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Research article

Characterization and classification of soils of Bako Tibe District, West Shewa, Ethiopia

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ABSTRACT

The study was carried out at Bako Tibe District, West Shewa zone, Oromiya Region of Ethiopia, to characterize and classify agriculturally important acidic soils. Four soil types were considered and six representative pedons were opened and a total of 27 disturbed and 20 core ring soil samples were collected from identified horizons of each pedon and analyzed. The field and laboratory data revealed the soils were clay and sandy clay in texture, slightly acidic to strongly acidic in reaction (pH 5.2–6.63). The organic carbon content of the soil ranges between moderate 21.4 g kg^{-1} to high 30 g kg^{-1} for surface soil while very low (4 g kg^{-1}) to high (26 g kg^{-1}) for sub-surface soils. Both the surface and subsurface soils were very low (1.7–2.2 g kg^{-1}) in total N and deficient (5.99–7.85 mg kg^{-1}) in available P content. The cation exchange capacity (CEC) was high for all surface and sub-surface percent base saturation was low (25 cmol $_{(+)}kg^{-1}$) for Alisols and medium for Nitisols, Luvisols, and Cambisols (51 and 50 $cmol_{(+)}kg^{-1}$). The soils were sufficient in available Fe, Mn, and Zn but deficient in B and Cu. Pedon-1 was Dystric, Rhodic Nitisols (Humic); pedon-2, Dystric Nitisols (Humic); pedon-3, Umbric Nitisols; pedon-4, Rhodic Alisols (Hyperdystric); pedon-5, Rhodic Luvisols (Hypereutric); pedon-6, Leptic Cambisols (Humic). Soil characterization is helpful to use the land according to its capability and limitations. pedons 2 and 4 were categorized under LCC IIs. pedons 1, 3, and 5 were grouped within LCC IIIes while Pedon 6 was grouped under LCC IVes. All the soil profiles studied can be used for crop production with appropriate management practices. Different agronomic and physical soil and water conservation measures such as cover crops, counter farming, graded bands, and lime application are some of the corrective measures for the limitations.

1. Introduction

In the horn of Africa, Ethiopia has diverse topography, climatic conditions, and geology (FAS, 2019). The elevation ranges between two extremes from 125 m below sea level (bsl) Denakil Depression to 4620 m above sea level (asl) Ras Dashen peak. This wide range of topographic variation with its climatic diversity creates variations in the country's natural resources like soils and vegetation (Berhanu et al., 2013). Similarly, Wassie (2020) said that the country has abundant natural resources, proper land, fertile soil, favorable climate, water, wildlife, etc. However, many of its resources have not been properly identified, managed, and fully utilized.

Unwise utilization of these natural resources and intensive farming for thousands of years without protection degrades the soil, the natural reservoirs of essential plant nutrients, consecutively resulting in crop yield reduction. Amsalu & de Graaff (2006) reported that agricultural land degradation is a major problem for current and potential food production in the Ethiopian high lands. To evaluate the quality of our natural resources and their potential to produce food, fodder, fiber, and fuel for the present and future generations, detailed information on soil properties is needed. Accurate land evaluation is a great concern to achieve sustainable agricultural production (Fadl and Sayed, 2020). Moreover, understanding soil properties and their distribution over an area are useful for sustainable development and the efficient use of limited land resources (Sanchez et al., 2003).

Pedological characterization and classification of soils of a given area is crucial for the determination of its potential and constraints for enhanced and sustained agricultural production (Alemu Lelago and Tadele Buraka, 2018). Soil characterization is intended to classify soil and determine chemical and physical attributes (that can reflect the capacity of soil to function) not visible in field examination (Sanchez et al., 2003). According to Assen and Yilma (2010), soils classification is helpful

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to identify the most appropriate use of the land, estimate the production, and facilitate technology transfer and information exchange between soil scientists, policymakers, planners, researchers, and agricultural extension consultants. Among the serious problems hindering agriculture in it is required for maintaining soil productivity and realization of land use planning in most parts of the country. It is important to characterize and describe soil and land use to make recommendations for sustainable land use in Ethiopia (Zebire et al., 2019).

According to IUSS Working Group WRB (2015) soil classification, about 19 types of reference soil groups are identified throughout the country. Nitisols, Cambisols, Luvisols, and Alisols are among the most extensive soil types accounting for 13.5, 11, 5.8, and 5 % of the agricultural landscapes of the Ethiopian highlands, respectively (Mengistu, 2006). With appropriate management, they have medium to high potential for rain-fed agriculture. Alisols are particularly important in high rainfall upland farming systems of the southwestern highlands of Ethiopia. Based on the classification of IUSS Working Group WRB (2015), the major soils identified at Bako Tibe district are Alic Nitisols, Haplic Nitisols, Luvic Nitisols, Litic Leptosols, Haplic Luvisols, Cutanic Luvisols, Vertic Luvisols, Nitic Luvisols, Leptic Luvisols, Haplic Regosols and Rhodic Alisols (Hyperdystric) (Elias, 2016). However, these different soil types were not fully characterized and their properties were not well documented in the study area. Different agricultural technologies and inputs were recommended at some specific areas in the country and extrapolated to other areas with different soil types that vary in morphological, physical, and chemical properties. This means the same inputs and technologies are recommended for different soil types with dissimilar properties, capabilities, and limitations the recommendations are not site and soil specific (Soil Science Division Staff., 2016).

Several studies were conducted on soil characterization but these are not disaggregated by soil type and rather missing (Assen and Yilma, 2010). Soils vary both in their properties and, in turn, agricultural production is governed by major soil types and rainfall regimes. Assen & Yilma (2010) reported that considering differences in soil types can enhance agricultural productivity and sustainable land management practices in Ethiopia. Information on the soil types, morphological, physical, and chemical characteristics of agricultural soils in the western highlands are essential in making decisions and sustaining land productivity (Elias, 2016) For these reasons, it becomes fundamental to conduct site-specific soil characterization to identify the existing heterogeneity of the soil system and to generate adequate information to determine soil potential and a proper soil management practices. Hence, there is a need to characterize and classify the soils at Bako Tibe of Western Shewa, Ethiopia which is useful to come across the full production potentials of the area together with the identification of the factors, which are likely to limit production. For that reason, the current study was intended:

1. To characterize some agriculturally important soils at Bako Tibe District.
2. To study the major morphological, physical, and chemical characteristics and classify some agriculturally potential soils at Bako Tibe District.

2. Materials and methods

2.1. Description of the study area

The sites considered in the present study are among agriculturally important soils in the Bako Tibe District, Western Shewa Zone of Oromiya, Ethiopia (Figure 1). The sites were selected based on differences in soil type and their acidity problem and P sorption capacities. They ate located 250 km West of Addis Ababa. The district is characterized by flat plains, high mountains, and rolling ridges. The geological feature of the district is characterized by Tertiary sediments from the Cenozoic era on the plain and basaltic rocks in the High Mountains and rolling ridges. BakoTibe The district has three agro-climatic zones: Dega (highland), Woina Dega (mid-land), and Kolla (low land). The rainfall data obtained from the nearest weather station (Bako Agricultural Research Center) reveals that the rainy season covers April to November and maximum rain is received in June, July, and August (Figure 2). The long period (1976–2017) average annual rainfall is 1267 mm with a unimodal distribution. It has a warm humid climate with the mean minimum, mean maximum, and mean air Temperatures of 13.9 °C, 28.1 °C, and 21 °C respectively and the altitudinal of the district is in the range of 1650–2800 masl. According to the Reference Base for soil resources IUSS

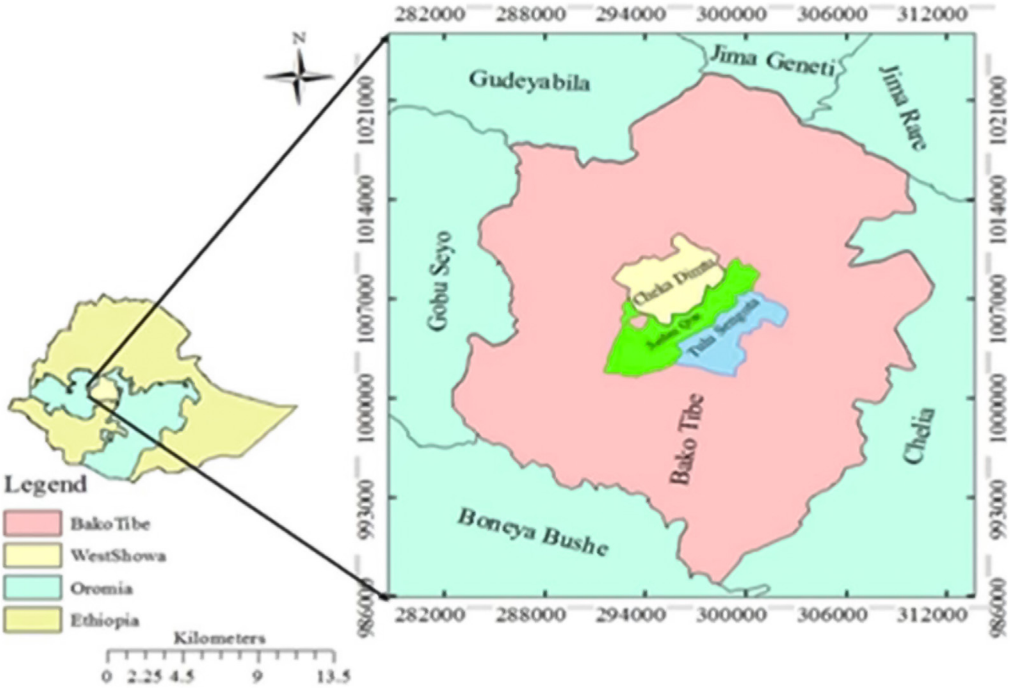

Figure 1. Bako Tibe District of Western Shewa Zone.

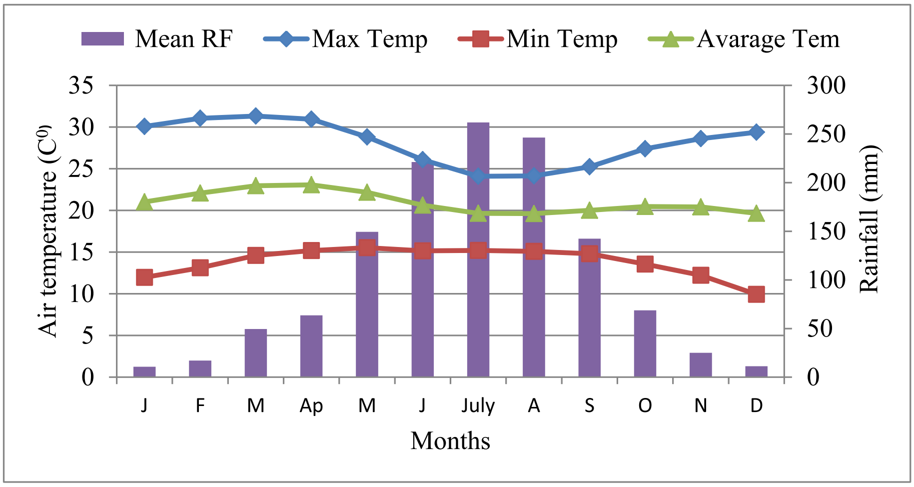

Figure 2. Long-term (1976–2017) mean monthly rainfall distribution and air temperature (°C) of Bako Tibe District. Source: BARC, unpublished data.

Working Group WRB (2015), the major soils identified on the geomorphological map of BakoTibe district (Figure 3) include Endoeutric Nitisols, Hypereutric Nitisols, Hypereutric Luvisols, Eutric Vertisols, Lithic Leptosols, and Hypereutric Fluvisols. The pH range of the surface and subsurface soils differs from 5.39 to 6.00 and 5.20 to 6.60 respectively. Therefore, the topsoil is strongly acidic to moderately acidic while the subsurface soils are strongly acidic to slightly acidic (Hazelton and Murphy, 2016).

2.2. Soil profile description, sampling, and sample preparation

The soil characterization was carried out using soil profile pits that were opened at the representative locations (Table 1). The sites were selected for four soil types (Nitisols, Alisols, Luvisols, and Cambisols) and a total of 6 pits opened to a depth of 2 m with 1 m width and 2 m length (Figure 4). The soil profiles were described *in-situ* for morphological characteristics based on the FAO Guidelines for Soil Description (FAO, 2006a). The soil color was described using soil color charts (MUNSELL COLOR Org, 2000). Undisturbed core samples were collected at different points across each horizon for the determination of bulk density (G.R.Blake, 1965). Standard laboratory procedures were followed for soil laboratory analysis.

2.3. Laboratory analysis of soil physical and chemical properties

The standard soil lab analysis procedures adopted by Waterworks and Design (Addis Ababa), Horticoops soil laboratory (Bishoftu), and Ambo University Chemistry laboratory were followed for the determination of selected soil chemical and physical properties. Soil particle size determination was carried out by the Bouyoucos hydrometer method (Reeuwijk, 2002), while bulk density was measured using the core sampling method (Blake, 1965). The soil moisture contents at field capacity (FC) and permanent wilting point (PWP) were determined by the pressure plate apparatus technique. Available water holding capacity (AWHC) was obtained by deducting the value of PWP from the FC (AWHC = FC - PWP). Soil pH was analyzed potentiometrically in H_2O and 1 M KCl solution at the ratio of 1:2.5 for soil: H_2O and soil: KCl solutions using a combined glass electrode pH meter. The change in pH was determined by subtracting soil pH (KCl) from soil pH (H_2O) (Okalebo, 2002). Determination of soil organic carbon was carried out by oxidizing the organic carbon (OC) under the standard condition with potassium dichromate in sulfuric acid solution as described by Walkley and Black (1934). Total N was determined by the Kjeldahl method using micro- Kjeldahl distillation unit and Kjeldahl digestion stand as described by Jackson (1958). Available P was extracted by the Olson procedure, the most commonely

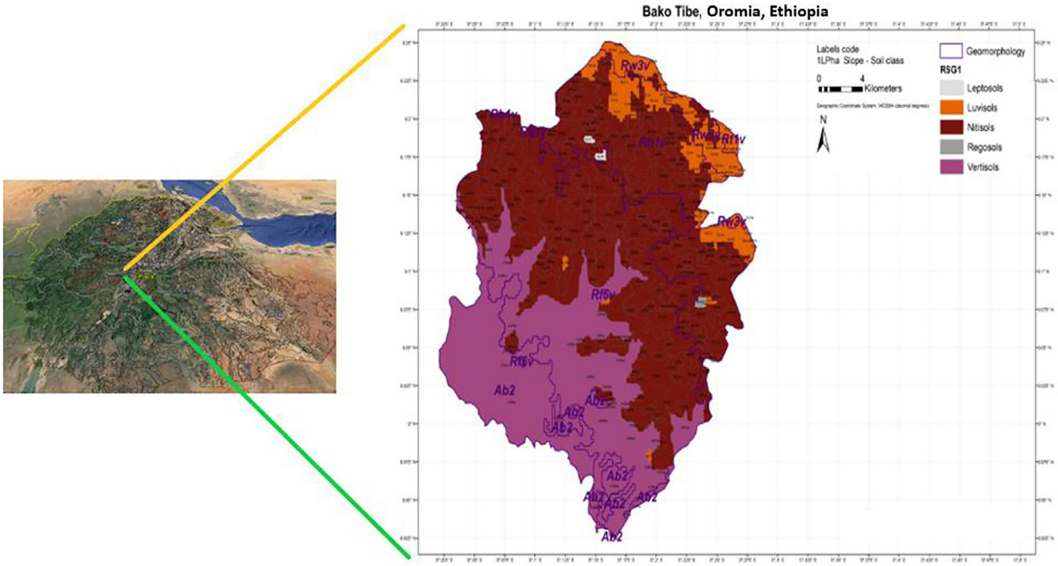

Figure 3. Geomorphological map of Bako Tibe District.

Table 1. Selected environmental information of representative profiles at Bako Districts.

Profile No.	Location		Altitude (m.a.s.l)	Slope (%)	Drainage class	Position	Erosion/Deposition	Parent material	Land use
	Latitude (N)	Longitude (E)							
P-1	9° 05.196N	37°08.196 E	1724	8	Well drained	upper slope	Sheet & rill	Basalt	Annual field crop
P-2	9° 05.198 N	37°08.161 E	1674	6	Well drained	Middle slope	Sheet & rill	Basalt	Annual field crop
P-3	9° 05.391N	37°08.079 E	1710	9	Well drained	Middle slope	Sheet & rill	Basalt	Annual field crop
P-4	9°05.199 N	37°9.549 E	1716	3	Well drained	Middle slope	Sheet & rill	Basalt	Annual field crop
P-5	9° 06.23.4N	37° 07.334 E	1735	10	Well drained	Upper slope	Sheet & rill	Basalt	Annual field crop
P-6	9° 05.074′N	37° 07.70 E	1790	19	Well drained	Upper slope	Sheet & rill	Basalt	Annual field crop

P-1, BA/SK1/NT; P-2, BA/SK2/NT; P-3,BA/CD1/NT; P-4,BA/TS1/LV; P-5,BA/CD21/LV; P-6,BA/CD3/CM.

P-1: BA/SK1/NT P-2: BA/SK2/NT P3: BA/CD1/NT

P-4: BA/TS1/LV P-5: BA/CD2/LV P-6: BA/CD3/CM

Figure 4. The Pedon 1–6, that opened for different soil types at the study sites.

used for P extraction under a wide range of pH both in Ethiopia and elsewhere in the world (J R Landon, 1991; Mamo and Richter, 2002). Cation exchange capacity (CEC) was determined by measuring NH4$^+$ from the 1M ammonium acetate (NH$_4$OAc, pH 7.0) saturated soil samples (Chapman, 1965). The CEC of clay was computed by dividing CECsoil by percentage clay (x 100). All exchangeable macro elements and available microelements were determined by Mehlich 3 method. Exchangeable acidity (Al and H) was determined by saturating the soil samples with 1M KCl solution and titrating with sodium hydroxide as described by McLean (1965). Percent base saturation was calculated as the percentage of the basic cations (Ca, Mg, K and Na) to the CEC of the soil.

Finally, based on the absence or presence of particular diagnostic horizons, properties, materials, and qualifiers, the soils were categorized into their respective reference soil groups following the World Reference Base for soil resource (IUSS Working Group WRB, 2015).

The land capability classification was made based on USDA (2007) land capability classification.

2.4. *Statistical analysis*

Simple descriptive statistics were used to measure the variability of the soil properties within the horizons of the pedon and standard errors (SE) were used to measure the errors.

3. Results and discussion

3.1. *Selected soil morphological characteristics*

3.1.1. *Soil color*

Some important soil morphological properties of the studied profiles are presented in Table 2. The soil color (moist) in all the surface layers of Nitisols (Pedon 1, 2, and 3) was dark reddish-brown (2.5YR 2.5/3 to 2.5YR 2.5/4) while the surface layers of Alisols (Pedon 4), and Luvisols (pedon 5) varied from very dark brown (5YR 2.5/3) to dark brown (7YR 3/2). The surface layer of Peon 6 (Cambisols) was dark reddish-brown

Table 2. The organized soil morphological data 0–200^{+}cm for Nitisols, Alisols, Luvisols and Cambisols.

Depth (cm)	Horizon	Color (Moist)	Structure Type/size/grade	Consistence Dry/moist/wet	Roots Abundance/size	Boundary Distinctness/Topography
Pedon 1, BA/SK1/NT						
0–20	Ap	2.5YR 2.5/4	SAB, CO, ST	HA,FR, ST, PL	C, F	G,S
20–50	Bt1	2.5YR 2.5/4	AB, CO, ST	HA,FR, ST, PL	C, F	G,S
50–80	Bt2	10R ¾	AB, CO, ST	HA,FR, ST, PL	F, F	C,S
80–125	Bt3	10R 3/3	SAB, CO, ST	HA,FR,ST,PL	F, F	G,S
125–145	Bt4	10R 3/3	AB, CO, ST	HA,FR,ST,PL	F, F	G,S
145-200^{+}	Bt5	10R 3/6	AB, CO, ST	HA,FR,ST,PL	F,F	—
Pedon 2, BA/SK2/NT						
0–20	Ap	2.5YR 3/3	SAB, CO, ST	HA,FR, ST, PL	C,F	C,S
20–62	A	2.5YR 2.5/4	AB, CO, ST	HA,FR, ST, PL	F,F	G,S
62–110	B	10R 3/3	AB, CO, ST	HA,FR, ST, PL	F,F	G,S
110-190^{+}	Bt1	7.5R 2.5/4	SAB,CO,ST	HA,FR, ST, PL	—	—
Pedon 3, BA/CD1/NT						
0–15	Ap	2.5YR 2.5/3	SAB, CO, ST	HA,FR, ST, PL	C,F	G,S
15–28	A	2.5YR 3/3	AB, CO, ST	HA,FR, ST, PL	F,F	G,S
28–60	Bt1	10R 3/3	AB, CO, ST	HA,FR, ST, PL	F,F	D,S
60–140	Bt2	10R ¾	AB, CO, ST	HA,FR, ST, PL	F,F	D,S
140–200^{+}	Bt3	7.5R ¾	AB,ME,ST	HA,FR, ST, PL	—	—
Pedon 4, BA/TS1/AL						
0–20	Ap	7.5YR 2.5/3	SAB, CO, ST	SHA, FR,ST,PL	C,M	C,S
20–50	AB	7.5YR 2.5/3	AB, CO, ST	SHA, FR,ST,PL	C,F	G,S
50–80	Bt1	7.5YR 3/3	SAB,ME,ST	HA,FR,ST,PL	C,F	G,S
80–110	Bt2	5YR 3/2	SAB,ME,ST	HA,FR,ST,PL	F,F	C,S
110–153	Bt3	5YR 3/3	SAB,Me,MO	SHA,FR,ST,PL	C, F	A,S
153-200^{+}	Bt4	2.5YR 3/3	SAB,Me,MO	HA,FR,ST,PL	F,F	—
Pedon 5, BA/CD2/LV						
0–18	Ap	7.5YR 3/2	SAB, CO, ST	HA,FR, ST, PL	M, F	C,S
18–50	Bt1	2.5YR 2.5/2	SAB, CO, ST,	HA,FR, ST, PL	C, F	C,S
50–102	B	5YR ¾	AB, CO, ST	HA,FR, ST, PL	F, F	—
Pedon 6. BA/CD3/CM						
0–10	Ap	2.5YR2.5/3	SAB, ME, ST	HA,FR, ST, PL	M,M	C,S
10–28	B	7.5YR 3/1	SAB, CO, ST	HA, FR, ST, PL	C,F	C,S
28–55	BC	7.5YR3/3	AB,ME, ST	HA, FR, ST, PL	F,F	—

A = abundance; G = grade; Na = nature; ST = stickiness; C = contrast; Cn = continuity; Moi = moist condition; H = horizons; S = structure; Sh = shape; Ty = type; T = topography; Co = color; K = kind; Si = size; FR = Friable; PL = plasticity.

(2.5YR 2.5/3) in color. The subsurface soil color of Nitisols (pedon 1, 2, and 3) varied from dark reddish-brown (2.5YR 2.5/4) to Dusky red (7.5R 3/4), and the subsurface soil colors of Alisols (pedon 4), Luvisols (pedons 5), and Cambisols (pedon 6) varied from very dark brown (7.5YR 2.5/3) to dark brown (7.5YR 3/3). The reddish color indicates good soil drainage condition, aerated, and oxidation of iron. Similarly, the difference in color among the pedons and within a pedon is most probably due to variation in forms of iron oxide, the types of parent material, OM content, and drainage conditions (Ali et al., 2010; Buol et al., 2011; Abate, 2014).

3.1.2. Soil structure and consistency

The structure of Nitisols, Alisols, Luvisols, and Cambisols (pedons 1–6) in the surface soils were weak, coarse, subangular blocky, continuously changing in the lower surface from strong, coarse, angular blocky in Pedon 1, 2, and 3 to strong, medium and sub-angular blocky in pedons 4, 5, and 6. Yitbarek et al. (2016) reported that granular soil structure in the upper horizons changed to angular and subangular structure in the subsurface pedons. Granular soil structures are formed with more OM levels of the surface horizons. In the subsurface horizon, blocky structures are formed due to the overlying layers, reduction in the level of soil organic matter, higher clay content, and reduction in the abundance of plant roots.

The dry consistency of both the surface and subsurface horizons of Nitisols, Alisols, Luvisols, and Cambisols (pedons 1–6) were hard. The moist consistency for all the surface and subsurface layers of all the pedons studied were friable and at optimum moisture content, it is good to work with the soils. The wet consistency is also in the range of slightly sticky/slightly plastic in the surface horizons to very sticky/very plastic in the soil horizons below the surface (Table 2). These sticky, very sticky and plastic, and very plastic consistency at the subsurface layers attributed to the decrease in OM content, the more clay particles, and hard to work with the soils. Abay Ayalew et al. (2014) reported similar results in that the sticky and plastic consistency indicates the existence of high clay content and difficulty in working. Ali et al. (2010) reported that the existence of a very sticky and very plastic consistency mainly shows the soils contain smectic clay minerals.

3.1.3. Soil depth and horizon boundaries

According to FAO, (2006a) soil depth class description, all the pedons were very deep (>150 cm) except Pedon 5 which was deep (102 cm), and pedon 6, which was moderately deep (0–55 cm). The amount of plant nutrients and water available to plant roots are determined by the rooting depth of the soil and the depth of the soils does not restrict the plants' roots growth and the availability of nutrients and water in the study area. The lower boundaries of surface and subsurface horizons in Nitisols (Pedons 1)

Table 3. Selected soil physical characteristics of the soil profile at Bako-Tibe District.

Depth (cm)	Horizon	Particle size analysis (%)				Si/C	BD (Mg m^{-3})	FC (%)	PWP (%)	AWC (%)
		Sa	Si	C	Class					
Pedon 1, BA/SK1/NT										
0–20	Ap	41	5	54	Clay	0.09	1.10	40	29	11
20–50	Bt1	44	5	51	Clay	0.10	1.20	-	-	-
50–80	Bt2	39	5	56	Clay	0.09	1.05	-	-	-
80–125	Bt3	29	8	64	Heavy Clay	0.12	1.02	-	-	-
125–145	Bt4	41	5	54	Clay	0.09	-	-	-	-
145-200^{+}	Bt5	34	10	56	Clay	0.18	-	-	-	-
Mean	38	6.33	55.83	-	0.11	1.09	40	29	11	
SE	2.25	0.88	1.79	-	0.01	0.03	-	-	-	
Pedon 2, BA/SK2/NT										
0–20	Ap	23	23	55	Clay	0.38	1.07	44	28	16
20–62	A	40	1	59	Clay	0.38	1.16	-	-	-
62–110	B	36	8	56	Clay	0.09	1.16	-	-	-
110-190^{+}	Bt1	29	8	64	Heavy Clay	0.15	-	-	-	-
Mean	32	10	58.50	-	0.25	1.13	44	28	16	
SE	3.76	4.63	2.02	-	0.07	0.03	-	-	-	
Pedon 3, BA/CD1/NT										
0–15	Ap	36	18	46	Clay	0.38	1.00	40	26	14
15–28	A	41	16	43	Clay	0.38	1.00	-	-	-
28–60	Bt1	39	5	56	Clay	0.09	1.09	-	-	-
60–140	Bt2	41	8	51	Clay	0.15	1.14	-	-	-
140-200^{+}	Bt3	35	4	61	Heavy Clay	0.06	-	-	-	-
Mean	38.4	10.2	51.4	-	0.21	1.05	40	26	14	
SE	1.24	2.87	3.26	-	0.07	0.03	-	-	-	
Pedon 4, BA/TS1/AL										
0–20	Ap	29	15	56	Clay	0.27	1.04	39	28	11
20–50	AB	41	18	41	Clay	0.42	1.05	-	-	-
50–80	Bt1	30	18	53	Clay	0.33	1.20	-	-	-
80–110	Bt2	39	8	54	Clay	0.14	1.09	-	-	-
110–153	Bt3	31	16	53	Clay	0.31	-	-	-	-
153-200^{+}	Bt4	26	8	66	Heavy Clay	0.11	-	-	-	-
Mean	32.66	13.83	53.83	-	0.26	1.09	39	28	11	
SE	2.43	1.90	3.26	-	0.04	0.03	-	-	-	
Pedon 5, BA/CD2/LV										
0–18	Ap	41	13	46	Clay	0.27	1.15	42	31	11
18–50	Bt1	34	10	56	Clay	0.18	1.21	-	-	-
50–102	B	40	16	44	Clay	0.37	1.15	-	-	-
Mean	38.33	13	48.66	-	0.27	1.17	42	31	11	
SE	2.18	1.73	3.71	-	0.05	0.02	-	-	-	
Pedon 6, BA/CD3/CM										
0–10	Ap	41	15	44	Clay	0.34	1.07	41	27	14
10–28	B	46	13	41	Clay	0.30	1.15	-	-	-
28–55	BC	45	18	38	Sandy Clay	0.47	-	-	-	-
Mean	44	15.33	41	-	0.37	1.11	41	27	14	
SE	1.52	1.45	1.73	-	0.05	0.04	-	-	-	

Note: Sa = sand; Si = silt; C = clay; Si/C.
= silt to clay ratio; BD = bulk density; FC = water content at field capacity; PWP = water content at field capacity; AWC = available water content. NT = Nitisols; LV = Luvisols; CM = Cambisols; SE = standard error.

were gradual and smooth; the lower boundary surface horizon of the pedon 2 was clear and smooth that changed to gradual and smooth at sub-surface horizons. The lower boundary of the surface horizon of the pedon 3 was gradual and smooth up to the depth of 60 cm and below 60–140 cm the sub-surface boundaries were diffuse and smooth. For Pedons 4, 5, and 6 all the lower boundaries of the surface horizons and the lower boundaries of the sub-surface horizons of pedons 5 and 6 were clear and smooth while lower boundaries of pedon 4 were gradual and smooth (Table 2).

3.2. Soil physical characteristics

3.2.1. Soil particle size distribution

Results on the soil's physical properties were displayed in (Table 3). According to Hazelton and Murphy (2016), the percentage of soil mineral particles (clay, sand, or silt) were categorized into Very high (>50%), High (>40%), Moderate (25–40%), low (10–25%) and Very low (<10). Based on this ratting, Nitisols and Luvisols were in the range of medium to high in sand content, Very low to low in silt content, and high to very high in their clay content. Cambisols were high in sand, low in silt, and moderate to high in clay content. The clay content was slightly increased with the depth of profiles except for pedon 6. It revealed most subsoil horizons are argic (Bt) which were formed by illuviation of clay minerals from the upper horizons. This finding was in line with El Ghonamey et al. (2020) that state, clay minerals might be present as a result of inheritance from the parent material through weathering, degradation of primary minerals, and addition. The mineral structure of the clay and its transformations as a result of the weathering processes are the determining factors that influence the soil fertility and water holding capacity (Bahnasawy, 2018). The clay content of pedon 6 (Cambisol), decreased with increasing soil depth. The sand and silt particle size distribution in most of the studied pedons shows a decreasing trend across the soil depth (Table 3). The cutans (clay skins) were found on the sides of ped faces, implying the downward migration of clay particles.

3.2.2. Silt/clay ratio

The silt/clay ratio of the surface and subsurface soils of the pedons were in the range of 0.09 (Pedon 1) to 0.47 (pedons 6) (Table 3). There was no clear trend of decrease or increase of clay/silt ratio with soil types and depth in the pedons 1–6 (Nitisols, Alisols, Luvisols, and Cambisols). According to Ahukaemere et al. (2017) soils with silt/clay ratio <0.15 are considered to be highly weathered soils. For this particular study, the soil lab analysis data revealed that Nitisols ($Si/C < 0.15$) are weathered soils, and Cambisols with ($Si/C > 0.15$) are comparatively younger with a higher intensity of weathering potential.

3.2.3. Bulk density

As ratted by Hazelton and Murphy (2016), the optimum bulk densities of mineral soils of surface horizons are in the range of 1.3–1.6 (Mg m^{-3}). In most of the profiles, the bulk density increases irregularly with depth which could be a result of the mass of the overlaid soil, low porosity, and the comparatively less content of OM in the lower surface soil layers. For this study, surface horizons bulk density ranges from 1.00 Mg m^{-3} to 1.15 Mg m^{-3}; being minimum in profile 3, and maximum in profile 5. Consequently, in the underlying horizons, bulk density varies from 1.0 Mg $m^{-3}$to 1.21 Mg m^{-3}. The bulk density of the studied soils was low and does not negatively affect the root penetration, soil's available moisture-holding capacity hence the crop production.

3.2.4. Soil moisture characteristics of the surface soils

Hazelton and Murphy (2016) rated the AWHC of the soil with <10%, 10–20%, and >20% as low, medium, and high respectively. Accordingly, the mean AWHC of the soils under study were in the medium range (11–16% AWHC) which is suitable for crop production. The highest AWHC (16%) for pedon 2 was most probably due to its lowest sand percentage (23%) and the highest silt (23%) and clay (55%) content and low bulk density (1.07 g cm^{-3}). Similarly, Reichert et al. (2009) reported that the amount of plant-available water capacity was lowest in the sand textural class due to low specific surface area, while the greatest AWHC was detected in the textural classes with higher silt content. In line with this, various reports indicated that clay content had a positive relationship with the quantity of water retained at FC and PWP (C.N., Mbach 2012; Nagaraju and Gajbhiye, 2014). The water retention at PWP (1500 kPa) is roughly 0.4 times the clay percentage. The water content at air dryness is about 10 percent of the clay percentage, assuming complete dispersion of clay (USDA, 2017).

3.3. Soil chemical characteristics

3.3.1. Soil pH

Some selected soil chemical characteristics of the studied pedons are displayed in Tables 4, 5, and 6. The soil pH (H_2O) value was generally revealed a slightly increasing trend with depth. The soil pH values are <7 at surface and subsoil horizons. In the surface horizons, the pH ranges from 5.2 to 6.0 in pedon 1 and pedon 2 respectively (Table 4). This low pH was because of the uptake of basic cations from crops, and the relatively more quantity of OM in the surface horizons. The pH values (<6.5) of the current study are generally considered non-calcareous. In subsurface horizons, pH (H_2O) ranges from 5.25 to 6.63. Soil pH of <5.5 most probably indicates the presence of Al^{3+} and the removal of exchangeable cations. As rated by Hazelton and Murphy (2016), the pH (H_2O) values throughout the horizons of all pedons were in the range of strongly acidic to slightly acidic. On this strongly acidic pH range, there is a yield decrease for less acid-tolerant crops such as barley and alfalfa. This dictates the application of lime to reclaim the soils or choosing crops more suitable for the local conditions.

3.3.2. Soil organic carbon and total nitrogen

Variation was observed in the OC content of the studied Pedons (Table 4). The OC content of the surface soil horizons was in the high range 21.4–30 g kg^{-1} and very low (4.4 g kg^{-1}) to high (22.6 g kg^{-1}) for subsurface soil layers as ratted by Hazelton and Murphy (2016). High OC content at surface soil was because of the high amount of rainfall that favors high biomass production, hence high OM in the soil. The soil OC content was in a decreasing trend as the soil depth increases for all pedons (Table 4). This implies a comparatively greater addition of decomposable organic materials on the surface horizons than the subsurface horizon.

Based on the rating of Hazelton and Murphy (2016); FAO, (2006b), total nitrogen (TN) in the surface horizon was in the medium range (1.7 g kg^{-1}) – (2.2 g kg^{-1}). In the sub-surface horizon, the TN level varies from deficient (0.5 g kg^{-1}) to sufficient (1.4 g kg^{-1}). The quantity of TN in the upper soil layer was higher than that of the lower soil layers and it followed similar trends with that of OC in all pedons studied, implying that there is a strong relationship between TN and soil OC. This study is in harmony with the study of Meysner et al. (2006) which stated as about 93–97% total N content of the soils is mainly related to OC. The soil's TN content of the surface layers was optimum for agricultural crop production.

3.3.3. Available phosphorous

The Olsen available phosphorus (P) contents of the soils in the upper horizons was highest in the pedon 3 (7.85 mg kg^{-1}) followed by pedon 2 (7.84 mg kg-1) and pedon 4 (7.66 mg kg-1) while the least was recorded in the pedon 6 (6.49 mg P kg^{-1}) (Table 4). The low available P indicated by the results could be related to the acidic properties of the soils and the types of clay mineralogy of the soils. The low soil pH (high H^{+}) increases the solubility of Al oxides and hydroxides through hydrolysis of Al. The $Al^{3}{}_{(aq)}$ inters into the soil solution and reacts with solution P and forms insoluble Al-phosphate ($AlPO_4 . H_2O$) (s) i.e. P is fixed to Al and becomes less available for crops uptake. Based on the standard ratting of FAO, (2006b), the Olsen available P determined for the soil samples collected from all pedons were in the deficient range (<10 mg kg^{-1} soil). The most probable reason for the low value of soil available P was the fixation of P by Al^{3+} in the low soil pH range. Phosphorus fixation is a common problem associated with acidic tropical soils. Therefore, P deficiency is one of the bottleneck problems for crop production in the study area. This study is comparable with the findings of Melese, Gebrekidan, Yli-halla, & Yitaferu (2015); Daniel Adhanom and Tefera Toshome (2016) and Mesfin et al. (2017) that states phosphorus is deficient in Ethiopian soils. The available P shows a declining trend across the soil depth for all the soil profiles that is due to the decreasing of soil OM level, low external inputs of P sources, and fixation by clay minerals which were found to increase with profile depth at subsoil horizons, which is in harmony with the finding of (Ayalew et al., 2014).

3.3.4. Exchangeable bases, cation exchange capacity (CEC), and base saturation (BS)

The major cations occupying the exchange sites with decreasing order were $Ca^{2+} > Mg^{2+} > K^{+}>Na^{+}$. The concentration of Calcium (Ca^{2+})

Table 4. Soil pH, OC, TN and Available P in Nitisols, Alisols, Luvisols and Cambisols profiles.

Depth (cm)	Horizon	pH (H$_2$O)	OC (g kg^{-1})	TN (g kg^{-1})	AP (mg kg^{-1})
Pedon 1, BA/SK1/NT					
0–20	Ap	5.20	23.5	1.7	6.66
20–50	Bt1	5.50	11.9	1.0	4.48
50–80	Bt2	5.72	8.4	0.8	6.72
80–125	Bt3	5.56	6.3	0.7	4.37
125–145	Bt4	5.70	5.3	0.5	4.74
145-200+	Bt5	5.66	5.0	0.6	3.95
Mean		5.55	10.06	0.88	5.15
SE		0.07	2.88	0.17	0.49
Pedon 2, BA/SK2/NT					
0–20	Ap	6.00	25.9	1.8	7.84
20–62	A	6.15	8.9	0.8	7.28
62–110	B	6.32	6.3	0.7	3.09
110-190^{+}	Bt1	6.27	4.5	0.6	8.45
Mean		6.18	11.40	0.67	6.66
SE		0.07	4.91	0.27	1.21
Pedon 3, BA/CD1/NT					
0–15	Ap	5.47	25.9	1.9	7.85
15–28	A	5.60	22.6	1.7	7.68
28–60	Bt1	5.93	9.7	0.8	4.11
60–140	Bt2	5.73	7.3	0.7	2.70
140–200^{+}	Bt3	5.46	4.4	0.6	3.60
Mean		5.63	13.98	1.14	5.18
SE		0.08	4.30	0.27	1.07
Pedon 4, BA/TS1/AL					
0–20	Ap	5.39	30.8	2.2	7.66
20–50	AB	5.40	26.0	2.0	2.96
50–80	Bt1	5.52	22.6	1.4	2.31
80–110	Bt2	5.75	21.9	1.2	3.09
110–153	Bt3	5.25	21.1	1.2	2.46
153-200^{+}	Bt4	5.40	9.4	0.8	2.10
Mean		5.45	21.96	1.16	3.43
SE		0.06	2.90	0.62	0.86
Pedon 5: BA/CD2/LV					
0–18	Ap	5.93	21.4	1.9	6.49
18–50	Bt1	6.60	12.2	1.1	3.64
50–102	B	6.62	8.8	0.8	3.02
Mean		6.38	14.13	1.26	4.38
SE		0.22	3.76	0.32	1.06
Pedon 6, BA/CD3/CM					
0–10	Ap	5.72	22.6	2.0	5.99
10–28	B	6.35	13.3	1.3	8.61
28–55	BC	6.63	9.0	0.8	5.83
Mean		6.23	14.96	1.36	6.81
SE		0.26	4.01	0.34	0.90

OC, organic carbon; TN, total nitrogen; AP, available phosphorous SE = standard error.

decreased consistently with the depth of the soil pedons (Table 5). The highest Ca^{2+} content (15.31 cmol$_{(+)}$ kg^{-1}) of the surface soil was recorded in the surface layer of Pedon 6 (Cambisols) and the lowest (6.93 cmol$_{(+)}$kg^{-1}) was in Pedon 1 (Nitisols). This highest concentration of Ca^{2+} indicates the degree of weathering (less intensive) and the pH (H$_2$O) value of 5–9 was the more optimum pH range for the availability of Ca^{2+} (Hazelton and Murphy, 2016). According to the same rating, the exchangeable Ca^{2+}content in the soils was in the medium to the high range which is indicative to the soils vary in their weathering stage from well-developed Nitisols to the younger Cambisols.

Exchangeable Mg^{2+} contents varied from 2 cmol$_{(+)}$kg^{-1} in Pedon 4–4.64 cmol$_{(+)}$kg^{-1} in Pedon 6 of the surface horizons and 0.89 cmol$_{(+)}$kg^{-1} in Pedon 4–6.13 cmol$_{(+)}$kg^{-1} of Pedon 5 in the subsoil horizons. Generally, the Mg^{2+} content was rated as low to high in the study site of the soil pedons (Hazelton and Murphy, 2016). In the surface horizon, the lowest exchangeable K^{+} (0.38 cmol$_{(+)}$kg^{-1}) was recorded in pedon 4 (Alisols) and the highest (2.15 cmol$_{(+)}$kg^{-1}) was recorded in pedon 5 (Luvisols). In the subsoil horizon, the lowest K^{+} content (0.12 cmol$_{(+)}$kg^{-1}) was recorded under pedon 1 (Nitisols) and the highest (2.01 cmol$_{(+)}$kg^{-1}) was recorded under pedon 5 (Luvisols). As ratted by Hazelton and Murphy (2016), the exchangeable K^{+} varied from moderate to very high in surface horizons and differs from very low to very high in subsurface layers of all pedons and was not consistent with depth. Therefore, currently, the exchangeable K^{+} was not the limiting element for crop production in the study area. Exchangeable sodium (Na^{+}) is low throughout the profiles of the studied soils due to the parent material and the climate (high rainfall) doesn't lead to accumulation of Na^{+} in the soil.

As there is a strong relationship between CEC and OM, the CEC of surface horizons was higher than that of subsoil horizons. In the surface horizons, CEC varies from 33 cmol$_{(+)}$kg^{-1} soil (pedon 1) to 45 cmol$_{(+)}$kg^{-1} soil (pedon 6). CEC values generally show a systematic variation (decrease) with depth in pedons 1 and 6 and vary non-systematically with depth in other pedons. In the subsoil horizons, CEC varies between 22.6 cmol$_{(+)}$kg^{-1} soil (pedon 2) and 44 cmol$_{(+)}$kg^{-1} soil (pedon 6). Additionally, the CEC of clay Varied from 48.15 cmol$_{(+)}$kg^{-1} clay (pedon 1) to 101.68 cmol$_{(+)}$kg^{-1} clay (pedon 6) in the surface soils while at the subsoil horizons CEC of clay varied from 35.00 cmol$_{(+)}$kg^{-1} clay (pedon 4) to 108.84 cmol$_{(+)}$kg^{-1} clay (pedon 6). CEC of clay values generally show a systematic variation (increase) with depth in pedon 6 and vary non-systematically with depth in other pedons. The CEC of clay in the study area indicates more percentage of 2:1 clay minerals, most probably illite, montmorillonite, and vermiculite with greater nutrient reserves. The soil lab result of CEC of clay (Table 5) further revealed that Pedons 1, 2, and 3 were composed of illite and montmorillonite clay minerals, while pedons 4 and 5 were mainly composed of montmorillonite clay minerals and pedon 6 was composed of Vermiculite clay minerals. Generally, the CEC values of the soils studded were in the medium to very high range (FAO, 2006b) which had good nutrient retention and buffering capacity.

3.3.5. Cation ratios and nutrient balance in the studied pedons

3.3.5.1. The Ca/Mg ratio. The Ca: Mg ratio of surface horizons varies from 3:1, pedon 5 (Luvisols) to 3.6:1, pedon 3 (Nitisols) fell within (1–4:1), low Ca value for most crop production. As rated by Hazelton and Murphy (2016), the Ca: Mg ratio below 4:1 resulted in low availability of Ca that shows the probable shortage of Ca uptake because of surplus amount of Mg or washing out of basic cations by the high amount of rainfall. Across the soil depth, the Ca: Mg ratio was regularly decreased for most of the pedons (1, 3, 4, and 6) and irregularly distributed for other pedons (2 and 5). For the subsurface horizons, the lowest Ca: Mg ratio (2:1) was recorded for pedon 1 and the highest (3.7:1) was recorded under pedon 4 (Table 5). The Ca: Mg ratio trend in this study is similar to the work reported by Alemayehu et al. (2014) for soils along with the landscapes at Abobo, Southwestern low lands of Ethiopia.

3.3.5.2. Percent base saturation (PBS). The decrease of percent base saturation across the soil depth was inconsistent for all the pedons (Table 5). Percent base saturation of surface soil horizons ranged from 28% in Pedon 4 (Alisols) to 50% in Pedon 6 of (Cambisols). In the subsurface soils, PBS ranged from 10% in the Bt3 horizon (Pedon 4) to 63% in the bottom layer of the BC horizon (Pedon 6). This was most probably, the BC sub horizon was in the process of soil development and the bases were not leached out yet. According to the rating described by Hazelton and Murphy (2016), the PBS in the surface horizon was in the range of

Table 5. CEC, exch. bases and BS percent of Nitisols, Alisols, Luvisols, and Cambisols profiles.

Depth	Horizon	Cmol(+)/kg							Ca/mg Ratio	BS (%)
		CEC	CEC clay	Ca^{2+}	Mg^{2+}	K^+	Na^+	Sum		
Pedon 1: BA/SK1/NT										
0–20	Ap	33	48.15	6.93	2.27	0.54	0.14	9.88	3.05	30
20–50	Bt1	34	52.51	6.79	2.53	0.19	0.18	9.69	2.68	28
50–80	Bt2	29	49.39	7.07	2.71	0.15	0.14	10.07	2.61	37
80–125	Bt3	28	45.28	5.40	2.12	0.12	0.15	7.79	2.55	28
125–145	Bt4	27	63.37	5.73	2.5	0.12	0.15	8.5	2.29	32
$145–200^+$		26	56.66	5.47	2.75	0.12	0.14	8.48	1.99	33
Mean	29.5	25.56	6.23	2.48	0.20	0.15	9.06	2.52	31.33	
SE	1.33	2.68	0.31	0.10	0.06	0.01	0.38	0.14	0.40	
Pedon 2: BA/SK2/NT										
0–20	Ap	34	61.44	10.03	2.99	1.08	0.19	14.29	3.35	42
20–62	A	29	49.36	7.39	3.04	0.52	0.15	11.10	2.43	38
62–110	B	23	40.46	6.46	2.33	0.22	0.14	9.15	2.77	40
$110-190^+$	Bt1	27	41.52	5.87	1.94	0.19	0.22	8.22	3.03	31
Mean	28.25	48.19	7.43	2.57	0.50	0.17	10.69	2.89	37.75	
SE	2.28	4.84	0.91	0.26	0.20	0.01	1.34	0.19	2.39	
Pedon 3: BA/CD1/NT										
0–15	Ap	36	78.20	8.92	2.44	1.27	0.15	12.78	3.66	36
15–28	A	38	89.35	8.50	2.18	0.44	0.11	11.23	3.90	29
28–60	Bt1	25	44.46	5.47	2.16	0.28	0.12	8.03	2.53	32
60–140	Bt2	21	40.78	4.89	1.98	0.79	0.13	7.79	2.47	38
$140–200^+$	Bt3	29	46.92	5.09	2.21	0.62	0.14	8.06	2.30	28
Mean	29.80	59.94	6.57	2.19	0.68	0.13	9.57	2.97	32.60	
SE	3.21	9.93	0.87	0.07	0.17	0.01	1.02	0.33	1.93	
Pedon 4: BA/TS1/AL										
0–20	Ap	35	62.09	7.27	2.00	0.38	0.20	9.85	3.64	28
20–50	AB	36	88.98	6.72	2.25	0.19	0.21	9.37	2.99	26
50–80	Bt1	38	72.51	8.41	2.26	0.18	0.24	11.09	3.72	29
80–110	Bt2	37	68.31	7.13	2.00	0.17	0.28	9.58	3.57	26
110–153	Bt3	41	76.58	2.69	0.89	0.12	0.27	3.97	3.02	10
$153-200^+$	Bt4	23	35.00	4.14	1.25	0.14	0.26	5.79	3.31	25
Mean	35	67.24	6.06	1.77	0.19	0.24	0.27	0.34	24	
SE	2.54	7.42	0.88	0.23	0.03	0.01	1.12	0.12	2.86	
Pedon 5: BA/CD2/LV										
0–18	Ap	44	93.83	12.74	4.21	2.15	0.13	19.23	3.03	44
18–50	Bt1	40	70.70	13.45	4.89	2.01	0.17	20.52	2.75	52
50–102	B	43	98.18	13.84	6.13	1.95	0.15	22.07	2.26	51
Mean	42.33	87.57	13.34	5.07	2.03	0.15	20.60	2.68	49	
SE	1.20	8.52	0.32	0.56	0.05	0.01.821	0.82	0.22	2.51	
Pedon 6: BA/CD3/CM										
0–10	Ap	45	101.68	15.31	4.64	2.04	0.13	22.12	3.30	50
10–28	B	44	106.83	14.94	4.78	1.39	0.13	21.24	3.13	48
28–55	BC	41	108.84	18.64	6.22	0.81	0.20	25.87	3.00	63
Mean	43.33	105.78	16.29	5.21	1.41	0.15	23.07	3.14	53.66	
SE	1.20	2.13	1.17	0.50	0.35	0.02	1.41	0.08	4.70	

Note: BA, Bako-Tibe; CD1, CD2, CD3 = Cheka Dimtu kebele field (pit) 3,5and 6 respectively; NT, Nitisols; SK1 and Sk2, Sadan Kite kebele, field (pit) 1 and 2 and TS1, Tulisangota kebele; Lv, Luvisols, AL = Alisols; SE = standard error.

low (20–40%) in Pedon 4 to moderate (40–60%) in (pedons 6) and very low (0–10%) in pedon 4 to high (63%) in the subsurface layer. The variation observed in PBS indicates the degree of leaching which was used as a diagnostic character for classifying soils (Meena, 2014). Furthermore, the low PBS of the soils might indicate the leaching of bases due to the high rainfall in the study area.

3.3.5.3. Available Micronutrients (Fe, Mn, Zn, Cu, and B). The available micronutrients (Fe, Mn, Zn, Cu, and B) content in all pedons had irregular trends along with soil depth (Table 6). For this study, the ratting of soil's micronutrient content was based on the criteria set by (Ransom, 2004). Accordingly, the concentration of available Fe for surface horizons was in the range of high (201.9 mg kg^{-1}) pedon 4 to very high (276.1 mg kg^{-1}) pedon 6. For the subsurface horizon, the concentration of available Fe was in the high range (53–185 mg kg^{-1}). In the surface layer, the available Mn content was very high (between 169 to 293.6 mg kg^{-1}) in pedons 4 and 5 respectively and moderate (20 mg kg^{-1}) to very high (130 mg kg^{-1}) in the subsurface horizon of pedon 4 and 5 respectively. For the surface soil layer, the available Zn content was in the moderate to high range (0.9–1.57 mg kg^{-1}) under pedon 4 and 5 respectively and for

Table 6. Available micronutrients in Nitisols, Alisols, Luvisols, and Cambisols profiles.

Depth (cm)	Horizon	mg kg^{-1}				
		Fe	Mn	Zn	Cu	B
Pedon 1: BA/SK1/NT						
0–20	Ap	229	255	1.31	3.16	0.48
20–50	Bt1	141	157	0.9	2.19	0.45
50–80	Bt2	115	126	0.78	1.87	0.45
80–125	Bt3	65	63.3	0.24	1.29	0.41
125–145	Bt4	91	111	0.26	1.26	0.45
145-200^{+}	Bt5	76	86.5	0.34	1.11	0.37
Mean		119.50	133.13	0.63	1.81	0.43
SE		24.59	27.69	0.63	1.81	0.45
Pedon 2: BA/SK2/NT						
0–20	Ap	248	273	1.44	3.25	0.32
20–62	A	79	67	0.32	1.58	0.40
62–110	B	63	65	0.35	1.34	0.46
110-190^{+}	Bt1	75	91	0.20	1.34	0.48
Mean		116.25	124	0.57	1.87	0.41
SE		44.04	50.01	0.28	0.46	0.03
Pedon 3: BA/CD1/NT						
0–15	Ap	246	238	1.38	3.53	0.22
15–28	A	233	189	1.16	3.15	0.12
28–60	Bt1	96	108	0.22	1.22	0.27
60–140	Bt2	66	81	0.16	1.11	0.26
140–200^{+}	Bt3	99	128	0.34	1.31	0.34
Mean		148	148.80	0.65	2.06	0.24
SE		37.85	28.51	0.25	0.52	0.13
Pedon 4: BA/TS1/AL						
0–20	Ap	202	169	0.90	2.90	0.38
20–50	AB	177	105	0.56	3.02	0.50
50–80	Bt1	185	118	0.47	2.87	0.49
80–110	Bt2	104	46	0.37	2.53	0.52
110–153	Bt3	53	20	0.20	1.73	0.59
153-200^{+}	Bt4	64	59	0.36	1.38	0.51
Mean		130.53	86.16	0.47	2.40	0.49
SE		26.69	22.32	0.09	0.28	0.02
Pedon 5: BA/CD2/LV						
0–18	Ap	253	294	1.57	1.44	0.24
18–50	Bt1	137	130	0.53	1.52	0.30
50–102	B	112	94	0.39	1.30	0.41
Mean		167.33	172.66	0.83	1.42	0.31
SE		43.43	61.55	0.37	0.06	0.04
Pedon 6: BA/CD3/CM						
0–10	Ap	276	244	1.20	1.69	0.26
10–28	B	158	119	0.35	1.25	0.36
28–55	BC	143	102	0.33	1.24	0.44
Mean		192.33	155	0.62	1.39	0.35
SE		42.05	44.76	0.28	0.14	0.05

Fe, iron; Mn, manganese; Zn, Zinc; Cu, copper; B, boron, SE = standard error.

subsurface horizons the lowest (0.16 mg kg^{-1}) and highest (0.36 mg kg^{-1}) Zn content were also recorded under pedon 3 and 4respectively. According to (Ransom, 2004), the surface horizon was in the range of moderate to high and the subsurface horizons were in the range of very low to low in its Zn content. The distribution of Cu was consistently decreased across the soil depth, which might be attributed to the strong association of Cu with soil organic matter. For the surface horizons, the lowest Cu content (1.44 mg kg^{-1}) was recorded under Pedon 5 and the highest (3.53 mg kg^{-1}) was under pedon 3. In the subsurface horizon, the lowest (1.11 mg kg^{-1}) and highest (2.87 mg kg^{-1}) Cu content was recorded under pedon 1 and pedon 4 respectively. Based on the above ratting, the Cu content of surface and subsurface horizons was in the low to the medium range which was insufficient for crop production.

The distribution of B follows an irregular train across the soil depth. The lowest (0.22 mg kg^{-1}) and highest (0.38 mg kg^{-1}) content of B at surface horizons was recorded in pedon 3 and pedon 4 correspondingly. In the subsurface horizon, the lowest (0.0.26 mg kg^{-1}) and highest (0.59 mg kg^{-1}) B content were recorded in pedon 3 and pedon 4 respectively. Bothe in the surface and subsurface horizon, the lowest exchangeable B was recorded in pedon 3 and the highest was recorded under pedon 4. The B content of surface and subsurface horizons was in a very low to low range (Ransom, 2004). Application of external B inputs is highly important for optimum crop production.

4. Soil classification based on WRB

Pedon 1 was described at the upper slope and it was deep, clay in texture and strongly developed angular blocky structure, > 30% clay, silt/clay ratio of <0.4, CEC of <36 cmol$_{(+)}$kg^{-1}, medium in OC but low in PBS. These attributes of the pedon qualify the diagnostic criteria for *Nitic* subsurface horizon. Also, the pedon has a base saturation of less than 50% between 20 and 50 cm of the soil surface, which qualifies for the *hyperdystric* principal qualifier. 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. Accordingly, the soil is classified as Hyperdystric Nitisols (Humic) (IUSS Working Group WRB, 2015).

Pedon 2 and 3 were described at middle slope position and deep, clay in texture and strongly developed angular blocky structure, > 30% clay, silt/clay ratio of <0.4, CEC of <36 cmol$_{(+)}$kg^{-1}, moderate in OC but low in PBS. These attributes of the pedon qualify the diagnostic criteria for *Nitic* subsurface horizon. Also, the pedon has a base saturation of less than 50% between 20 and 50 cm of the soil surface, and >0.6% OC content with a layer of >20 cm thick which qualifies for *Umbric* principal qualifier. Based on the diagnostic horizon and the qualifiers identified, the soil is classified as *Umbric* Nitisols (IUSS Working Group WRB, 2015).

Pedon 4 was described at the cultivated land of the middle slope positions. There was lower clay content in the topsoil than in the subsoil. An illuvial accumulation of clay formed *argic* subsoil horizon. The soils had high activity clays (CEC >24 cmol$_{(+)}$kg^{-1} soil) throughout the *argic* horizon and low base saturation in the 50–100 cm depth satisfy the definition of Alisols as a reference soil group. Within 25 and 150 cm of the soil surface, the soils have a layer ≥30 cm thick, that has, in ≥90% of its exposed area, a Munsell color hue redder than 5YR moist, a value of <4 (moist) prefixed as *Rhodic.* However, the presence of a base saturation of <50%; between 20 to 50 cm from the surface makes the use of *Hyperdystric* supplementary qualifier to classify the soil as Rhodic Alisols (*Hyperdystric*).

Pedon 5 was described at the cultivated land at the upper slope positions. There was higher clay content in the subsoil than in the topsoil. An illuvial accumulation of clay formed *argic* subsoil horizon (Bt1). Soils with high activity clays (CEC >24 cmol$_{(+)}$kg^{-1} soil) throughout the *argic* horizon and high base saturation in the 50–100 cm depth satisfy the definition of Luvisols as a reference soil group. Within 25 and 150 cm of the soil surface, the soils have a layer ≥30 cm thick in ≥90% of its exposed area, a Munsell color hue redder than 5YR moist, and a value of <4 moist, prefixed as *Rhodic.* However, the presence of a base saturation of ≥50%; between 20 to 50 cm from the surface makes the use of Hypereutric supplementary qualifier to classify the soil as Rhodic Luvisols (Hypereutric).

Pedon 6 was described at the upper slope position of the cultivated land. Soils in this pedon have a strong medium to coarse sub-angular blocky structure, sandy clay in texture, silt/clay ratio of >0.4, evidence of pedogenic alteration, and absence of illuviated clay that satisfies the definition of Cambisols as a reference soil group and the Cambic horizon (B) has higher clay content and OM than the underlying horizon (BC), a Munsell color hue ≥2.5, Chroma of >1, clay content of >4%. Since continuous rock starting ≤100 cm from the soil surface, Leptic is

Table 7. Land capability parameters and thresholds (USDA, 2007) (Rossiter, 2011).

Parameters	Land capability class (LCC)							
	I	II	III	IV	V	VI	VII	VIII
Slope (L) %	0 to 2	2 to 8	8 to 15	15 to 30	0 to 30	30 to 50	>60	0 to 50
Erosion (e)	No sign to slightly	Moderate	severe	Very severe	None or slight	Not class determining		
Stoniness (% area coverage)	0–40	>40				>40		
Soil depth (cm)	>100 deep and very deep	>100 deep and very deep	50–100 Moderately dep	25–49 Shallow	25–49 Shallow	25-49 shallow	10–24 Very shallow	<10 extre. shallow
Soil drainage	Never saturated	Never saturated	Rarely saturated	Saturated for a short period	Saturated for a long period			
Soil texture (t)	L, LS, SL	Si, SCLSiCL, SiL CL	SiC, SC	S, C		Any		
AWC at rooting depth (mm m^{-1})	>100 from moderate to high	>100 from moderate to high	51–99 low	<50 very low	–	–	–	–
pH	5.5–7.9	4.5–7.5 or 7.9–8.4	<4.5 or >8.4			<4.5 or >8.4		
OC (%)	>1	0.8–1	0.6–0.8	0.4–0.6		0.2–0.4	–	–
CEC (cmol$_{(+)}$ kg^{-1} soil)	>10 Good	5- 10 partly good	<5 Moderate	Any Low	Any From good to low	Any From good to low	Any Very low	any
Base saturation (%)	>50 Good	35- 50 partly good	<35 Moderate	Any Low	Any From good to low	Any From good to low	Any Very low	any

L = loam; SL = sandy loam; LS = loamy sand; Si = silt; SCL = sandy clay loam; SiL = silty loam; CL = clay loam; SiC = silty clay; SC = sandy clay; S = sand; C = clay.

Table 8. Land capability indices of the study sites.

Pedon (P)	Land capability Classes
P1	IIIes
P2	IIs
P3	IIIes
P4	IIs
P5	IIIes
P6	Ives

e = erosion is the dominant problem; s = soil limitations within the rooting zone.

prefixed; whereas the presence of more than 1% OC to a depth of 50 cm from the mineral soil surface indicates the soil has a *humic* supplementary qualifier. Based on the diagnostic horizon and the qualifiers identified, the soil is classified as Leptic Cambisols (Humic) (IUSS Working Group WRB, 2015).

5. Land capability classification

The land characterization was carried out based on the USDA system of land capability classification (LCC) (Table 7). The lands on which the pedons opened were capable of crop production with some limitations of erosion (e), soil fertility (s), and slope (L). Accordingly, Pedon 1, 3, and 5 were grouped under LCC IIIes, Pedon 2 and 4 were categorized under IIs, and Pedon 6 was rated as LCC IVes (Table 8). The land characteristics of the studied pedons 1–6 were displayed in Table 9. The major limitations for pedon 1 were severe sheet erosion, low soil reaction, and low present base saturation, and moderate soil chemical fertility. Pedon 2, the land was affected by moderate rill erosion and partly good in chemical fertility. Pedon 3 was affected by moderate rill erosion and slow runoff and the land has moderate chemical fertility. Pedon 4 was strongly acidic in reaction and also low (28.84%) in percent base saturation. Pedon 5 exhibits severe limitations such as severe sheet and slight gully erosions, 25% stone coverage, and low (23.10) percent base saturation. The land has moderate chemical fertility. Pedon 6 has limitations due to severe rill and slight gully erosion, 19% slope, shallow rooting depth (55 cm), and 40% stony coverage. The land was affected by rapid surface runoff and minimum AWC storage and low chemical fertility compared to other pedons.

6. Summary and conclusions

Detailed information on soil properties used for soil characterization and grouping is essential to design effective land use planning, soil fertility management, and boosting agricultural crop production. Soil classification is useful to identify the most suitable use of soil, estimating production, facilitate technology transfer, and knowledge exchange

Table 9. Land characteristics of the pedon studied.

Pedons	Slope (%)	Soil depth (cm)	AWC at rooting depth (mm)	Texture	Stoniness (%)	Past erosion	Drainage	pH 1:2.5	OC %	CEC (cmol$_{(+)}$ kg^{-1} soil)	BS (%)
P 1	8	>200	110	C	None	Mo	Well	5.49	2.28	31.92	28.85
P 2	6	190	160	C	None	Mo	Well	5.89	2.37	33.60	59.70
P 3	9	>200	140	C	None	Mo	Well	5.76	1.96	32.56	64.19
P 4	3	>200	110	C	None	Mo	Well	5.46	2.56	34.80	28.84
P 5	10	102	110	C	25	Sev	well	5.80	2.15	48.79	23.10
P 6	19	55	100	SC	40	Very Sev	well	5.94	1.93	41.09	33.13

Note: C = clay, SC = sandy clay; Mo = moderate; s = severe.

between soil scientists, policymakers, planners, researchers, and agricultural extension consultants.

According to the studied morphological, physical, and chemical parameters, the soils under this study were: pedon 1, Dystric, Rhodic Nitisols (Humic); pedon 2, Dystric Nitisols (Humic); pedon 3, Umbric Nitisols; pedon 4, Rhodic Alisols (Hyperdystric); pedon 5, Rhodic Luvisols (Hypereutric); pedon 6, Leptic Cambisols (Humic).

The land capability classification is a grouping of lands according to their limitations that is also used as a guide to evaluating the suitability of the land for agricultural activities. According to USDA land capability classification, pedons 2 and 4 (LCC IIs) were good lands with moderate limitations. Counter cultivation and growing of cover crops are helpful for the wise management of these lands. pedons 1, 3, and 5 (LCC IIIes) have severe limitations and the integrated use of cover crops, contour plowing and the use of graded bunds are necessary to reduce the problem of soil erosion and land degradation. The growth of acid-sensitive crops such as barley and alfalfa may be affected by acidic soil reaction and liming is important to correct this problem. Pedon 6 (LCC IVes) is fairly good land and has very severe limitations. Finally, based on this information, the community should use the land according to its capability and treat it as per its need.

Declarations

Author contribution statement

Berhanu Dinssa; Eyasu Elias: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data will be made available on request.

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The authors declare no conflict of interest.

Additional information

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