Cation exchange capacity due to the clay fraction (CEC_{clay}) was estimated by subtracting the value of CEC associated with the percent of OM from the value of soil (CEC_{soil}) assuming OC has a cation exchange capacity of 200 $cmol_c\ kg^{-1}$ (Yerima, 1993) as:

$$CEC_{clay} = [CEC_{soil} - (OM \times 200)] / \%clay$$

Soil classification and mapping

Based on the morphological characteristics and the laboratory analysis, the soils of the study area were classified based on FAO (2014). The geographic coordinates of each soil observation and the boundaries of each mapping unit were recorded in the field using GPS. Later, soil map was prepared by employing Arc GIS 10 (Geographic Information System). The auger points and identified map units coordinates were recorded in excel spread sheet, and later displayed in Arc map. Based on soil-landscape relations, soil depth and texture, soil boundaries were identified in each topographic positions, and the coordinates were recorded with GPS. The respective map units were later polygonized and their area was determined. Each polygon was labeled with the classified taxononomic soil unit.

Results and Discussion

Morphological properties

Soil color

The soil color (moist) in the surface layers varied from very dark (2.5 YR 2/1) in Pedon 1 to dull reddish brown (2.5 YR 4/3) in Pedon 2. Similarly, the subsurface color (moist) changed from grayish red (2.5 YR 3/1) in Pedon 2 to brown (7.5 YR 3/4) in Pedon 4. The variation in color change among the pedons and within a pedon could be attributed to difference in OM content, parent material, and drainage conditions (Ashenafi et al., 2010; Buol et al., 2011; Nahusenay et al., 2014; Alem et al., 2015).

Table 1. Selected site characteristics of representative soil pedons

Pedon	Location (UTM)		Altitude (m)	Slope (%)	Slope position	Drainage class	Erosion / deposition	Parent material	Land use
	Latitude	Longitude							
1	1298509	418572	3596	45	Upper slope	Well drained	Sheet and rill erosion	Eluvium of basalt	Annual field cropping/barely/
2	1298954	419888	3318	20	Middle slope	Well drained	Sheet	Eluvium of basalt	Annual field cropping/wheat/
3	1300063	420744	3268	12	Middle slope	Well drained	Sheet	Eluvium of basalt	Natural forest
4	1299895	422253	3174	8	Lower slope	Moderately drained	Deposition	Colluvium from Basalt fragments	Grazing
5	1300117	421692	3173	2	Toe slope	Weakly drained	Deposition	Colluvium from Basalt fragments	Annual field cropping/potato/
6	1298413	421195	3227	6	Lower slope	Weakly drained	Deposition	Colluvium from Basalt fragments	Annual field cropping/potato/

Table 2. Selected morphological characteristics of soil pedons

Depth (cm)	Horizon	Color		Structure grade /size/ type/	Consistence Dry/moist/wet			Root abundance /size	Boundary distinct/ topography/
		Dry	Moist		Dry	Moist	Wet		
Pedon 1 (Upper slope)									
0-20	A	2.5 YR 2/2	2.5 YR 2/1	WE,FI,GR	SHA	FR	SST, SPL	C, F	A, S
20-60	B	2.5 YR 3/2	2.5 YR 2/1	MO, ME, SB	HA	FR	SST, NPL	F,VF	C, S
Pedon 2 (Middle slope)									
0-20	Ap	2.5 YR5/3	2.5 YR4/3	WE, FM, GR	SHA	FR	SST, SPL	F, VF	A, S
20-100	Bt$_1$	2.5YR 4/2	2.5YR 3/1	WE, ME, SB	SHA,	FR	SST, SPL	V, VF	C, W
100-125	Bt$_2$	2.5YR 5/2	2.5YR 3/1	MO, ME, SB	HA	FI	SST, SPL	V, VF	C, B
125-190+	C	2.5YR 5/2	2.5YR 4/3	ST, MC, SB	VA	FI	SST, SPL	N	------
Pedon 3 (Middle slope)									
0-20	A	7.5YR 4/3	7.5YR 3/2	WE, FI, GR	SHA	FR	SST, SPL	C, C	G, W
20-105	Bt$_1$	7.5YR 4/4	7.5YR 3/4	MO, FM, GR	SHA	FR	ST, NPL	F, M	C, S
105-135	Bt$_2$	7.5YR 4/3	7.5YR 4/3	MO, FM, AB	HA	FI	ST, SP	F, F	G, B
135-210+	C	7.5YR 4/3	7.5YR 3/3	ST, ME, SB	HA	FI	SST, NPL	V, VF	------
Pedon 4 (Lower slope)									
0-20	Ap	7.5YR 2/3	7.5YR 3/2	WE, FI, GR	SHA	FR	SST, SPL	C, C	G, W
20-95	Bt$_1$	7.5YR 4/4	7.5YR 3/4	MO, FM, GR	SHA	FR	ST, NPL	F, M	C, S
95-180	Bt$_2$	7.5YR 4/3	7.5YR 4/3	MO, FM, AB	HA	FI	ST, SP	F, F	G, B
180-225+	C	7.5YR 4/3	7.5YR 3/3	ST, ME, SB	VHA	FI	SST, NPL	V, VF	------
Pedon 5 (Toe slope)									
0-20	A	2.5YR 5/4	2.5YR 4/3	WE, FI, GR	SHA	FR	SST, PL	C, F	D, S
20-50	B	2.5 YR 5/3	2.5 YR4/2	WM, ME, AB	HA	FI	ST, VPL	F, F	C, S
50-110	C	2.5YR 5/1	2.5YR 4/1	MO, ME, AB	VHA	FI	ST, VPL	N	------
Pedon 6 (Lower slope)									
0-20	A	10YR 3/2	10YR 3/2	WE, FI, GR	SHA	FR	SST, SPL	C, F	G, W
20-45	B	10 YR 4/2	10YR 3/1	WM, ME, AB	HA	FI	ST, PL	F, VF	G, W
45-95	BC	7.5 YR 3/1	7.5 YR3/1	MO, ME, AS	VHA	FI	ST, PL	F, VF	D, W
95-165+	C	7.5 YR 4/1	7.5 YR4/1	ST, ME, AS	VHA	VFI	VST, VPL	N	------

Notes: Structure: WE = weak, MO = moderate, ST= strong, WM = weak to moderate, FI = fine, FM=fine medium, ME = medium, MC=medium and coarse, AB = angular blocky, AS = angular and sub-angular blocky, SB = sub-angular blocky, GR = granular, Horizon Boundary: A = abrupt, C = clear, D=diffuse, G = gradual S = smooth, W = wavy, B = broken. Consistence: SHA = slightly hard, HA = hard, VHA = very hard, FR = friable, VFR = very friable, FI = firm, SST = slightly sticky, ST = sticky, VST = very sticky, NPL = non-plastic, SPL = slightly plastic, PL = plastic, VPL = very plastic. Root abundance: C=common, F=few, V=very few, N=none. Root size: C=coarse, M=medium, F=fine, VF=very fine (FAO, 2006).

Soil structure and consistence

The structure of all pedons in the surface soils were weak, fine, granular, gradually changing in the subsurface from weak to moderate, medium angular blocky in Pedon 4 to strong, medium, angular and sub-angular blocky in Pedon 6. Similar results were reported by (Yitbarek et al., 2016; Kebede et al., 2017) who found granular soil structure in the surface horizons that changed to angular and sub-angular structure in the subsurface pedons. The presence of OM in the surface soil might be attributed to the formation of granular type of soil. Pressure faces on soil matrix due to micro-swelling, the low level of OM, reduction in abundance of plant roots and higher clay in subsurface may be mentioned for the formation of blocky structure. The dry consistence varied from slightly hard to very hard, whereas the moist consistence varied from friable to firm. On the other hand, the wet consistence ranged from slightly sticky/slightly plastic in the surface layers to very sticky/very plastic in the subsurface soil layers (Table 2). The very friable and friable consistence observed in the surface soils of the pedons could be attributed to the higher OM content (Table 4). In consent with this finding, the contribution of OM in modifying soil consistence was pointed out by Mulugeta and Sheleme (2010). Ashenafi et al. (2010) also reported that the friable consistence of the soils show workability of the soils at appropriate moisture content. In contrast, the sticky, very sticky, plastic and very plastic consistencies show the presence of high clay content, and difficulty to till (Abay et al., 2015). The presence of very sticky and very plastic consistence could be indicative of presence of smectitic clays in the soils (Ashenafi et al., 2010).

Soil depth and horizon boundaries

Based on soil depth class described by USDA (2010), all the pedons are very deep (> 150 cm) except Pedon 1, which was moderately deep (50-100 cm) and limited by massive basalt. For any given soil, the greater the rooting depth, the larger will be the quantity of soil water available to the crop. This is particularly important for annual crops as they have less time to develop deep and extensive rooting systems than perennial crops (FAO, 2003). The lower boundaries of surface horizons in Pedons 1 and 2 were abrupt and smooth that changed into clear and smooth, and clear and wavy, respectively in the subsurface horizons. This could be due to repeated anthropogenic influence like plowing the land for crop production (Alem et al., 2015). Pedons 3 and 4 had gradual and wavy lower boundaries of surface horizons grading to clear and smooth in the subsurface horizons as these lands are under forest and grazing land uses, where there is no soil mixing by plowing, gradual transformation, homogenization, or erosional/depositional processes (Ande, 2010).

Soil physical properties

Soil particle size distribution

The particle size distribution in most of the studied pedons did not show any consistent trend with both depth and topographic position (Table 3). However, the clay content observed in the B horizons of all the pedons was higher than the clay content of the surface horizons. Lack of definite trend in soil separates along the topographic position might be due to the dominance of erosion and accumulation in influencing the pedogenic processes (Alem et al., 2015), whereas irregular trend with depth, might be due to variation in weathering of parent material (Sekhar et al., 2014). The general increase in clay content with depth might be attributed to the vertical translocation of clay through the processes of lessivage and illuviation. Higher clay content in the B horizon of soils as a result of illuviation, predominant *in situ* pedogenetic formation of clay in the subsoil, and destruction of clay in the surface horizon, have been reported (Chukwu, 2013; Yitbarek et al., 2016; Kebede et al., 2017).

Table 3. Selected physical characteristics of soil pedons

Depth (cm)	Horizon	Particle size analysis (%)			Textural class	Si/C	BD (g cm^{-3})	Porosity (%)	FC (%V/V)	PWP (%V/V)	AWC (mm m^{-1})
		sand	silt	clay							
					Pedon 1 (Upper slope)						
0-20	A	28.7	48.6	22.7	Silt loam	2.1	0.92	65	28.5	20.2	83
20-60	B	32.7	44.6	22.7	Silt loam	2.0	1.16	56	38.3	30.2	81
					Pedon 2 (Middle slope)						
0-20	Ap	16.7	36.6	46.7	Clay	0.8	1.07	60	40.7	34.2	65
20-100	Bt$_1$	0.7	36.6	62.7	Clay	0.6	1.44	45	59.0	48.9	101
100-125	Bt$_2$	26.7	28.6	44.7	Clay	0.6	1.47	45	48.5	38.2	103
125-190+	C	12.7	24.6	62.7	Clay	0.8	1.49	44	58.1	46.2	119
					Pedon 3 (Middle slope)						
0-20	A	36.7	32.6	30.7	Clayloam	0.4	1.07	60	32.1	21.4	107
20-105	Bt$_1$	18.7	28.6	52.7	Clay	1.1	1.33	50	37.2	27.9	93
105-135	Bt$_2$	16.7	14.6	68.7	Clay	0.5	1.45	45	52.2	40.6	116
135-210+	C	14.7	22.6	62.7	Clay	0.2	1.59	40	49.3	38.2	111
					Pedon 4 (Lowerslope)						
0-20	Ap	28.7	30.6	40.7	Clay	0.4	0.89	66	34.7	19.6	151
20-95	Bt$_1$	16.7	24.6	58.7	Clay	0.8	1.14	57	49.0	43.3	57
95-180	Bt$_2$	16.7	20.6	62.7	Clay	0.4	1.42	46	64.8	53.3	115
180-225+	C	32.7	18.6	48.7	Clay	0.3	1.44	46	46.9	42.6	43
					Pedon 5 (Toe slope)						
0-20	A	28.7	22.6	48.7	Clay	0.4	1.25	53	46.3	40.0	63
20-50	B	22.7	10.6	66.7	Clay	0.5	1.43	46	58.6	48.6	100
50-110+	C	38.7	12.6	48.7	Clay	0.2	1.45	45	52.2	42.1	101
					Pedon 6 (Lower slope)						
0-20	A	14.7	16.6	68.7	Clay	0.3	1.17	56	39.8	25.8	140
20-45	B	14.7	14.6	70.7	Clay	0.2	1.43	46	55.8	45.8	100
45-95	BC	10.7	12.6	76.7	Clay	0.2	1.43	46	58.6	52.9	57
95-165+	C	10.7	8.6	80.7	Clay	0.2	1.50	43	67.5	58.5	90

Bulk density and porosity

The bulk density varied from 0.89 to 1.25 g cm^{-3} on the surface, and from 1.14 to 1.59 g cm^{-3} in the subsurface horizons of the soil pedons (Table 3). The relatively lower bulk density values (< 1 g cm^{-3}) in the surface horizons of Pedons 1 and 4 could be related to the structural aggregation of the soils as a result of relatively high OM content. The bulk density in soils, irrespective of landforms, increased with depth which might be due to weight of the overlying soil and the relatively low amount of OM in the subsurface soil layers. Similarly, Chaudhari et al. (2013) reported increase in bulk density with pedon depth, due to changes in OM content, porosity, and compaction. The critical value of bulk density for plant growth at which root penetration is likely to be severely restricted is 1.4 g cm^{-3} for clay soils (Hazelton and Murphy, 2007). Following this critical value, the bulk density values of the surface horizons in the crop lands were in the favorable range. In contrast, the total porosity decreased along the horizons of all soil profiles in the watershed (Table 3). However, it did not show clear trend with topographic positions. Total porosity ranged from 53% in Profile 5 to 66% in Profile 4 of the surface soil horizons. On the other hand, it varied from 40% in Profile 3 to 57% in Profile 4 of the subsurface soil horizons (Table 3). According to Brady and Weil (2008), the ideal porosity value for healthy root growth is > 50%. Thus, porosity values of the recognized pedons in the surface layers are in the acceptable range for crop production.

Soil water retention characteristics

Except in Pedons 1 and 6 where it increased with soil depth, water retention at FC and PWP did not show any consistent pattern with soil depth (Table 3). Also, the retention at both points did not vary consistently along the topographic positions albeit relatively higher values for each were recorded in the toe slope position where the clay content is also high at the surface layer. Available water content varied from 63 mm m^{-1} in Pedon 5 to 151 mm m^{-1} in Pedon 4 of the surface soil horizons, and from 43 mm m^{-1} in Pedon 4 to 119 mm m^{-1} in Pedon 2 of the subsurface soil horizons. In soil Pedons 2 and 5, AWC increased with depth. Various reports (Gill et al., 2012; Nagaraju and Gajbhiye, 2014) indicated the positive relationship between clay content and the amount of water retained at -33 and -1500 kPa. The high amount of water at both FC and PWP in some of the soils with high clay content, thus resulting in small AWC might be due to the water is held so tightly in the micropores that the plants cannot access it (Easton and Bock, 2016).

Soil chemical properties

Soil pH and exchangeable acidity

The pH (H_2O) values increased along soil depth in Pedons 1, 2, 3 and 6 (Table 4). In Pedons 4 and 5, there was no regular variation of soil pH with soil depth except slight decrease at the bottom layers. Similarly, the pH of the surface layer soils did not show any systemic variation along the topographic positions although relatively higher values were recorded in soils of Pedons 3 and 6. Following the pH rating suggested by Hazelton and Murphy (2007), the pH of the soils was within the range of very strongly acid in Pedon 4 of the surface layer (4.5-5.0) to slightly acid (6.1-6.5) in the bottom layer of Pedon 6. The increased pH values with soil depth might be due to less H^+ ions released from low OM decomposition, which is caused by decreased OM content with depth (Abay and Sheleme, 2012). Furthermore, the increase with soil depth might be related to the increase in some of the basic cations with soil depth. The low pH in most of the pedons could be due to the high rainfall in the study area that activates leaching and continuous removal of bases from the soil surface. Several researchers in different parts of Ethiopia reported various values of pH for acid soils (Mulugeta and Sheleme, 2010; Abreha et al., 2013; Melese et al., 2015). The exchangeable acidity decreased with depth in all the pedons except in the bottom layers of Pedons 2 and 5. The values of exchangeable acidity decreased with increased pH in the soil pedons studied regardless of the landform in the watershed. Baquy et al. (2017) suggested that the critical level of exchangeable Al^{3+} concentration ranged from 0.56-1.72 cmol$_c$ kg^{-1} depending on the type of crops and soils. The exchangeable Al^{3+} values of the surface horizons of cultivated lands (Pedons 1 and 4) are within this range to influence crop growth adversely.

Organic carbon, total N, and C:N ratio

Topographic position, and elevation of the soils affected the spatial variability of OC and TN. Considering the depth of the pedon, OC and TN showed a decreasing pattern (Table 4). Relatively higher values were recorded in the upper slope positions of the surface horizons of all the soil pedons. The OC of the surface layer soils ranged from 0.90% in the lower slope position (Pedon 6) to 5.60% in the freshly cultivated Pedon 1 of the upper slope position (Table 4). As per the rating criteria set by Tekalign (1991), the OC contents of surface soil horizons in Yikalo subwatershed were in the range of high (> 3.3%) to low (0.5-1.5%) category.

Table 4. Selected chemical characteristics of soil pedons

Depth (cm)	Horizon	pH (H_2O)	TN (%)	OC (%)	Av.P (mg kg^{-1})	C/N	Exchangeable bases and CEC $cmol_c\ kg^{-1}$ soil					CEC/Clay $cmol_c\ kg^{-1}$	BS (%)	Ex Acidity $cmol_c\ kg^{-1}$	Ex Al $cmol_c\ kg^{-1}$
							Ca	Mg	K	Na	CEC				
Pedon 1 (Upper slope)															
0-20	A	5.24	0.34	5.60	0.77	16.54	6.68	3.38	0.05	-	53.44	150.20	19	1.60	0.69
20-60	B	5.43	0.25	3.56	0.77	14.21	6.93	4.14	0.05	-	46.57	151.00	24	1.57	0.67
Pedon 2 (Middle slope)															
0-20	Ap	5.3	0.29	2.93	3.25	10.25	12.17	7.95	0.07	-	38.26	60.25	53	0.58	0.26
20-100	Bt_1	5.48	0.25	2.77	0.75	10.86	13.52	0.51	0.09	-	42.48	52.52	33	0.45	0.21
100-125	Bt_2	5.89	0.10	1.03	0.30	9.87	14.54	1.10	0.21	-	29.06	57.01	55	0.23	-
125-190+	C	6.02	0.06	0.13	1.65	2.27	17.50	7.78	0.07	-	30.32	47.64	84	0.33	-
Pedon 3 (Middle slope)															
0-20	A	5.46	0.26	2.09	0.66	7.98	9.21	10.90	0.12	-	37.79	99.56	54	0.46	0.25
20-105	Bt_1	5.81	0.17	1.19	5.33	7.00	9.72	6.93	0.26	-	34.75	58.17	48	0.23	-
105-135	Bt_2	5.82	0.06	0.05	19.47	0.86	10.90	3.47	0.12	-	35.35	51.17	41	0.18	-
135-210+	C	6.00	0.05	0.30	15.99	5.65	19.44	0.59	0.05	-	38.78	60.15	52	0.10	-
Pedon 4 (Lower slope)															
0-20	Ap	4.57	0.33	3.51	2.20	9.98	7.78	7.52	0.09	-	42.54	74.73	36	3.65	1.93
20-95	Bt_1	5.13	0.21	1.53	0.96	7.28	12.26	3.72	0.12	-	40.98	60.82	39	2.90	1.16
95-180	Bt_2	6.24	0.09	0.54	1.97	6.09	14.71	7.52	0.14	-	51.27	78.79	44	0.27	-
180-225+	C	5.98	0.03	0.01	0.96	0.33	17.08	9.89	0.12	-	44.77	91.83	60	0.07	-
Pedon 5 (Toe slope)															
0-20	A	5.18	0.15	1.51	2.70	10.26	13.19	9.38	0.12	-	36.02	63.26	63	0.17	-
20-50	B	6.13	0.06	0.57	3.62	9.71	15.38	3.47	0.07	-	42.82	61.25	44	0.08	-
50-110+	C	6.08	0.01	0.01	1.13	0.84	15.55	7.69	0.09	-	37.32	76.52	63	0.11	-
Pedon 6 (Lower slope)															
0-20	A	5.40	0.14	0.90	0.21	6.58	18.51	9.55	0.16	-	51.40	70.30	55	0.57	0.25
20-45	B	5.57	0.06	0.43	2.08	6.74	20.46	10.31	0.09	-	54.14	74.44	57	0.19	-
45-95	BC	5.86	0.05	0.08	4.49	1.65	24.85	9.13	0.05	-	52.80	68.46	65	0.06	-
95-165+	C	6.42	0.04	0.03	0.98	0.67	29.42	7.19	0.12	-	54.10	66.91	68	0.05	-

The high level of OC in the surface horizon of Pedon 4 could be due to biomass turnover of grass on the grazing land. The studied soils were located in an elevation of above 3000 m that might favor lower rate of decomposition and a relatively higher accumulation of OC in the upper slope positions. Abayneh et al. (2006) marked that soils located at elevations higher than 1850 m, the relatively lower temperatures may facilitate the organic C accumulation. However, the observed low OC content in some of the pedons could be ascribed to the complete removal of crop residues, and reduced input of organic amendments such as FYM and compost to these cultivated lands. Moreover, repeated tillage of the land might favor the mineralization of OC in the lower and toe slope positions. In line with this, variable distribution in OC content of soils in different areas of the country was reported by different researchers (Ashenafi et al., 2010; Daniel and Tefera, 2016).

Total N varied from 0.34% in the upper slope to 0.14% in the foot slope position of the surface horizons. The TN content of the surface horizons was higher as compared to the subsurface soil horizons and it followed similar pattern with that of OC in all the studied pedons implying that there is a strong relation between OC with TN in the soil system. In agreement with this result, Meysner et al. (2006) indicated that as much as 93 to 97% of the total N in soils is closely associated with OC. Based on the rating of total N set by Tekalign (1991), the total N contents of the surface layers of Pedons 1, 2, 3, and 4 were rated as high (> 0.25%), while it was medium (0.12 and 0.25%) in Pedons 5 and 6. The high total N content in the surface layers indicates that the soils of the study area have the potential in N to support proper growth and development of crops. The medium total N content in Pedons 5 and 6 might be due to weakly drained condition, which slows down mineralization. However, the site must be fertilized with external N inputs for sustainable production as N is dynamic and prone to leaching and volatilization loses. Similar to the current finding, high total N was found in Arsi highlands (Assen and Yilma, 2010) whereas, low to medium in total N was reported in Delbo Wegene watershed, Wolaita zone (Ashenafi et al. 2010).

The carbon-to-nitrogen ratio (C:N) demonstrates a systematic variation with depth for some of the studied pedons (Pedons 1, 4, and 5), suggesting the existence of similar conditions of mineralization in the recognized horizons. The high C: N ratio (16.54) was observed for the surface horizon of Pedon 1, which has low temperature at the highest elevation. The C: N ratio for Pedon 1 was higher than the ideal 10, indicating the slower decomposition rate of OM and organic N by the soil microbial activity (Ge et al., 2013). In general, a C: N ratio of about 10:1 suggests relatively better decomposition rate, serving as index of improved N availability to plants and possibilities to incorporate crop residues to the soil without having any adverse effect of nitrogen immobilization (Assen and Yilma, 2010).

Available P

Available P contents did not show consistency across the slope positions and soil depth (Table 4). Available P contents varied from 0.77 mg kg^{-1} in the surface horizons of Pedon 1 in the upper slope to 19.47 mg kg^{-1} in the subsurface horizon of the middle slope positions. Based on the rating of available P suggested by Jones (2003), the available P content of the soils in the surface horizons of all the pedons was in the range of low (6-10 mg kg^{-1}) to very low (1-5 mg kg^{-1}) rating. Phosphorus deficiency in Ethiopian soils is well documented in various research works (Melese et al., 2015; Daniel and Tefera, 2016; Kebede et al., 2017). On top of the inherent low occurrence of P, its availability is limited by strongly acid characteristics of the soils in the study environment.

Cation exchange capacity and exchangeable bases

The CEC of the soils in all the pedons did not show any regular pattern with either soil depth or topographic positions (Table 4). On the other hand, it somehow followed the trend of the clay content particularly in the soils of the lower and toe slopes. The higher values of CEC in the upper slope could be attributed to the recent land use change from virgin to cultivation that implied better OC content and less nutrient depletion through crop removal, whereas that in Pedon 6 of the lower slope position might be due to the deposition of various cation-rich materials. According to Landon (1991), the CEC of the soils in the watershed qualifies for the high and very high signifying that the soils have better nutrient reserve.

The principal cations occupying the exchange site were in the order of $Ca^{2+}>Mg^{2+}>K^{+}>Na^{+}$. The concentration of Ca increased consistently with depth of the soil pedons. The highest value (29.42 cmol$_c$ kg^{-1}) was recorded in the bottom layer of Pedon 6 and the lowest (6.68 cmol $_c$ kg^{-1}) was in Pedon 1. Considering the effect of topographic positions, the content of Ca^{2+} increased from the upper slope to the toe slope except Pedon 3 of the middle slope and Pedon 4 of the foot slope positions. The consistent accumulation of Ca^{2+} with depth could be ascribed to the leaching by high amount of rainfall in the area. Supporting to this finding, other authors (Ashenafi, et al., 2010; Nahusenay et al., 2014) indicated that accumulation of exchangeable Ca^{2+} with depth could be due to leaching from the overlying horizons. The trend of Ca^{2+} on the surface horizons across the landscape may be due to the lateral movement of the ion from the upper slope to the toe slope (Lawal et al., 2013). According to Hazelton and Murphy (2007) rating of exchangeable Ca^{2+}, the soils were in the medium to very high range. Exchangeable Mg contents varied from 3.38 cmol $_c$ kg^{-1} in Pedon 1 to 10.9 cmol $_c$ kg^{-1} in Pedon 3 of the surface horizons and 0.5 cmol $_c$ kg^{-1} in Pedon 2 to 10.3 cmol $_c$ kg^{-1} of Pedon 6. Higher Mg^{2+} content was observed in the middle slope of Pedon 3 and the lower slope of Pedon 6. Generally, the Mg content was rated as low to very high in the exchange site of the soil pedons (Hazelton and Murphy, 2007). Exchangeable K^+ varied from low to very low in all the pedons and was not consistent with depth. Though soils were rich in CEC, they were deficient in K^+, which is one of the major elements limiting crop production in the area. The exchangeable K^+ content was below the critical level of 0.38 cmol $_c$ kg^{-1} (Landon, 1991). The result was in agreement with the findings of Tena and Beyene (2011) who reported K^+ deficiency in Alfisols. Therefore, K fertilization is required to enhance crop production in the study area, where K removal takes place through crop harvest. Exchangeable Na^+ is well below the permissible limit of exchangeable sodium percentage (ESP) throughout the pedons of the studied soils (Table 4). The variation was irregular with depth of the pedons.

The percent base saturation increased with depth in Pedons 1, 4, and 6, while it was inconsistent in the other pedons, and topographic positions (Table 4). Percent base saturation of surface soil horizons ranged from 19% in Pedon 1 to 63% in Pedon 5. In the subsurface soils, PBS ranged from 24% in the B horizon of Pedon 1 to 84% in the bottom layer of Pedon 2. The higher values in some of the subsurface horizons marked the accumulation of soluble bases due to rainfall prevailing in the watershed and the composition of the parent material. According to the rating described by Hazelton and Murphy (2007), Pedon 1 in the upper slope and Pedon 4 in the lower slop positions were very low (<20%) and low (20-40%), respectively in PBS, whereas soils represented by Pedon 5 in the toe slope position were high in PBS. The higher values of per cent base saturation observed is due to higher amount of exchangeable Ca^{2+} ions occupying the exchange sites on the colloidal sites (Sekhar et al., 2014). Soils of Pedons 2, 3, and 6, on the other hand, were within the range of medium PBS (40-60%). The variation observed in PBS indicates the degree of leaching which was used as diagnostic character for classifying soils (Meena et al., 2014). Furthermore, the low PBS of the soils might indicate the leaching of bases due to the high rainfall in the study area. These situations may result in low and unbalanced availability of exchangeable bases for plants to be taken up. Therefore, liming may be required in the cultivation of soils of the study area and elsewhere in similar environments (Assen and Yilma, 2010).

The CEC/clay ratios are also greater for the surface than the subsoil horizons of some of the studied pedons (Pedons 1, 2, and 3). High CEC/ clay ratio was recorded for Pedon 1, which is found at the upper slope of the watershed. The CEC of clay fraction can be used as an indication of type of clay mineralogy (Buol et al., 2003). Accordingly, most of the horizons of Pedons 4, 5, and 6 are expected to have smectite group clay minerals (60-100 cmol$_c$ kg^{-1}).

Soil classification

Pedon 1 is limited in depth, loam in soil texture and granular in structure. The soil was recently cultivated, high in OC but low in PBS. The subsurface horizon has pedogenetic transformation of the rock, indicating that the soil pedon was developed through subsurface soil formation following initiation of structure and color change. These attributes of the pedon qualify the diagnostic criteria for *cambic* subsurface horizon. Furthermore, the pedon has a base saturation of less than 50% between 20 and 50 cm of the soil surface, which qualifies for *hyperdystric* principal qualifier. In addition to this, the presence of more than 1% OC to a depth of 50 cm from the mineral soil surface indicates the soil to have *humic* supplementary qualifier. Based on the diagnostic horizon and the qualifiers identified, the soil is classified as Hyperdystric Cambisols (Humic) (FAO, 2014). This soil covers 471 ha in the watershed (Figure 4).

Pedons 2 and 3 are characterized by subsurface horizons with higher clay content than the overlying horizon. The textural differentiation may be caused by an illuvial accumulation of clay. This characteristic may indicate the development of *argic* subsurface horizon in these pedons. Additionally, the *argic* subsurface horizons in Pedons 2 and 3 are characterized by having a CEC of ≥ 24 cmolc kg^{-1} clay throughout or to a depth of 50 cm of its upper limit, and having a base saturation, calculated on the sum of exchangeable bases plus exchangeable Al of < 50% in the major part between 50 and 100 cm from the mineral soil. The leaching of base cations particularly exchangeable Ca^{2+} was also observed owing to the humid environment in these pedons. Hence, these soils meet the definition of Alisols soil unit. Since no other principal qualifier can express the soil unit, *haplic* is prefixed, while for the presence of more than 1% OC to a depth of 50 cm from the mineral soil surface, *humic* is suffixed to classify the soil as Haplic Alisols (Humic), with an area coverage of 660 ha (Figure 4).

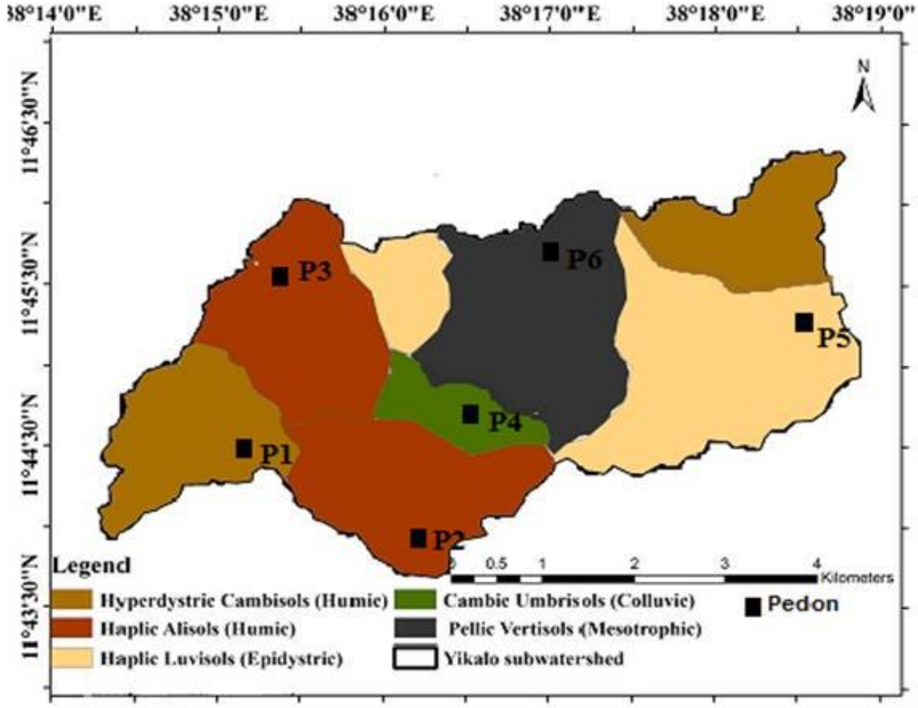

Figure 4. Soil map of the study area

Pedon 4 was dug in the lower slope position of the grazing land. Soils in this pedon have weak fine granular structure on the surface, high OC with dark brown color, and a base saturation of < 50% on a weighted average, throughout the entire thickness of the horizon with acid in reaction thus qualifying as *umbric* A horizon (FAO, 2014). The horizon has significant accumulation of OC in the mineral surface soil and a low base saturation within the first 100 cm. This pedon was therefore, recognized to meet Umbrisols at reference soil level. The subsurface horizon shows some evidence of pedogenetic alteration, and higher clay content than the bottom layer. The pedogenetic alteration is identified from the overlying mineral horizon, which is richer in OM and therefore have a darker colour, indicating *cambic* as a principal qualifier. Due to the accumulation of colluvic materials which has been transported as a result of erosional wash or soil creep in the slope positions, the supplementary qualifier *colluvic* is added as a suffix, and hence the soil is classified as Cambic Umbrisols (Colluvic), covering 116 ha of land.

Pedon 5 was opened on the cultivated land at the toe slope position, where there was higher clay content in the subsoil than in the topsoil. The movement and build up of clay formed *argic* subsoil horizon. Soils with high activity clays throughout the *argic* horizon and a high base saturation in the 50-100 cm depth satisfy the definition of Luvisols as a reference soil group. These characteristics entirely defined the soil without the requirement of other principal qualifier and thus *haplic* was prefixed. However, the presence of a base saturation of less than 50% between 20 to 50 cm from the surface makes the use of *epidystric* supplementary qualifier to classify the soil as Haplic Luvisols (Epidystric), which covers 607 ha.

Pedon 6 was excavated in the lower slope position where the pedon was developed with weathered and deposited sediments with large proportion of clay. The soil in the subsurface is rich in clay content exceeding 30% throughout the pedon; hard to very hard during dry, and sticky and plastic consistence during wet conditions that shrink and swell alternatively to form deep cracks and slickensides in the surface and subsurface horizons to meet *vertic* subsurface diagnostic horizon. A *vertic* horizon starting ≤ 100 cm from the soil surface, clay content higher than 30% between the soil surface and the vertic horizon throughout, and shrink-swell cracks that start at the soil surface meets the requirements of Vertisols. Vertisols having in the upper 30 cm of the soil a Munsell colour value of ≤ 3 and a chroma of ≤ 2, both moist are prefixed by *pellic* principal qualifier. Moreover, according to FAO (2014), soils having a base saturation of < 75% at a depth of 20 cm from the soil surface were defined with *mesotrophic* supplementary qualifier. Therefore this soil was identified as Pellic Vertisols (Mesotrophic), and covers an area of 440 ha.

Conclusion

Adequate information on soil and land characteristics is required for maintaining soil productivity and realization of land use planning. Therefore, soil characterization, classification and mapping of soils were conducted at subwatershed level of the Guna Mountain in Lay Gayint district. The morphological, physical and chemical characteristics of the soils showed variation along the topographic positions and soil depth. The soils represented by pedon 1 in the upper slop position were relatively shallow whereas the pedons in the middle and lower slope positions were very deep. The clay content in the B horizons of all pedons was higher as compared to the surface horizons. Soil formation in most of the pedons is characterized by clay illuviation from the surface to the subsurface soil horizons. Soils differed from very strongly acid to slightly acid in reaction. The exchangeable Al^{3+} values of the surface horizons of cultivated lands (Pedons 1 and 4) are with the range that may influence crop growth adversely. The soils had medium to high total N, very low to high OC, low to high available P, high to very high CEC, medium to very high exchangeable Ca, low to very high exchangeable Mg, very low to low exchangeable K. Based on the studied morphological, physical and chemical parameters, Hyperdystric Cambisols (Humic), Haplic Alisols (Humic), Cambic Umbrisols (Colluvic), Haplic Luvisols (Epidystric), and Pellic Vertisols (Mesotrophic) were the identified soil types in Yikalo subwatershed of Lay Gayint district.

In general the soil characteristics and pedon development of Yikalo subwatershed is affected by topographic positions, leading to erosion and leaching. Thus, the upper and middle slope positions need soil management practices such as bench terraces in the upper slope, and stone bunds in the middle slope reinforced with suitable grass and tree species. Excess water in the areas dominated by Vertisols should be drained during rainy season. In addition to this, application of optimum rates of FYM, compost, biofertilizers, and lime integrated with inorganic fertilizers containing N, P and K may help to reduce the level of soil acidity, and improve the fertility level of the soils for better crop production and productivity.

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