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Characterization and Classification of Soils of Zamra Irrigation Scheme, Northeastern Ethiopia

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ABSTRACT: Understanding soil types of a given area is an important prerequisite to design optimum management strategies such as irrigation water management. The study was thus conducted on characterization and classification of Zamra irrigation scheme in Abergelle district of Amhara Region, which has an area of 196.16 ha. For this study, 53 auger observations, four profile pits, extensive visual observations, reconnaissance survey, and descriptions of soil profiles and laboratory analysis were used to study the morphological and physicochemical properties of the soils of the scheme. Twelve disturbed and undisturbed soil samples were collected from all profiles of each genetic horizon for laboratory analysis. The soils of the study area were identified based on Food and Agricultural Organization of the United Nations/World Reference Base for Soil Resources (FAO/WRB) 2015. The results revealed that the textural classes of all profiles of the study site ranged from sandy clay loam to sandy loam. The chemical properties of the soil in terms of total nitrogen, organic matter, and available phosphorus were in the very low and low categories as per the criteria developed by Tekalign and Olsen, respectively, whereas exchangeable bases (Ca, Mg, K, and Na), cation exchange capacity, and extractable micronutrients (Fe, Mn, Zn, and Cu) were medium to high. Based on morphological, physical, and chemical analyses, the soils were classified as Leptic Regosols (Eutric, Loamic; 21.99% of the area), Vertic Cambisols (Hypereutric; 17.87%), Haplic Regosols (Eutric; 36.69%), and Rhodic Nitisols (Eutric; 23.44%). Therefore, management techniques that enhance soil fertility (including crop rotations, manuring, fallow periods, proper management of crop residues, and leguminous cover crops) and water-saving technologies suitable to the terrain of the area are the best options to enhance land productivity in the area.

KEYWORDS: Morphology, chemical property, physical properties, soil profile, soil horizon, soil

TYPE: Original Research

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Introduction

Soils are natural bodies of various ages that evolve through pedogenic processes, depending on the type of parent materials and relief under a specific climate, and thus specific vegetation and litter with the characteristic of biotic communities (Blume et al., 2016). These factors of soil formation are interdependent. Changing one of these soil-forming factors causes change to others, and this presents differences in soil patterns (Malo, 2006). Soils show variation at different times within the development of a landscape. Hurni et al. (2007) confirm that due to high variation in soil-forming factors such as climate, topography, parent material, and vegetation from place to place, the types of soils occurring in the various regions of Ethiopia are diverse. Similarly, Mesfin (1998) reported that soil types and characteristics show great variations across the regions of Ethiopia because of the country's wide range of topographic, geologic, and climatic features. Various studies on soil properties at a watershed level as well as in farmlands of Ethiopia also confirm that topographic position largely governs the change in types and characteristics of soils (Abayneh et al., 2001; Assefa, 2002; Ali et al., 2010; Beyene, 2011; Hagos et al., 2015). Pedogenesis influences soil type and characteristics, which in turn influence the use and productivity of the soils (Mesfin, 1998). Knowledge of the soil resource is of huge importance in any agricultural system. According to Breimer et al. (1986), pedological studies provide a better understanding of spatial changes in the characteristics of the soil continuum so that soils may be used more efficiently for the benefit of mankind. Hence, for appropriate land use and soil management practices, reliable soil data are required, but adequate such data are not currently available in Ethiopia. However, the previous soil resource studies are characterized by their small scales with a high level of generalization. To address this problem, intensive research work is mandatory in all irrigation schemes, particularly in dryland and remote areas such as Abergelle district. Nevertheless, the soil of this irrigation site and the district is not yet well studied. Therefore, this study was initiated with the objectives to characterize and classify the soils of Zamra irrigation scheme of Abergelle district of Amhara Region, Ethiopia.

Materials and Methods

Description of the study area

The study was conducted at Zamra irrigation scheme, which is located at Abergelle district of Wag Himra *Zone* in northeastern Ethiopia (Figure 1). The district is located about 65 km north of Sekota town (Wag-Himra *Zonal* Capital) and 785 km north of Addis Ababa. The geographical location of the scheme is 13°01′37.50″ latitude and 38°58′36.50″ longitude with an altitude of 1,270 meters above sea level (m a.s.l). The climate of the study area is characterized by unimodal rainfall characteristics, and the rainfall pattern has a high amount of rainfall occurring during the main rainy season of July and August. Nine years of climatic data were obtained from "MarkSimWeather file generator" (2018), and the study area indicates that the mean annual rainfall is 622.37 mm with erratic and uneven

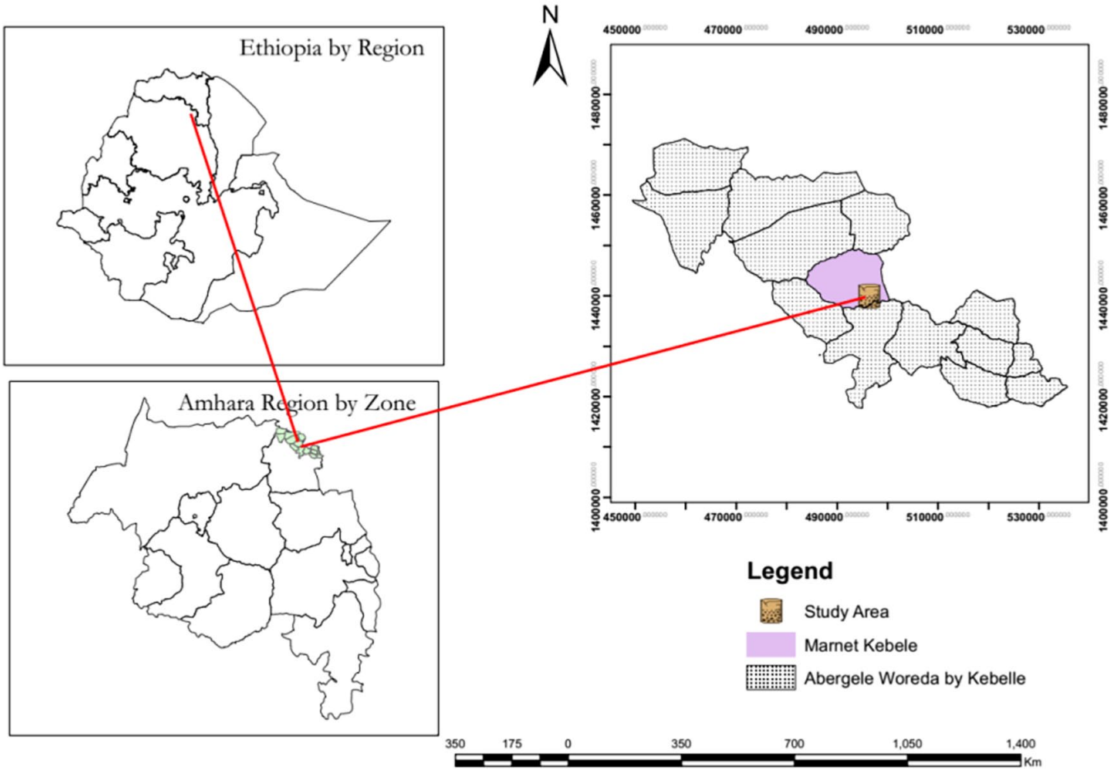

Figure 1. Location map of the study area.

distribution over seasons and years. The mean minimum and maximum annual air temperatures of the area are 19.19°C and 36.08°C, respectively, with a mean annual air temperature of 24.54°C. According to Sembroni et al. (2017), the geology of Tekeze basin is characterized by a Precambrian basement unconformably overlain by a Paleozoic–Mesozoic sedimentary succession capped by Tertiary volcanics. These rocks are deformed by several Neoproterozoic to present tectonic structures, including folds, faults, shear zones, and lineaments.

Table 1. Characteristics of the Soil Mapping Units (SMU) in the Study Area.

PROFILE NAME	DEPTH (CM)	SLOPE (%)	SOIL COLOR	TEXTURE (BY FEEL METHOD)
SMU1	>120	3–5	Red	Sandy clay loam
SMU2	>120	0–3	Dark brown	Sandy clay loam
SMU3	>120	5–8	Reddish yellow	Sandy loam
SMU4	<50	>8	Light red	Sandy loam

Field survey and pedon site selection

A topographic map (1:50,000) of the study area was obtained from the Ethiopian Mapping Agency and used to get general information about the area and to define the preliminary boundary of the irrigation site before starting the actual field survey. A reconnaissance field visit was carried out to have a general overview of the variation in the land surface of the irrigation site. After preliminary site observation and boundary delineation, auger observations were made to study the characteristics of the farmland. Fifty-three auger samples from different areas of the scheme (196.16 ha) were taken to characterize soil variation in the study area. The auger observation points (53) were geo-referenced using a global positioning system (GPS Garmin 65s). The auger observations were employed using an "Edelman" auger to a depth of 1.2 m to identify variation in soil depth and texture characteristics. In addition to auger observations, soil color (Munsell color chart), slope (clinometers), and texture by feel method in each augering point were observed in the field to identify similar/homogeneous land units. The slope of the scheme was divided into four categories (0–3, 3–5, 5–8, and >8). Four mapping units were distinguished (Table 1), and the area of each of the mapping units was delineated and mapped using arc GIS 10.2.1 software (Esri, Redlands, CA, USA). One pit was opened in each of the four mapping units to expose a 1.5-m wide by 2-m deep soil profile.

Soil profile description and sampling

The soil field descriptions were done according to the Food and Agricultural Organization (FAO, 2006a) guidelines for soil profile and site descriptions. Important morphological and physical properties along with other relevant site information were recorded on a standard profile description sheet in the field. Soil samples were collected from each genetic horizon, starting with the lowest horizon and working to the uppermost to avoid contamination for laboratory analysis. The soil profiles were divided according to the evidence of pedogenic horizon development and described using the procedures outlined by FAO (2006a), and the color of each layer (both in moist and in dry conditions) was interpreted with the help of the Munsell color chart (Munsell, 2000). A total of 12 disturbed and 12 undisturbed soil samples were collected from each evident genetic horizon for laboratory analysis. The undisturbed soil samples were collected for the determination of bulk density (BD) using a core sampler.

Soil sample preparation

Soil samples collected from each horizon in the soil profiles were bagged, labeled, and transported to Sekota Dryland Agricultural Research Center (SDARC) and Amhara Design and Supervision Soil Laboratories for preparation and analysis of selected soil physicochemical properties following standard laboratory procedures. In preparation for laboratory analysis, the soil samples were air-dried in shade, ground with pestle and mortar, and made to pass through a 2-mm sieve. For organic carbon (OC) and total N, the soil samples were passed through 0.5 mm sieve to avoid coarser material. The bulk densities of the soils were determined from samples collected using the core sampler.

Laboratory analysis

Physical properties. The particle size distribution of the soil was analyzed by the Bouyoucos hydrometer method (Day, 1965). The Bulk density (BD) of the soil was estimated from undisturbed soil samples collected using a core sampler from the determined horizons and weighed at field moisture and then determined following the procedures described by Blake (1965).

Total porosity was estimated using Equation 1, assuming an average particle density (PD) value of 2.65 g cm^{-3}:

$$P\ (\%)\ =\ \left[1-\frac{BD}{PD}\right]\times\ 100 \qquad (1)$$

where P is the total porosity (%), PD is the particle density, which is assumed to be 2.65 g cm^{-3}, and BD is the bulk density (g cm^{-3}) (Hazelton & Murphy, 2007). The moisture contents at field capacity (FC) and gravimetric water content (PWP) were measured at soil water potentials of −0.33 bar and −15 bar, respectively, using the pressure plate apparatus technique (Richards, 1965)

The depth of available water content (AWC; mm m^{-1}) was determined using Equation 2:

$$AWC=1{,}000\times\left[\frac{FC-PWP}{100}\right]\times AS \qquad (2)$$

where AWC is the available water content (mm m^{-1}), FC is the gravimetric water content at field capacity (% weight), PWP is the gravimetric water content at permanent wilting point (% weight), and AS is the apparent specific gravity (the ratio of soil BD to the density of water) (Asawa, 2005).

Chemical properties. The parameters soil pH, electrical conductivity (EC), OC, total N, available P, exchangeable bases (Ca, Mg, K, and Na), cation exchange capacity (CEC), and micronutrients (Fe, Mn, Zn, and Cu) were analyzed in the laboratory. Soil pH was measured using a pH meter method in the supernatant suspension of 1:2.5 soil to water ratio described by Carter and Gregorich (2008). EC was measured with a conductivity meter in a soil–water extract (Okalebo et al., 2002). OC was determined following the wet digestion method as described by Walkley and Black (1934), whereas the percentage of organic matter of the soils was determined by multiplying the percent OC value by 1.724. Soil total nitrogen (TN) was analyzed by the wet-oxidation procedure of the Kjeldahl method (Bremner & Mulvaney, 1982). The available phosphorus was determined by the standard Olsen method (Olsen et al., 1954). Cation exchange capacity was determined at soil pH 7 after displacement using the 1-N ammonium acetate method in which it was, subsequently, estimated titrimetrically by distillation of ammonium that was displaced by sodium (Chapman, 1965). Exchangeable Ca and Mg were measured from the extract with atomic absorption spectrophotometer, whereas exchangeable K and Na were determined from the same extracts with flame photometer as described by Rowell (1994). Calcium carbonate content was determined following the acid neutralization method in which the soil carbonate was decomposed by excess standard HCl solution and back-titrated with standard NaOH after filtering it (Jackson, 1973).

Percent base saturation (PBS) was calculated using Equation 3 (Hazelton & Murphy, 2007):

$$PBS\ =\left(\frac{\text{Sum of Exchangeable bases}}{\text{CEC}}\right)\times 100 \qquad (3)$$

Extractable micronutrient (Fe, Mn, Zn, and Cu) contents of the soils were extracted by the DTPA (diethylenetriaminepentaacetic acid) method (Lindsay & Norvell, 1978), and the contents in the extract were determined by atomic absorption spectrophotometer.

Statistical analysis

Simple descriptive statistics were used to analyze the data obtained. Critical levels defined by different authors were also used to evaluate the figures obtained from the lab. Soil types were identified based on the methods described by FAO/WRB (2015). Simple linear correlation analysis was used to explore the magnitude and direction of relationships among the soil physicochemical properties with the help of the Statistical Analysis System (SAS, 2003) version 9.1.0 model (IMB crop.

Armonk NY USA). The soil map of the study area was prepared using Arc GIS 10.2.1.

Results and Discussion

Morphological characteristics of the studied soils

The depths of the studied profiles varied from shallow (39 cm) to very deep (178 cm). The morphological characteristics of the profiles are summarized in Table 2.

Physical characteristics of the pedons

Texture. The sand proportion was the highest in all horizons of the profiles, and as a result, the textural classes of the soils of the study sites were sandy loam and sandy clay loam (Table 3). The sand contents of all soil profiles show an unsystematic pattern with increasing depth.

Bulk densities and total porosity

The BD values of surface soil ranged from low to moderate (1.38 g cm^{-3}) in Profiles 2 and 3 to 1.45 g cm^{-3} in Profile 1. In Profiles 2, 3, and 4, BD increased with soil depth (Table 3). The values ranged from 1.38 to 1.45 g cm^{-3} in the Ap horizon (surface soil) and from 1.40 to 1.57 g cm^{-3} in the subsurface soils. In subsurface soils, the BD value ranged from 1.40 g cm^{-3} in Profile 1 to 1.57 g cm^{-3} in Profile 3. Thus, the relatively highest value of BD was found in subsurface soil. According to Hazelton and Murphy (2007), BD rating <1 is very low; 1–1.3, low; 1.3–1.6, moderate; 1.6–1.9, high; and >1.9%, very high. The bulk densities in the studied area ranged from low to moderate. The moderate values show that BD is not expected to cause root and water movement restriction in these soils. The result is in line with Brady and Weil (2008), who reported that the BD of soil increases with increasing soil depth. Nevertheless, the BD values of all profiles of the study soils are favorable for crop production. According to Zonn (1986), these values are within the common range for tropical soils and would favor crop growth. The total porosity of the surface soil ranged from 44.94% (Profile 1) to 48.02% (Profiles 2 and 4), whereas in the subsurface soil it ranged from 40.75% (Profile 3) to 46.86% (Profile 1). Hence, the value of total porosity lies within the usual range of 30% to 70% (Hazelton & Murphy, 2007).

Soil moisture content

Relatively higher water content at FC and PWP was recorded in surface soils compared with subsurface soils for Profiles 2 and 3, whereas in Profiles 1 and 4 it showed an unsystematic trend (Table 3). Surface soil water retention at FC of the soils of the study area ranged from 21.5% in Profile 1 to 32.3% in Profile 2, whereas in the subsurface horizons it ranged from 20.1% in Profile 3 to 31.6% in Profile 2. The relatively higher water retention was recorded in Profile 2 which had relatively higher clay content compared with the other profiles, which might cause higher water retention. This is supported by the positive and significant correlation between clay content and water retention at FC (r = .76**) and PWP (r = .72**) (Table 4).

AWC showed an unclear trend, increasing or decreasing with depth in all profiles. This unsystemic trend for AWC might be due to variability in soil texture, OM content, rooting depth, and structure of the soil (Miller & Donahue, 1995). In surface soils, AWC ranged from 117.45 to 190.44 mm m^{-1}, whereas values from 93.33 to 216.08 mm m^{-1} were recorded in the subsurface soil. According to McIntyre (1974), the AWC of the surface soils was rated as medium (100–200 mm m^{-1}), and in the subsurface it varied from very low (<100 mm m^{-1}) to high (>200 mm m^{-1}).

Chemical characteristics of the studied soils

Soil pH, EC, and calcium carbonate content

Soil pH. The pH (H_2O) values of soils of the study area varied from 6.2 to 7.3, which is slightly acid to neutral (Tadesse, 1991) (Table 5). The lowest pH values were found in the surface soils at each sites, with higher pH values at depth.

Similar results were observed and reported by Ali et al. (2010), Sharu et al. (2013), Assen and Yilma (2010), and Yitbarek et al. (2018). This slight increase in pH with depth might be due to movement cations from surface soil to subsurface soil. Ayalew and Beyene (2012) confirmed that an increase in soil pH with depth may indicate the presence of vertical movements of exchangeable bases, and fewer H^+ ions are released from the decomposition of organic matter, which is caused by decreased organic matter content with depth. All soil pH values documented at the study site are favorable for most agricultural crops (Landon, 1991).

EC and calcium carbonate content

The highest EC value of 0.32 ds m^{-1} was recorded in subsurface soils of Profile 2, whereas the lowest value (0.06 ds m^{-1}) was recorded in Profile 4. The EC values indicate non-saline soils. The EC values measured in the studied soils indicated that the concentrations of soluble salts are below the levels at which growth and productivity of most agricultural crops are affected due to soil salinity (Landon, 1991; United States Salinity Laboratory Staff, 1954).

Calcium carbonate content of the surface soils ranged from 0.5% (Profile 1) to 3% (Profile 4), whereas in the subsurface soils it ranged from 0.6% to 3.8%. Relatively higher calcium carbonate content was recorded in the subsurface compared with surface soil; this might be due to the parent material.

Total Nitrogen (TN). The TN content of the studied surface and subsurface soils for all profiles ranged between 0.019% and 0.031% (Table 5) and was rated as very low (Tadesse, 1991). The trends showed a slight decrease with depth in

Table 2. Morphological Characteristics of the Soil.

DEPTH CM	HORIZON	COLOR		STRUCTURE			CONSISTENCE WET				HORIZON BOUNDARY	
		DRY	MOIST	GRADE	CLASS	TYPE	STICKINESS	PLASTICITY	DRY	MOIST	TOPO	DISTI
			PROFILE 1									
0–25	Ap	5YR4/6	2.5YR3/6	ST	VF	AB	SST	SPL	SHA	VFR	I	D
25–63	AB	2.5YR3/6	5YR3/4	ST	FI	SB	SST	VPL	HA	FR	I	C
63–113	B	2.5YR2/6	2.5YR3/4	MO	FI	SB	SST	PL	VHA	VFR	W	D
113–178	C	2.5YR5/8	10R5/4	WE	VC	GR	NST	PL	SO	LO	–	–
			PROFILE 2									
0–22	Ap	10YR3/4	7.5YR3/4	MO	ME	GR	VST	VPL	HA	FR	S	D
22–109	B	10YR3/3	7.5YR3/2	ST	VC	SB	VST	VPL	VHA	FR	S	C
109–167	C	2.5Y3/2	5Y5/4	MO	FI	PL	ST	PL	HA	VFR	–	–
			PROFILE 3									
0–20	Ap	7.5YR8/6	7.5YR4/4	MO	FI	AB	ST	VPL	SHA	VFR	S	C
20–63	C1	7.5YR4/6	7.5YR4/4	WE	FI	SB	NST	SPL	SO	LO	W	D
63–134	C2	5YR4/6	5YR/3/3	MO	CO	SB	SST	VPL	SHA	VFR	–	–
			PROFILE 4									
0–30	Ap	7.5YR6/8	2.5YR4/8	MO	CO	SB	SST	PL	Soft	VFR	S	D
30–39	C	10Y4/8	2.5YR4/6	WE	ME	GR	VST	PL	EHA	EFI	—	—

Consistence: SO = soft; SHA = slightly hard; HA = hard; VHA = very hard; LO = loose; VFR = very friable; FR = friable; NST = non-sticky; SST = slightly sticky; ST = sticky; VST = very sticky; NPL = non-plastic; SPL = slightly plastic; PL = plastic; VPL = very plastic. *Structure*: WE = weak; MO = moderate; ST = strong; VST = very strong; CO = coarse; ME = medium; FI = fine; SB = sub-angular blocky; GR = granular; AB = angular blocky; PL = platy. *Horizon boundary*: A = abrupt; C = clear; W = wavy; D = diffuse; S = smooth; I = irregular.

Table 3. Selected Physical Properties of the Soil.

DEPTH (CM)	SAND (%)	SILT (%)	CLAY (%)	TC	S:C	BD (G CM^{-3})	TP (%)	FC (%)	PWP (%)	AWC (MM M^{-1})
Profile 1										
0–25	60	9	31	SCL	0.29	1.45	44.94	21.5	13.4	117.45
25–63	58	9	33	SCL	0.27	1.40	46.86	24.7	16.1	120.4
63–113	61	8	31	SCL	0.25	1.56	41.09	22.2	13.5	135.72
113–178	64	6	30	SCL	0.2	1.45	44.94	25.4	17.3	117.45
Profile 2										
0–22	62	7	31	SCL	0.22	1.38	48.02	32.3	18.5	190.44
22–109	58	9	33	SCL	0.27	1.46	44.94	31.6	16.8	216.08
109–167	61	21	18	SL	0.22	1.53	42.26	23.1	17.0	93.33
Profile 3										
0–20	71	14	15	SL	0.93	1.38	48.02	26.5	14.4	166.98
20–63	74	12	14	SL	0.85	1.47	44.52	20.1	11.2	130.83
63–134	81	5	14	SL	0.35	1.57	40.75	22.3	13.5	138.16
Profile 4										
0–30	76	10	14	SL	0.71	1.43	45.90	23.4	14.3	130.13
30–39	69	13	18	SL	0.72	1.51	43.20	27.2	14.6	190.26

TC = textural class; SL = sandy loam; SCL = sandy clay loam; BD = bulk density; S = silt; C = clay; TP = total porosity; FC = field capacity; PWP = permanent welting point; AWC = available water content.

Profiles 1 and 2, whereas in Profile 3 and 4 TN increased with increasing depth. The result of the two profiles is in agreement with the findings of Tegene (1997), Demiss and Beyene (2010), and Yitbarek et al. (2018) who found that TN content decreased with increasing depth at their study sites. In general, the level of TN showed little variation throughout all profiles. Similarly, very low TN values have been reported by Demiss and Beyene (2010) and Hagos et al. (2015) in southern Ethiopia and Wollo Ethiopia, respectively. The low values of TN may be attributed to complete removal of crop residues, which is a common practice in the study area due to livestock feed shortage, which decreases the amount of organic matter in the surface soil.

Available phosphorus. The available phosphorus contents were low in the surface horizons of all profiles (Table 5). It ranged from 1.34 to 5.17 ppm, whereas in the subsurface horizons it ranged from 1.71 to 7.29 ppm. According to a rating set by Olsen et al. (1954), the available phosphorus observed in all surface horizons was categorized as low levels. Similar observations were made by Adhana and Toshome (2016) and Fikadu et al. (2018), who reported low phosphorus content in the surface and subsurface soils in Western Ethiopia and Northwestern Ethiopia, respectively. In Profile 4, the trend of available phosphorus decreased with increasing soil depths, whereas in Profile 3 the available phosphorus content increased with increasing depth, but Profiles 1 and 2 did not show clear trends. A relatively high amount of available phosphorus in the Profile 4 surface soil compared with the subsurface soils might be due to the application of farmyard manure and compost. The high OM content could also be due to the application of manure and compost. This result is in agreement with the findings of Ali et al. (2010) and Dejene (2013), who reported that the highest amount of available P contents in soil was recorded in the surface horizon.

Soil organic matter and C:N ratio. The organic matter contents of the studied soils were extremely low, ranging from 0.77% to 0.88% in the surface soils and from 0.13% to 0.74% in the subsurface soils (Table 5). In all the profiles, however, organic matter content decreased with soil depth, showing that surface soils receive more residues as litter and root leftovers. Similar results had been reported by many scholars (Assefa, 2002; Assen and Yilma, 2010; Beyene, 2017; Fikadu et al., 2018; Hagos et al., 2015; Isreal et al., 2018) in different parts of Ethiopia. Possible explanations for this low organic matter content in the study area include high oxidation or mineralization rates of organic matter and the complete removal of agricultural residue and intensive cultivation. FAO (2005) confirms that organic matter content is influenced by the burning of natural vegetation and crop residues, overgrazing, and removal of crop residues, tillage practices, and drainage. The current result is in

Table 4. Correlation Analysis for Soil Physical and Chemical Properties.

	BD	FC	PWP	AWC	PH	EC	TN	OM	AVAI. P	CA	MG	K	NA	CEC	PBS
Clay	−0.12	0.76**	0.72**	0.37	0.88**	0.76**	0.34	0.26	0.16	0.51	0.43	0.31	−0.16	0.38	0.12
BD		−0.45	−0.19	−0.41	0.29	0.08	−0.32	−0.57	0.21	−0.31	−0.14	−0.03	−0.05	−0.49	0.34
TP		0.49	0.2	0.44	−0.29	−0.08	0.41	0.56	−0.19	0.34	0.16	0.06	0.00	0.54	−0.35
FC			0.59*	0.77**	0.44	0.45	0.26	0.41	0.47	0.44	0.42	−0.12	0.44	0.53	−0.22
PWP				−0.06	0.41	0.26	0.12	0.24	−0.12	0.37	0.34	0.26	−0.07	0.31	0.09
AWC					0.18	0.34	0.35	0.15	0.38	0.25	0.05	0.02	−0.49	0.41	0.35
pH						0.74**	0.32	−0.09	0.36	0.16	0.13	0.17	−0.19	−0.02	0.24
EC							0.23	0.24	0.35	0.43	0.38	0.27	0.00	0.06	0.42
TN								0.43	−0.26	0.56	0.52	0.41	0.04	0.57	−0.08
OM									−0.17	0.32	0.21	0.21	−0.11	0.28	0.01
P										0.11	−0.09	0.22	−0.48	−0.18	0.25
Ca											0.94**	0.87**	0.19	0.75**	0.26
Mg												0.86**	0.43	0.66*	0.21
K													0.13	0.48	0.52
Na														−0.03	0.41
CEC															−0.41

Numbers are Pearson's correlation coefficients (*r*). Number of observation (*n*) = 19. BD = bulk density; TP = total porosity; FR = field capacity; AWC = available water content; EC = electrical conductivity; TN = total nitrogen; OM = organic matter; Avai. P = available phosphorus; CEC = cation exchange capacity; PBS = percent base saturation.
*Significant at $p \leqslant 0.05$; **$p \leqslant 0.01$.

Table 5. Selected Chemical Properties of the Soil.

DEPTH (CM)	PH (H_2O)	EC (DS M^{-1})	TN (%)	OM (%)	C:N RATIO	AVAI. P (PPM)	$CACO_3$ (%)
Profile 1							
0–25	6.4	0.11	0.024	0.77	18.75	1.34	0.5
25–63	6.7	0.13	0.024	0.67	16.25	1.71	0.8
63–113	6.8	0.18	0.017	0.57	19.41	1. 65	0.6
113–178	6.7	0.12	0.008	0.29	21.25	3.07	0.9
Profile 2							
0–22	6.8	0.12	0.028	0.84	17.50	2.17	2
22–109	7.3	0.32	0.019	0.74	22.63	7.29	2.4
109–167	6.9	0.12	0.018	0.60	19.44	2.63	1.8
Profile 3							
0–20	6.2	0.1	0.031	0.81	15.16	2.59	0.6
20–63	6.6	0.09	0.046	0.31	3.91	4.39	0.6
63–134	6.6	0.11	0.021	0.36	10.00	5.43	0.8
Profile 4							
0–30	6.6	0.06	0.025	0.88	20.40	5.17	3.0
30–39	6.8	0.06	0.039	0.13	2.00	4.13	3.8

EC = electrical conductivity; TN = total nitrogen; OM organic matter; C:N = carbon to nitrogen ratio; Avai. P = available phosphorus.

accordance with the findings of Negassa and Gebrekidan (2003) and Kassahun et al. (2009), who reported that low organic matter content was recorded in the cultivated land of Ethiopia. According to the ratings given by Tadesse (1991), the organic matter content of the studied soils was very low to low in both the surface and subsurface. The C:N ratio of the surface soils ranged from 15.16 to 20.4, whereas in the subsurface it ranged from 2 to 22.63. For both the surface and subsurface soils, this ratio is below 24:1, which is the carbon to nitrogen ratio that promotes net mineralization of organic matter by microorganisms. The ratio is within the range that provides nitrogen in excess of microbial needs (Landon, 1991), indicating optimum microbial activity for the humification and mineralization of organic residues.

Exchangeable base, CEC, and base saturation. The highest exchangeable Ca value was recorded in the surface horizons of Profiles 2 and 3 (13.4 and 12.26 cmolc kg^{-1}, respectively), whereas the lowest was in the surface horizons of Profiles 1 and 4 (7.85 and 6.81 cmolc kg^{-1}, respectively). Exchangeable Ca in the subsurface horizons was higher in Profiles 2 and 3 compared with the other Profiles. The value of exchangeable Ca did not show clear trends with soil depth across all profiles (Table 6). Similar patterns were found for other cations. This could be due to the presence of Ca-bearing parent materials distributed unevenly over the soil profiles. According to the rating set by FAO (2006b), the concentration of exchangeable Ca observed in the Profile 2 and 3 surface horizons is categorized as high levels, whereas in Profiles 1 and 4 it was medium, and the concentration of exchangeable Ca in the subsurface horizons is categorized as high to medium level (Table 6). Exchangeable Mg in the subsurface horizons was the highest in Profile 2 (2.28 cmolc kg^{-1}) at a depth of 109 to 152. Na concentrations in the surface soils fluctuated between 0.58 cmolc kg^{-1} in Profile 4 and 1.41 cmolc kg^{-1} in Profile 1, whereas in the subsurface horizons exchangeable Na ranged from 0.65 to 1.32 cmolc kg^{-1}. According to FAO (2006b), the concentration of exchangeable Mg observed in all the profiles is categorized as medium. This medium level of Mg in all profiles could be attributed to medium Mg content in the soil's parent material. The concentration of K and Na in the surface and subsurface horizons is categorized as medium to very high, and medium to high levels, respectively, in all profiles as per the FAO (2006b).

Generally, the distribution of exchangeable bases in the soils of the study area was dominated by Ca, followed by Mg, but K and Na had no such trend. The values of exchangeable bases are not likely to be limiting factors for crop growth and production in the study area. Cation exchange capacity for the soils generally ranged from moderate to high according to FAO (2006b) (<6, very low; 6–12, low; 12–25, medium; 15–40, high; and >40, very high). The highest surface soil value (35.2) was recorded in Profile 2 and the lowest (15.2) in Profile 1. In the subsurface, CEC ranged from 16.4 in Profile 4 to 24 in Profile 3.

Table 6. Exchangeable Base, Cation Exchange Capacity, Base Saturation, and Extractable Micronutrient Contents of the Study Site.

DEPTH (CM)	CA	MG	K	NA	CEC	PBS%	FE	MN	ZN	CU
cmolc kg^{-1}							mg kg^{-1}			
Profile 1										
0–25	7.85	1.82	0.58	1.14	15.20	74.94	16.28	8.68	1.62	1.12
25–63	8.62	1.64	0.65	1.03	17.00	70.23	13.09	9.42	1.12	0.49
63–113	8.25	1.72	0.48	0.95	19.80	57.57	12.71	6.98	1.23	0.31
113–178	9.50	1.92	0.52	1.32	21.10	62.84	12.67	7.54	1.09	0.48
Profile 2										
0–22	13.4	2.47	1.08	0.78	35.20	50.37	9.48	6.41	1.12	1.21
22–109	12.5	2.18	1.02	0.84	20.00	82.70	10.54	5.78	1.09	1.11
109–167	11.2	2.28	1.15	1.12	18.80	83.78	11.45	7.14	0.94	1.06
Profile 3										
0–20	12.26	2.25	0.99	1.08	24.80	66.85	9.54	5.48	0.87	0.39
20–63	11.35	2.14	1.02	1.21	24.00	65.50	10.42	6.74	0.95	1.04
63–134	9.82	2.04	1.11	0.89	16.40	84.51	9.82	7.24	0.84	0.42
Profile 4										
0–30	6.81	1.08	0.46	0.58	16.40	54.45	15.84	8.87	1.52	1.23
30–39	5.74	1.12	0.32	0.65	15.30	53.43	14.91	9.12	1.48	1.08

The PBS was found to be the highest (74.94%) in the surface horizon of Profile 1, whereas the lowest (50.37%) value was recorded in the surface horizon of Profile 2. In the subsurface soils, the highest percentage base saturation (84.51%) was found in Profile 3 and the lowest (53.43%) in Profile 4. In general, the percentage base saturation for both the surface and subsurface soils was above 50 % in all studied profiles and rated as moderate to very high (Hazelton & Murphy, 2007). This shows that there may be low levels of leaching of bases from the study area due to low rainfall.

Extractable micronutrients

Available iron (Fe) in the surface soils ranged from 9.48 to 16.25 mg kg^{-1} and in subsurface horizons from 9.82 to 14.91 mg kg^{-1}. Profiles 1 and 4 showed a decreasing trend of Fe concentration with increasing depth, whereas the patterns were inconsistent for Profiles 2 and 3. According to the interpretative values for DTPA-extractable micronutrients set by Jones (2003), extractable Fe in all profiles was rated as high for both the surface and subsurface soils. The concentration of manganese (Mn) in surface and subsurface soils ranged from 5.48 to 8.87 mg kg^{-1} and 7.14 to 9.42 mg kg^{-1}, respectively. Mn content increased consistently with soil depth in Profiles 3 and 4, whereas the pattern was not consistent for Profiles 1 and 2 (Table 5). According to Jones (2003), the concentration of Mn was high. The surface horizons had available zinc (Zn) content of 0.87 to 1.62 mg kg^{-1}, whereas subsurface soils showed values that ranged from 0.84 to 1.48 mg kg^{-1}. Profiles 2 and 4 showed a decreasing trend with soil depth, whereas there was no clear trend in Profiles 1 and 3 (Table 5). Zinc concentration was rated as low to high (Jones, 2003). The amount of copper (Cu) in surface and subsurface soils ranged from 0.39 to 1.23 mg kg^{-1} and 0.31 to 1.11 mg kg^{-1}, respectively, which was categorized as low (Jones, 2003).

Associations of different soil parameters

The results of the analysis showed that certain attributes of soil showed significant relationships with each other, whereas others did not show relationships among themselves. The following parameters were significantly correlated: total porosity with BD and sand with clay, FC, PWP, and AWC, whereas FC with AWC and PWP; clay with FC, PWP, pH, and EC; Ca with Mg, K, and CEC; and Mg with K and CEC were positively correlated parameters. Clay was significantly and positively correlated (r = .76** and r = .72**) with FC and PWP, respectively, which indicated that high clay content improves micropores and makes the high specific surface of clays, and it is responsible for high water retention (Table 6). Soil reaction (pH) was significantly and positively correlated with a clay content of the soil (r = .88**). This relationship indicates the high adsorption capacity of clay-size particles for exchangeable cations, which increases pH value.

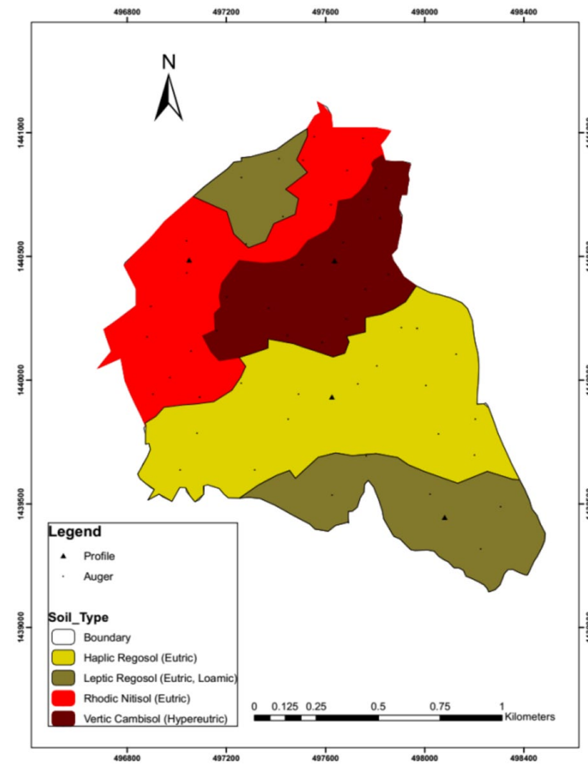

Figure 2. Soil map of the study area.

Description of mapping units and soil classification

Based on morphological, physical, and chemical properties, the soils were classified using FAO/WRB (2015) system and four types of soils were identified, namely, Rhodic Nitisols (Eutric), Vertic Cambisols (Hypereutric), Haplic Regosol (Eutric), and Leptic Regosol (Eutric, Loamic) (Figure 2).

Soil mapping unit 1. This soil mapping unit was represented by Profile 1 (Figure 3) which was dug in a gentle slope area (3%–5%). This site had very deep (0–178 cm) and well-drained soils. The profile had a diffused boundary between the surface and subsurface layers, without a ferric, plinthic, or vertic horizon, and there was no gleyic color pattern within 100 cm of the surface and subsurface horizon. It had a thickness of ⩾30 cm, clay content ⩾30%, and silt to clay ratio <0.4, identifying it as a nitic horizon. Therefore, the profile meets the requirements to be classified as a Nitosol. Furthermore, the subsurface had a layer ⩾30 cm thick that had colors redder than 2.5YR 3/4 when moist and 2.5YR 3/6 when dry, qualifying it for the rhodic prefix. It showed high base saturation (>50%) between 20 and 100 cm from the soil surface and meets the requirements for the Eutric qualifier. Accordingly, the soil represented by Profile 1 was classified as Rhodic Nitisol (Eutric) (FAO/WRB, 2015). This soil covers 45.99 ha in the irrigation command area, which is 23.44% of the total area.

Soil Mapping Unit 2. This soil mapping unit was characterized by deep soil (167 cm), flat to gentle slope (0%–3%), and poor drainage. The soil mapping unit occupies a small part of the study site compared with other mapping units, just 35.05 ha or 17.87%. The soil profile (Figure 4) had sandy clay loam to sandy loam subsurface textural class more than 15 cm thick; it had an absence of rock structure in ⩾50% of the volume of the fine earth fraction and shows evidence of pedogenetic alteration. This was identified as a cambic subsurface horizon, classifying this soil as a Cambisol. Furthermore, this mapping unit had cracks that open and close periodically and are 1 cm or wider, which qualifies it to receive the Vertic prefix qualifier. The soil had a base saturation of 50% or more throughout the 20- to 100-cm depth and 80% or more in some layers within 100-cm depth. Thus, it fulfilled the criteria for the Hypereutric suffix qualifier. As a result, this soil was classified as a Vertic Cambisol (Hypereutric).

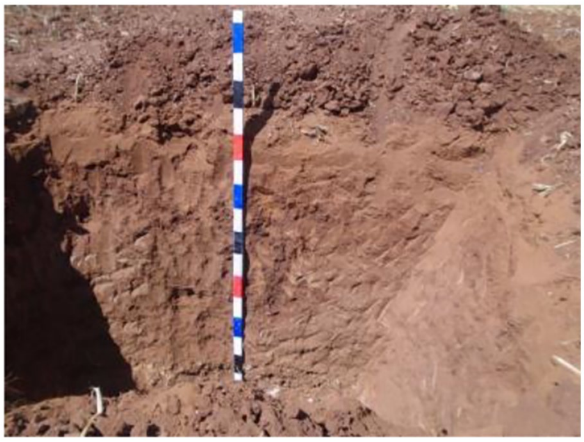

Figure 3. Representative soil profile for soil mapping unit-1.

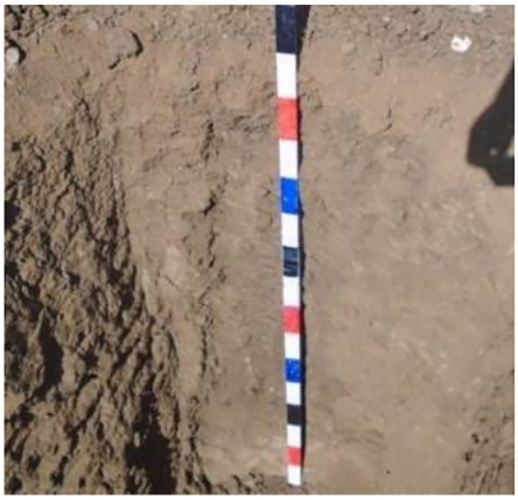

Figure 4. Representative soil profile for soil mapping unit-2.

Soil Mapping Unit 3. This soil mapping unit was represented by soil Profile 3 (Figure 5). It had a slope of 5% to 8%, was moderately deep with an effective soil depth of 0 to 134 cm, and was well-drained. The soil mapping unit was low in N, P, and OM and had very weakly developed mineral soils in

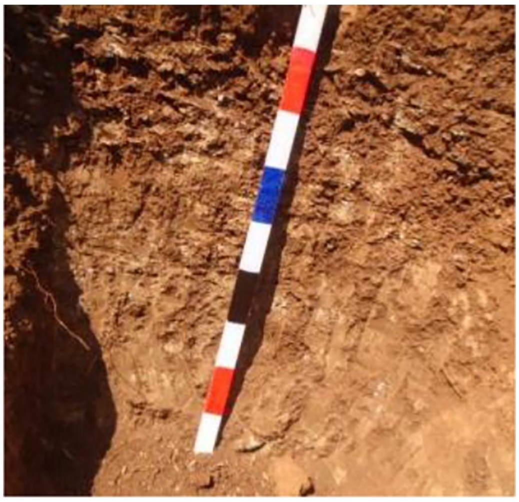

Figure 5. Representative soil profile for soil mapping unit-3.

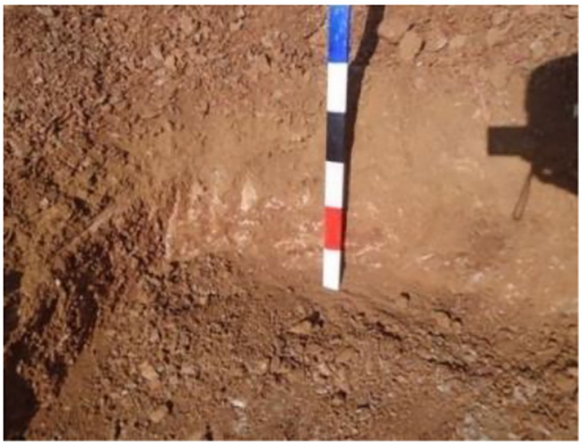

Figure 6. Representative soil profile for soil mapping unit-4.

unconsolidated material that did not have a mollic or umbric horizon. This mapping unit profile qualifies for the Reference Soil Group (RSG) Regosol. According to FAO/WRB (2015), Regosols are very weakly developed mineral soils in unconsolidated materials that do not have a mollic or umbric horizon, are not very shallow or very rich in gravels (Leptosols), are sandy (Arenosols), or with fluvic materials (Fluvisols). The profile showed a base saturation of 50% or more throughout the profile fulfilling the requirements for the Eutric suffix (FAO/WRB, 2015). Hence, the profile was classified as a Haplic Regosol (Eutric). Haplic is a kind of qualifier or prefix that expresses typical features (typical in the sense that there is no further or meaningful characterization) and is only used if none of the preceding qualifiers applies (FAO/WRB, 2015). This mapping unit covers the largest area of the scheme, 71.98 ha of land which is about 36.69% of the study area (Figure 5).

Soil Mapping Unit 4. This soil mapping unit was represented by Profile 4 (Figure 6), which has limited soil depth, continuous rock within 37 cm of the soil surface, and are well-drained soils with gravelly surface layers. The profile had a slope of 8% to 15 % and sandy loam soil texture. As a result, Profile 4 qualifies for RSG Regosol. The profile had a base saturation of 50% or more throughout the profile and qualifies for the Eutric suffix. The soil had a sandy loam texture that fulfills the Loamic supplementary qualifier. According to FAO/WRB (2015), the Loamic qualifier is used for soils that have loam, sandy loam, sandy clay loam, clay loam, or silty clay loam texture in a layer ⩾30 cm thick within ⩽100 cm of the mineral soil surface or in the major part between the mineral soil surface and continuous rock or technic hard material. The soil profile had a continuous rock or technic hard material starting ⩽100 cm from the soil surface and qualifies for the Leptic prefix qualifier. Therefore, the soils of this mapping unit were classified as Leptic Regosols (Eutric, Loamic). This mapping unit covers 43.14 ha which is 21.99% of the command area.

Conclusions and Recommendations

Soil classification of agricultural land is very important for countries like Ethiopia where agriculture is the backbone of the economy. Assessment of irrigation sites in terms of soil physiochemical characterization and suitability evaluation must be the first action before implementing different agricultural activities. Understanding these factors can help with site-specific fertilizer recommendation, technology transfer, decision-making, planning, and policy formulation for a given area. The results revealed that soil morphological, physical, and chemical characteristics of the study area had variations in their properties. The major soils of the scheme are Vertic Cambisol, Haplic Regosol, Eutric Nitisol, and Leptic Regosol. The soils in the study area had low total nitrogen (TN) and available phosphorus and soil organic matter; thus, agricultural land management should focus on the addition of organic fertilizer and avoid complete removal of crop residue. In the study area, some mapping units had a slope greater than 8%, so different soil and water conservation practices should be implemented to avoid surface erosion as well as to increase soil depth.

Availability of Data and Materials

The datasets of this article are available from the corresponding author on a reasonable request.

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