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Characterization of problem soils in and around the south central Ethiopian Rift Valley

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Some soils in Ethiopia reduce plant productivity due to physical and/or chemical limitations. The morphological, physical and chemical properties of problem soils, including sodic, acidic, and saline soils, around southern Ethiopia were characterized and are described in this chapter. The intention is to characterize the soils and better understand the specific nature of the limitations. Sodic soils of Alage, acid soils of Hagereselam, and saline soils of Zeway areas were sampled to represent the problem soils. The soil properties determined included color, electrical conductivity (EC), structure, consistency, bulk density, texture, pH, organic carbon (OC), total nitrogen, available phosphorus (P) and K, exchangeable bases and available micro-nutrients. The soils had considerable heterogeneity in solum and regolith thickness, horizon depth, structural development in surface soils and subsurface horizons, pH, EC and available nutrients. The classification of these soils was made according to Soil Taxonomy and World Reference Base for Soil Resources systems. The sodic soils of Alage had high pH and sodium (Na) content, and low level of OC, available P, copper (Cu) and zinc (Zn). The epipedon was classified as an ochric and the profile also had variation in clay content down the profile to satisfy the requirements of having an argilic horizon and therefore these soils were classified as Typic Natragids. Soils of Hagereselam had very low available P. Available Cu and Zn contents were found to be at the marginal levels for production of most crops. The Hagereselam profile had an argilic horizon with umbric epipedon and was classified as Typic Paleustults. The saline soils in Zeway area had relatively high amounts of calcium and low OC. The profile was found to have ochric epipedon and these soils are classified as Typic Haplocambids. Application of fertilizer including P, Cu and Zn, and removal of sodium and salts from the soil profile may be means of improving the productivity of these soils. Application of organic amendments including manures and crop residues may also be beneficial in increasing the fertility as well as organic carbon content.

Key words: Acidic, saline and sodic soils, reclamation, morphological, physical and chemical soil properties.

INTRODUCTION

Soil is a vital natural resource and must be well managed for sustainable agricultural production (Benton, 2003).

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Sound management of cropping systems requires knowledge of physical and chemical status of soils and crops during the growing season for profitable production (Benton, 2003). Replenishing soil fertility is the primary biophysical requirement for increasing food production in sub-Saharan Africa countries (Sanchez, 2010). In Ethiopia, where agriculture is the mainstay of the national economy, agricultural production has been highly dependent on natural resources for centuries (Amsalu et al., 2007). As a result, agricultural lands have expanded to meet the additional food demand for an increasing population (Kidanu, 2004). Expansion of agriculture has led to the cultivation of problem prone soils, including soils that have severe limitations as acidity, salinity, sodicity and other low fertility characteristics. Being an agrarian country, Ethiopia has faced considerable challenges in food security for the past four decades (FAO, 2001). Ethiopia is one of the sub Saharan African countries where low levels of agricultural productivity are the key cause of hunger. Decades of farming without replenishment of soil nutrients through applications of fertilizer and manure have stripped the soils of vital nutrients needed to support plant growth (IFPRI, 2010).

Despite its immense contribution to agricultural production and food security, data on soil fertility in Ethiopia is largely out of date at a national level, and locally is fragmented and difficult to access (IFPRI, 2010). For example, the last major survey of macronutrient status across the country was conducted in 1950-60`s. The old generalized claim that Ethiopian soils were less deficient in potassium (K) has not been supported by any recent study. As the result, K fertilization has been ignored from the national fertilizer program (Mesfin, 2007). Recent studies have indicated that elements like nitrogen (N), phosphorus (P), K, sulfur (S) and zinc (Zn) levels as well as Boron (B) and copper (Cu) are becoming depleted and deficiency symptoms are being observed on major crops in different areas of the country (ATA, 2013). In order to apply nutrients, it is necessary to know the site-specific variability in nutrient supply to overcome the mismatch of fertilizer types and crop nutrient demand (Dobermann and Cassman, 2002).

Soil acidity is also becoming a serious challenge for crop production in the highlands of Ethiopia. Currently, it is estimated that about 40% of the arable lands of Ethiopia are affected by soil acidity (Taye, 2007). Soil acidity limits or reduces crop production primarily by impairing root growth as a result of the toxicity to roots of high concentrations of soluble aluminum (Al). Moreover, low pH enhances the fixation of P through sorption by Al and irons (Fe) compounds and reduces biological N fixation and mineralization turnover. Acidic soils are typically poor in their basic cations such as calcium (Ca), K, magnesium (Mg) and some micronutrients which are essential for crop growth and development (Wang et al., 2006; Tisdale et al., 1985). The extent of damage posed by soil acidity varies from place to place depending on several factors, and crop species.

An inventory was made in 2006 to determine the current status of acidity of Nitisols occurring in western and central Ethiopia. The results revealed that all samples were acidic, though the degree varied from location to location (Abdenna et al., 2007). Soil acidity is expanding both in scope and magnitude in Ethiopia, severely limiting crop production. The increasing trend of soil acidity in arable and abandoned land has been attributed to intensive cultivation and continuous use of acid forming inorganic fertilizers (Wakene and Hiluf, 2006). Considering this fact, the federal government of Ethiopia has identified soil acidity as a key agricultural problem and directed the concerned stakeholders to find integrated and sustainable solutions to address the problem.

Salt-affected soils are distributed throughout the world, and no continent is free from the problem (Brady and Weil, 2002). Salinization of soil is one of the major factors limiting crop production particularly in arid and semi-arid regions of the world (Ahmed, 2009). Globally, a total land area of 831 million hectares is salt affected. African countries like Kenya (8.2 Mha), Nigeria (5.6 Mha), Sudan (4.8 Mha), Tunisia (1.8 Mha), Tanzania (1.7 Mha) and Ghana (0.79 Mha) are salt affected to various degrees (FAO, 2000). In Ethiopia, the naturally salt affected areas are normally found in the arid and semiarid lowlands and in Rift valley areas that are characterized by higher evapo-transpiration rates in relation to precipitation. It is reported that Ethiopia possesses over 11 million hectares of unproductive naturally salt affected wastelands (Tadelle, 1993). Tamirie (1994) has indicated that 44 million ha (36% of the country's total land areas) are potentially susceptible to salinity problems. Out of the 44 million ha, 33 million ha have dominantly salinity problems, while 8 million ha have combined salinity and alkalinity problems associated with sodium, and 3 million ha have dominantly alkalinity problems. According to Meron (2007) high salinity in the Ethiopian ground waters is apparent in some parts of the Rift Valley because of the influence of saline geothermal waters.

Soil sodicity is also a problem in arid and semi-regions of Ethiopian. Soil sodicity results in high pH (alkaline) as a consequence of high content of sodium in the soil. It is estimated that about 425,000 ha of land of Ethiopian soils are sodic, mainly in the warm, semiarid to sub humid climates (Bui et al., 1998).

According to Boul et al. (2003), classification and categorization of natural phenomena like soil genesis are generally done for one or more of the following purposes. These are to organize knowledge of subjects, provide maximum knowledge with least cognitive effort, provide a map or organizational chart of the structure of the world we perceive and live in, to satisfy our natural curiosity and for ease in communication, reveal and understand the relationship among individuals and classes, identify and learn new relationships and principles not previously

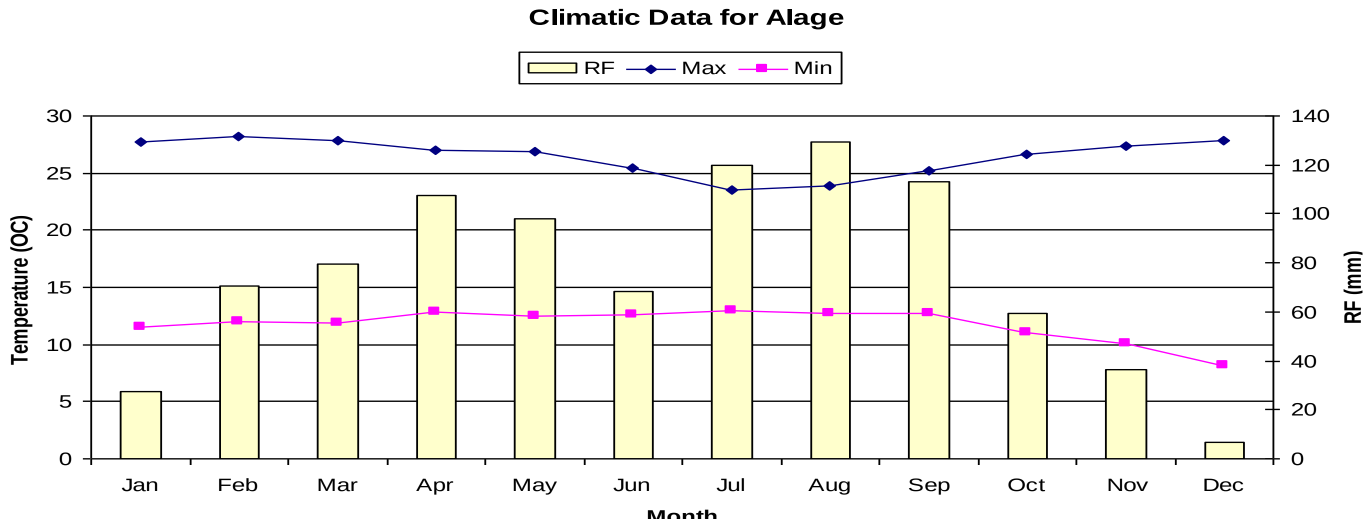

Figure 1. Annual rainfall and average monthly maximum and minimum temperature of the Alage (2000-2013 average). RF, Rainfall; Tmin and Tmax, minimum and maximum temperatures, respectively.

understood, provide objects or classes as subjects for research and experimentation and/or establish groups or subdivisions of the objects classified to enable a particular application of the knowledge. So far, there is no universally accepted soil classification system. However, at the international level, the World Reference Base for Soil Resources (FAO, 2006) and the Soil Taxonomy (Soil Survey Staff, 2014) are used.

Although the knowledge of important soil quality indicators is vital for recovering, reclaiming and maintaining soil fertility, little information is available in Ethiopia in general and the study area in particular. This study was therefore undertaken to provide basic information on the present morphological, physical and chemical characteristics of the problem prone soils that will contribute to maintain their sustainable crop production in south central Ethiopia.

MATERIALS AND METHODS

Description of the study areas

The study was conducted on problem soils of the great Ethiopian Rift Valley and its surrounding. The study sites were selected based on the information in their chemical properties. These are sodic soils of Alage, saline soils of Zeway and acid soils of Hagereselam. The sodic soils of the Alage area and the saline soils of Zeway are located within the great Rift Valley of Ethiopia, whereas the acid soils of Hagereselam are found along the escarpment of the great Ethiopia Rift Valley.

Alage

The Alage site is located at the geographical coordinates of 07° 34` 59`` N Latitude and 38° 25` 33`` E Longitude. The annual rainfall of the area varies from 750 to 1200 mm with mean annual temperature varying from 8 to 28°C (Figure 1). The major crops grown in the area includes maize (*Zea mays*), papaya (*Carica papaya*), mango (*Mangifera indica*) and banana (*Musa acuminata*). The specific study site is found inside the Alage Agricultural Technical Vocational Education Training College.

Hagereselam

Hagereselam site is located in Hula woreda Sidama Zone of Southern Nations Nationalities and People's Region (SNNPR) at geographical coordinates of 6° 29`38``N Latitude and 38° 30`50``E Longitude. The annual rainfall of the woreda varies from 900 to 1400 mm with mean monthly temperature ranging from 6 to 22°C (Figure 2). The specific study area is found at the western edge of the town called Hagereselam. Crops grown in Hageresl am region include barley (*Hordeum vulgare*), ensut (*Ensete ventricosum*), potato (*Solanum tuberosum*) and wheat (*Triticum aestivum*).

Zeway

Zeway site is located at 7˚ 59' 05" N Latitude and 38˚43'20" E Longitude and close to Zeway town, which is found at 160 km south of Addis Ababa, and at an altitude of 1628 m.a.s.l. The profile examined was obtained within the farm site of Hawassa University Research station. The area received average annual rainfall of 778 mm and has a mean annual temperature ranging from 14.4 to 27.0°C (Figure 3). Zeway agro-climatic conditions allow farmers to grow onion (*Allium cepa*), maize (*Zea mays*), and tomato (*Solanum lycopersicum*).

Profile description and sampling

In 2012, one representative soil pedon of 2 × 1.5 × 2 m deep was opened at each site. The soil profiles were described *in situ* following guidelines for field soil description (FAO, 2006). Soil samples were collected from entire area from any identified horizon. Additionally, surface random soil samples (0-30 cm depth) were collected from all directions surrounding each pedon and three composites were made per pedon.

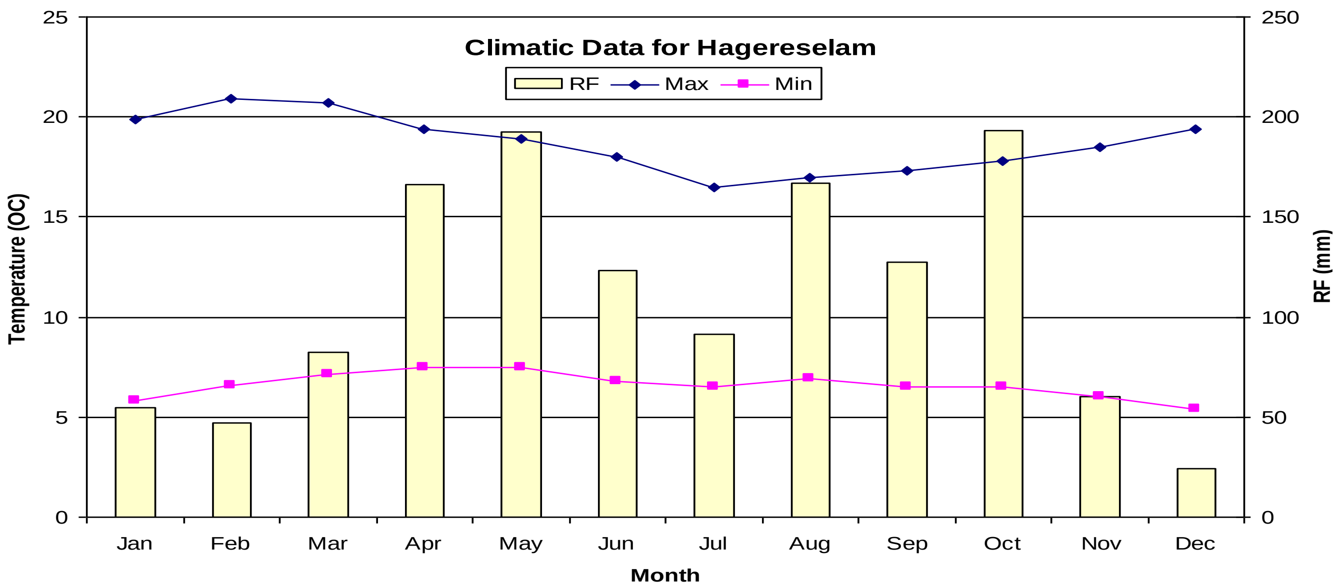

Figure 2. Annual rainfall and average monthly maximum and minimum temperature of Hagereselam (2000-2013 average). RF, Rainfall; Tmin and Tmax, minimum and maximum temperatures, respectively.

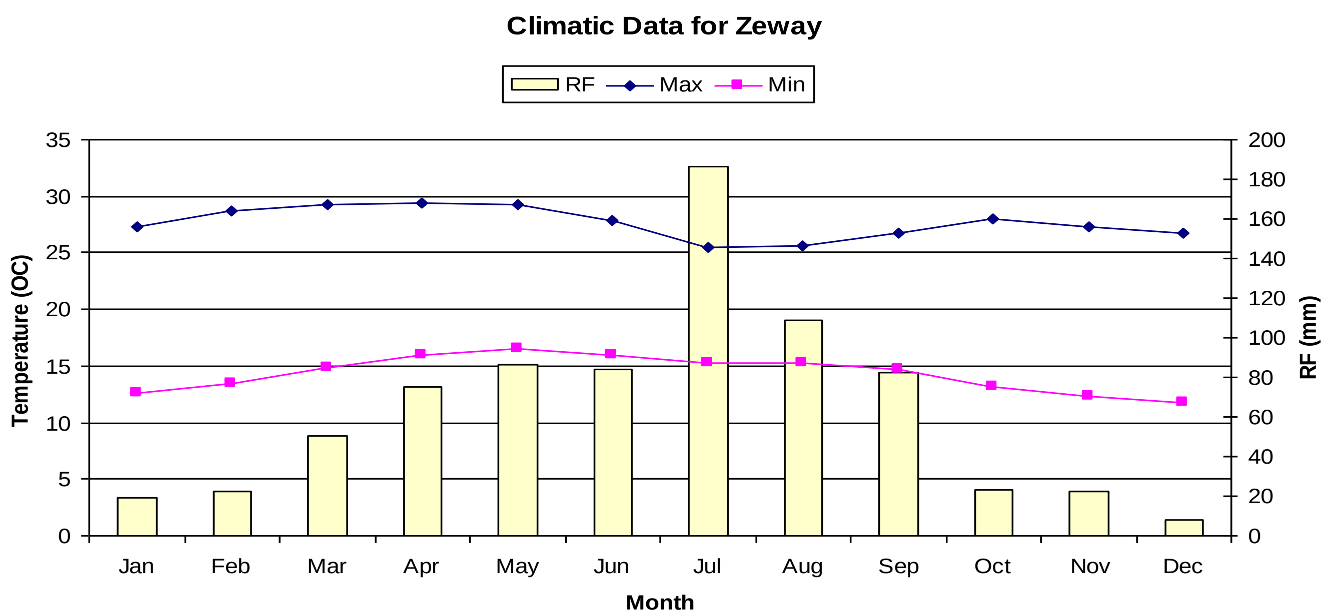

Figure 3. Annual rainfall and average monthly maximum and minimum temperature of the Zeway (2000-2013 average). RF, rainfall; Tmin and Tmax, minimum and maximum temperatures respectively.

Sample preparation

All soil samples were air-dried, ground and passed through a 2 mm sieve at the Soil Laboratory of the College of Agriculture, Hawassa University. Some physicochemical properties (cation exchange capacity - CEC, texture and bulk density) of the soil samples were conducted in the laboratory, and other physicochemical properties were assessed in the Department of Soil Science laboratories at the University of Saskatchewan, Saskatoon, Canada following standard laboratory procedures.

Laboratory analyses

Total nitrogen of the soil N and P was determined by wet acid Kjeldahl digestion method. A 0.25 g sample of fine air-dried soil was added to a digestion tube. The contents of each tube were digested at 360°C for 6 h using the wet ashing (sulfuric acid - 30% H_2O_2) procedure (Thomas et al., 1967). The final contents of the tubes were diluted to volume (75 ml) and total N and P concentrations were determined using automated colorimetry (Technicon Industrial Systems, 1973). The available phosphorus content of the soil was

Table 1. Location and physiographic settings of the pedons in the study sites.

Area	Topographic position	Location	Slope(%)	Altitude(m)	Surrounding landform	Parent material
Alage		N 07°34' 59'' E 38° 25' 33''	2	1518	Flat	Volcanic Ash (IP3)
Hagereselam	Upper	N 06° 29' 38'' E 38° 30' 52''	5	1800	Sloping	Basalt
Zeway		N 07° 59' 06'' E 38° 43' 20''	2	2765	Flat	Volcanic Ash (IP3)

Table 2. Selected morphological characteristics of soils of Alage.

Profile horizon	Depth(cm)	Color (moist)	Structure	CON(moist)	CON(wet)	Texture(feel)	BOU
A	0-18	10YR3/4	WE, FF, GR	LO	SST, SPL	SCL	C, S
Bw1	18-48	10YR4/4	WE, VM, SB	LO	ST, SPL	L	G, S
Bw2	48-73	10YR4/4	MO, VM, PR	VFR	SST, SPL	SCL	G, S
Bw3	73-94	10YR4/3	MO, FC, PR	FR	SST, SPL	SCL	G, S
Bw4	94-120	10YR4/4	MO, FM, PR	FR	SST, SPL	SCL	G, S
Bw5	120-200+	10YR4/3	MO, FC, PR	FR	ST, PL	C	-

The description and abbreviations in the table are in accordance with guidelines for field soil description (FAO, 2006). CON, consistency, BOU, boundary; WE, week; MO, moderate; VM, very fine to medium; FF, very fine and fine; FC, fine to coarse; GR, granular; SB, subangular blocky; PR, prismatic; FR, friable; Lo, loose; VFR, very friable; SST, slightly sticky; ST, sticky; PL ,plastic; SPL, slightly plastic; C, clay (for texture by feel); L, loam; SCL, sandy clay loam; C, clear (for BOU); S, smooth; G, gradual.

analyzed using 0.5 M sodium bicarbonate extraction solution (pH 8.5) following the method of Olsen Olsen et al. (1954). Soil organic carbon (OC) was determined by dry combustion using a LECO CR-12 Carbon Determinator (LECO Instruments Ltd, Mississauga, ON L5T 2H7). The exchangeable base cations (K+, Ca+, Mg 2+, and Na+) were extracted with 1 M- ammonium acetate at pH 7.0 (Van Reeuwijk, 1993). CEC of the soil was determined by measuring the sum of exchangeable cations from the ammonium acetate extracted sample. The hydrometer method was used for the determination of soil particle size distributions (Sahlemedhin and Taye 2002). The soil pH was measured using a glass combination electrode pH meter with the electrode inserted in the filtered supernatant solution of a 1:2.5 soil to water (10 g soil: 25 mL deionized water) extract. In the extract, the soil-water suspension was shaken on a rotary shaker at 142 rpm for 20 min and left to settle for 1 h. The supernatant solutions was filtered through a Whatman 1 filter paper into a plastic vial that was then capped (Rhoades, 1982). Soil pH measurements were obtained by inserting a pH probe into the extractant and the reading recorded from a Beckman pH meter. A Beckman electrical conductivity (EC) meter was used for the EC measurements (Richards, 1969) by inserting the probe into the extraction solution and recording the reading. The probe was rinsed thoroughly with distilled water between each measurement for both pH and EC. The EC was measured by inserting a conductivity electrode into the supernatant suspension attached to a conductivity meter. Bulk density was determined by using core-sampling method (BSI, 1975). A commonly used procedure using diethylenetriaminepenta -acetic acid or DTPA extraction was used to extract available Cu, Fe, Mn and Zn from the samples (Lindsay and Norvell, 1978).

RESULTS AND DISCUSSION

Both Zeway and Alage are located on level areas of the great Ethiopian Rift Valley, while Hagereselam study area is located along the eastern side at the upper slope position of the escarpment of the great Ethiopian Rift Valley (Table 1).

Soil of Alage

Morphological characteristics

Soil color is an important property and is especially useful as a guide to the extent of mineral weathering, the amount of organic matter (OM) and the state of aeration in the soil. The sodic soils of Alage are Dark yellowish brown in color with values of 3 and 4 and chroma of 3 and 4 (Table 2). Values greater than 3 indicate low organic matter content and chromas more than 2 suggest a deeper water table in these soils (Sharma et al., 2006). Absence of mottling (red, yellow or brown splotches) in all the profiles suggests that soil pores do not remain water-filled for prolonged periods. The absence of mottles further suggests minimum current pedogenic activities in the B horizons of the sodic soils of Alage. The plant roots have seldom probed beyond the A horizon. Soil texture is dominantly sandy loam, with silt to clay ratios greater than 0.67 indicating that the soils are young. Young parent materials usually have silt/clay ratio above 0.25 (Asomoa, 1973). Soil structure is granular in the surface horizon and prismatic in rest of the soil profile (Table 2). Surface horizons are non-sticky and non-plastic. The granular structure at the surface could be the dispersing

Table 3. Selected chemical and physical characteristics of soil horizons in the pedon at Alage.

Profile horizon	BD	pH (H_20)	EC (mS/cm)	Sand (%)	Silt (%)	Clay (%)	Silt:Clay	Texture
A	0.91	10.92	4.63	50	26	24	1.05	SCL
Bw1	0.97	10.12	4.88	43	27	30	0.89	CL
Bw2	1.17	10.10	5.23	46	22	32	0.66	SCL
Bw3	1.24	11.81	4.44	41	28	31	0.91	CL
Bw4	-	11.60	4.58	50	17	33	0.79	CL
Bw5	-	11.43	6.46	40	16	44	0.59	C

Texture: C=clay, CL=clay loam, SCL=sandy clay loam, BD=bulk density.

Table 4. Organic carbon (OC), total N (TN), available phosphorus (P) and micronutrient contents of Alage soils OC and TN denote total N and OC contents, respectively.

Profilehorizon	OC(%)	TN(%)	Available P(mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
A	2.22	0.24	3.67	0.37	4.44	66.89	0.28
Bw1	1.21	0.12	1.75	0.28	4.44	94.44	0.09
Bw2	0.47	0.11	0.78	0.61	16.42	90.97	0.16
Bw3	0.38	0.09	0.29	0.20	19.25	51.12	0.78
Bw4	0.28	0.05	0.23	0.16	27.71	91.60	0.82
Bw5	0.26	0.01	0.21	0.17	70.96	22.90	0.88

effect of sodium while, the non-sticky/non plastic consistence could be the low clay content as compared to the subsurface. The loose consistence observed in the surface soils of the pedons (Table 2) could be attributed to the higher OM contents of the layers (Table 4). Although consistence is an inherent soil characteristic, the presence of high OM in the surface horizon changes its consistence (Wakene and Heluf, 2006).

Physical characteristics of the Pedons

The texture of the soil determined by the feel method in the field agreed well with the determinations carried out in the laboratory (Tables 2 and 3). In all horizons of Alage soil, the sand content was very high (>40%) and the silt/clay ratios were greater than 0.66, indicating that the soils are relatively young with high degree of weathering potential. The highest bulk density (1.24 g/cm^3) was found in the Bw1- horizon, while the lowest (0.99 g/cm^3) was found at surface horizon (Ap) (Table 4). Moreover, bulk densities in the pedons increased with depth from A to B horizons. Lower bulk density in A horizon is due to OM content that is highest at the surface, with organic materials of lower density than minerals and also contributing to porous and well aggregated structure, and thereby lower bulk densities (Celik, 2005).

Chemical characteristics of the Pedons

The soil reaction was strongly alkaline throughout the soil profile, ranging from a value of 10.9 at the surface to 11.8 in the Bw3 horizon (Table 3). The soil was also salt affected, with an EC ranging from 4.44 dS m^{-1} for Bw3 to 6.46 dS m^{-1} for Bw5 horizon. The pH and EC values indicate that soils of Alage area are saline-sodic in accordance with the rating of Landon (2014) although there were irregular patterns in EC and pH with depth. The OC concentration in this soil (~ 2.2% OC in surface layer) is rated close to very low according to Landon (2014). Total N for the surface horizons was found to be 0.24% and is rated as medium according to Landon (2014) (Table 4). The trend in total N distribution within the pedons was similar to OC, implying that the OM was the major source of total N in the soils investigated. Moreover, there is also a strong and positive correlation (r=0.93) between OC and total nitrogen (data not shown). Similar results were found by Alemayehu (2007) and Mulugeta and Sheleme (2010) who reported strong correlation between total N and OC in soils of Wolayita area.

The available P content was found to be very low (Table 2), with Olsen extractable P levels less than 5 mg P kg^{-1}. The surface soils have available P content of 3.67 and the subsurface horizons as low as 0.21 mg P kg^{-1}. According to Landon (2014) these value are considered deficient for a tropical soil, even for low P requiring crops like beans. The low content of available P is consistent with the high sand content of this soil. Moreover, the low content of available P could be attributed to fixation by Ca content as Ca-P. Scholars reported that the Ca bounded (Ca-P) is the major inorganic P fraction in alkaline soils

Table 5. Exchangeable cation composition (cmol kg^{-1}) and total cation exchange capacity (CEC), exchangeable sodium percentage (ESP) and Ca:Mg ratio in soil profile of Alage.

Profile	Ca	Mg	K	Na	CEC	ESP(%)	Ca:Mg
A	15.25	2.80	3.63	16.32	41.38	42.95	5.446
B1	7.76	1.09	3.99	23.36	38.70	64.54	7.13
B2	7.40	0.67	4.50	37.22	56.23	74.77	11.12
C1	6.71	0.89	4.56	39.31	57.34	76.37	7.518
C2	6.41	1.27	4.72	38.27	58.63	75.54	5.057
C3	7.88	1.98	4.80	40.11	57.49	73.23	3.983

Table 6. Selected morphological characteristics of Hagereselam soil.

Profile horizon	Depth (cm)	Color (moist)	Structure	CON (moist)	CON (wet)	Texture (feel)	BOU
Ap	0-18	5YR2.5/2	WE, VM, GR	VFR	SST, PL	CL	C, S
AB	18-48	2.5YR3/3	WE, FF, SB	FR	SST, PL	CL	D, S
Bt1	48-73	5YR3/3	MO, FF, AN	VFR	ST, PL	C	D, S
Bt2	73-94	5YR3/4	MO,VM,AN	VFR	ST, PL	C	D, S
BC	94-120	7.5YR3/4	WE, FF, AN	VFR	SST, PL	SC	

The description and abbreviations in the table are in accordance with guidelines for field soil description (FAO, 2006). CON; consistency; BOU, boundary; WE, week; MO, moderate; VM, very fine to medium; FF, very fine and fine; GR, granular; SB, subangular blocky; AN, angular blocky; VFR, very friable; FR, friable; SST, slightly sticky; ST, sticky; PL, plastic; C, clear; S, smooth; D, diffuse.

(Landon, 2014). Piccolo and Huluka (1986) found in their studies on P status of some Ethiopian soils that the most abundant form of phosphorus in alkaline soils is Ca bounded P. The Ca:Mg ratio is used as a measure to evaluate the potential impact of calcium on the uptake of Mg and P. According to Landon (2014) a Ca:Mg ratio greater than 5:1 may reduce the availability of both Mg and P and the Ca:Mg ratio for the whole profile at Alage on average is greater than 5:1.

In Alage site, the extractable available Cu and Zn contents of the surface horizon were considered to be low (deficient) according to Havlin et al. (1999). The author's rated copper content less than 0.4 mg kg^{-1} and Zn content less than 0.5 mg Zn kg^{-1} as deficient. This could be due to the high pH where the high $CaCO_3$ could be responsible for sorption of Cu and Zn (Najafi-Ghiri et al., 2013). This is in agreement with findings of Wu et al. (2010) and Ghasemi- Ghasemi-Fasaei et al. (2006) who concluded that one of the major soil properties influencing the spatial distribution of Cu and Zn availability is soil pH. The result is in agreement with the findings reported by Baissa et al. (2007) on the Rift Valley soils of Ethiopia. On the other hand, the available Fe and manganese (Mn) contents were found to be in adequate amounts according to Havlin et al. (1999).

The CEC in soils of Alage ranged from 38.70 to 58.63 cmol kg^{-1} (Table 5). According to Landon (2014) this range is above the satisfactory value (15 to 25 cmol kg^{-1}) for agricultural lands. This indicates that the soils could be made productive by reclamation and addition of P and micronutrient containing fertilizers. But according to Landon (2014) exchangeable K was found to be sufficient. The result supports the common belief that Ethiopian soils contain sufficient K for crop production. As expected, the exchangeable Na content was high (Table 5) and consequently the ESP values were higher than 15%, which is usually taken as the critical limit for classification as a sodic soil (Brady and Weil, 2002).

Soil of Hagereselam

Morphological characteristics

Soils of Hagereselam are characterized by A, AB, Bt1, Bt2 and C1 horizon sequence. The clay enriched Bt horizons are evidence of a significant amount of clay translocation having occurred during pedogenesis with distinct clay coatings on ped surfaces (Table 6). The surface profile was characterized by a dark reddish brown (5YR2.5/2) color which graded to various shades of dark reddish brown and dark brown in the subsurface. The reddish color is indicative of soils with abundance of iron oxides. Both the surface and subsurface horizons were mottle-free, an indication of good surface drainage (Sharma et al., 2006). The surface horizon had a weak and granular structure that changed to angular blocky structure down the profile. Absence of cracks on the surfaces of the pedons infers that the soils largely have nonexpanding clay minerals like kaolinites. The texture

Table 7. Selected physico-chemical characteristics of soil horizons in pedon at Hagereselam.

Profile	BD	pH(H_2O)	EC(mS/cm)	Sand(%)	Silt(%)	Clay(%)	Silt:Clay	Texture
Ap	1.21	4.51	0.03	47	31	22	1.45	L
AB	1.25	4.75	0.02	44	32	24	1.36	L
Bt1	1.31	4.81	0.05	26	30	44	0.68	C
Bt2	1.37	4.90	0.02	28	25	47	0.54	C
C	-	4.96	0.02	45	21	34	0.63	CL

C = clay, CL = clay loam, L=sandy clay loam, BD=bulk density.

Table 8. Organic carbon, total N (TN), available phosphorus (P) and micronutrient contents of Hagereselam soils.

Profile	OC(%)	TN(%)	Available P(mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
A	3.44	0.35	7.08	0.41	39.79	24.19	0.59
B1	1.05	0.17	3.59	0.12	21.60	22.24	0.32
Bs	0.85	0.07	2.25	0.10	20.36	20.73	0.28
C1	0.74	0.05	0.39	0.07	11.02	7.51	0.27
C2	0.49	0.04	0.34	0.02	11.20	9.66	0.11

was clay loam at the surface overlaying clay textured subsurface illuvial B horizons.

Physical characteristics

When particle size distribution was directly measured by the hydrometer method, the clay sized fraction dominated the mineral fraction in the subsurface horizons of the profile (Table 7), which may be partly attributed to pedogenic processes involving sorting of soil materials by clay migration through eluviation and illuviation, and the action of water and surface erosion (Malgwi et al., 2000; Akinbola et al., 2009). The silt/clay ratio was 1.40 for the surface and 0.54 for the subsurface horizons (Bt2).

Chemical properties of the soils

The soil reaction of the Hagereselam soil, for all the surface and subsurface horizons was below pH 5, with the lowest pH value of 4.5 in the surface horizon (Table 7). Therefore, the Hagereselam soil is rated as strongly acid. Brady and Weil (2002) have established a pH range of 5.5 to 7.0 to be associated with satisfactory availability of plant nutrients. Therefore, the soils of Hagereselam need reclamation to raise the pH and make them favorable for plant growth. This low value of soil pH could be due to loss of base forming cations down the soil profiles even beyond sampling depth through leaching and drain to streams in runoff generated (Nigussie and Kissi, 2012). The OC concentration ranged from 3.44% for the surface horizon to 0.49% in the subsurface horizon. According to Landon (2014) the categories for the OC content of surface soils are: Very low (< 2%), low (2- 4), medium (4 - 10), high (> 10), very high (> 10). Thus, the OC content of the soil is rated as low to very low and this could be due to intensive agricultural activities that deplete soil organic matter content. Total N content of 0.35% in the surface layer is rated as medium (0.35%) according to Landon (2014). This N content suggests a high N mineralization capacity with relatively good N fertility. Higher total N content in the surface layers as compared to the subsurface layers is related to OM content, as there exists strong correlation between TN and OC.

According to Havlin et al. (1999), the available P content of the soil ranged from very low to low (Table 8). The authors rated Olsen P < 3 mg kg^{-1} as very low, 4 to 7 mg kg^{-1} as low, 8 - 11 mg kg^{-1}as medium, and > 12 mg kg^{-1} as high. The available P content of the soils decreased down the profile. Higher available P values in the surface horizon as compared to subsurface horizons could be attributed to the difference in OM content and application of P containing fertilizers.

Calcium and Mg are the dominant cations in the soils of Hagereselam (Table 9). According to Landon (2014), Ca, K and Mg were rated as medium for the surface horizons. The CEC of the surface and subsurface horizons soils was high probably due to relatively high OM and clay content.

The available micronutrient (Fe, Mn, Zn, and Cu) contents in all soil profiles decreased with increasing soil depth (Table 8). The concentration of available micronutrients was found in the order of Fe>Mn>Zn> Cu. The micronutrient contents of soils are influenced by several factors among which soil OM content, soil reaction and clay content are the major ones (Fisseha,

Table 9. Exchangeable cation composition (cmol kg^{-1}) and total cation exchange capacity (CEC) in soil profile of Hagereselam..

Profile	Ca	Mg	K	Na	CEC
A	8.37	1.83	0.46	0.09	33.90
B1	8.54	1.97	0.85	0.20	35.83
Bs	6.79	2.09	1.82	0.21	32.49
C1	5.26	2.62	1.98	0.26	29.89
C2	5.09	2.57	2.37	0.25	28.21

Table 10. Selected morphological characteristics of Zeway soils.

Profile	Depth(cm)	Color (moist)	Structure	CON(moist)	CON(wet)	Texture(feel)	BOU
Ap	0-24	2.5Y3/2	WE, FF, GR	FR	SST, SPL	L	D,S
Bw1	24-55	2.5Y3/1	WE, FF, SB	FR	SST, SPL	L	D,S
Bw2	55-81	2.5Y5/3	WE, FF, GR	FR	NST, NPL	SCL	D,S
Bw3	81-1.06	5Y4/3	WE, FF, SB	FR	NST, NPL	SCL	C, S
C1	1.06-1.29	G23/3/1	WE, FF, GR	FR	NST, NPL	SCL	C, S
C2	1.29-1.45	2.5Y3/3	WE, VM, SB	FR	SST, SPL	SCL	G, S
C3	1.45-1.62	5Y5/3	WE, VM, SB	FI	NST, SPL	SCL	D, S
C4	1.62-200+	5Y5/2	WE, VM, SB	FI	NST, NPL	SCL	

The description and abbreviations in the table are in accordance with guidelines for field soil description (FAO, 2006). CON, consistency; BOU, boundary; WE, week; VM, very fine to medium; FF, very fine and fine; GR, granular; SB, subangular blocky; FR, friable; FI, firm; SST, slightly sticky; NST, non-sticky; SPL ,non-plastic; SPL, slightly plastic; L, loam; SCL, sandy clay loam; C, clear; S, smooth; D, diffuse.

1992). The high content of extractable Fe is consistent with the acidic nature of this soil, as the solubility of Fe increases at low pH. Generally, the distribution of available Cu and Zn decreased consistently from the surface to the subsurface layers. These results were in agreement with earlier reports of Alemayehu (2007) and Mulugeta and Sheleme (2010). According to critical values of available micronutrients set by Havlin et al. (1999), the amounts of Fe and Mn in the surface layers are considered to be adequate for crop production, whereas the amounts of Zn and Cu were marginal. This is in agreement with other work which stated that Cu and Zn are most likely deficient, whereas Fe and Mn contents usually are at an adequate level in southern Ethiopian soils (Alemayehu, 2007; Ashenafi et al., 2010).

Soils of Zeway

Morphological characteristics

The soils of Zeway are very dark grayish brown (2.5Y3/2) in color when moist with typically higher values (> 3) in the sub surface horizon. The soils are characterized by A, AB, Bt1, Bt2 and C1, horizon sequence (Table 10). Higher color values indicate poor OM content and chromas more than 2 suggest deeper water table in these soils (Sharma et al., 2006). Absence of mottling (red, yellow or brown splotches) in all horizons of the profile suggests that soil pores have not been water-filled for prolonged periods (Sharma et al., 2006). Soil texture is dominated by sandy loam (Table 11). Soil structure is granular at Ap, Bw2 and C1 horizon and subangular blocky for the rest of the horizons. Surface horizons are found to be slightly sticky and slightly plastic. The friable and slightly sticky/slightly plastic consistency observed in the surface horizons of all pedons could be attributed to the relatively higher OM content of the surface than subsurface layers. These results were in agreement with that of Wakene (2001) who argued that although consistency is an inherent soil characteristic and mainly a reflection of the particle size composition of the soil, high OM content changed stickiness and plasticity of surface soil layer.

Physical characteristics

The sand content in Zeway soil was very high (>61%) and silt/clay ratios were greater than 0.76, (Table 11) indicating that the soils are relatively young with high degree of weathering potential (Asomoa, 1973). This could be due to the fact that parent materials around Zeway are composed of volcanic rocks, with alkaline lavas, ashes and ignimbrites, mainly of Tertiary and younger age (Meron 2007) which can eventually lead to

Table 11. Selected physico-chemical characteristics of soil horizons in pedon at Zeway.

Profile	BD	pH(H_20)	EC(dS/m)	Sand(%)	Silt(%)	Clay(%)	Silt:Clay	Texture
Ap	0.99	7.90	4.38	61	24	14	1.66	SL
Bw1	0.91	8.59	4.39	66	20	14	1.45	SL
Bw2	1.18	8.72	4.60	70	13	17	0.76	SL
Bw3	1.21	8.72	6.70	69	19	12	1.59	SL
C1		9.50	5.26	67	18	14	1.30	SL
C2		9.28	9.55	65	22	13	1.75	SL
C3		9.46	11.07	65	19	16	1.15	SL
C4		9.57	11.58	70	20	10	2.14	SL

BD=bulk density; EC=electrical conductivity and SL=sandy loam.

Table 12. Organic carbon (OC), total nitrogen (TN) and available phosphorus (P) and available micronutrient contents of Zeway soils.

Profile	OC(%)	TN(%)	Available. P (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
Ap	2.13	0.22	18.52	0.40	3.37	10.24	1.06
Bw1	1.18	0.07	13.53	0.45	3.58	88.08	0.35
Bw2	0.88	0.06	9.62	0.50	1.94	99.88	0.13
Bw3	0.65	0.04	7.22	0.69	1.39	76.50	0.58
C1	0.63	0.03	7.35	0.64	2.95	76.18	2.39
C2	0.61	0.02	6.45	0.11	2.65	72.04	0.17
C3	0.18	0.01	1.27	0.05	3.90	12.17	0.88
C4	0.16	0.01	0.86	0.05	1.60	2.53	0.20

young soils with courser texture. The highest bulk density (1.21 g cm^{-3}) was found in the Bw3 horizon, while the lowest (0.99 g cm^{-3}) was found at surface horizon (Ap) (Table 11). The lowest bulk densities were found in the surface horizons, reflecting higher OM content (Table 12).

Chemical characteristics

The soil reaction is slightly alkaline for the surface (7.90) and pH increased down the profile to alkaline, where the value in subsurface horizons reached up to 9.57 (Table 11). The EC ranged from 4.38 dS m^{-1} in the surface horizon to 11.58 dS m^{-1} in C4 horizon. The EC value indicated that the soils of Zeway area are salt affected (Havlin et al., 1999) but not sodic in the surface as the pH is below 8.5. This might be due to higher evapo-transpiration than precipitation in this area.

The OC concentration in the soil (Table 12) is rated as low, whereas the total N was rated medium to low according to Landon (2014). The lower amount of OM could be attributed to a complete removal of the organic residues from the soil (Selassie et al., 2015). The available P content was the highest of the three soils (18.52 mg P kg^{-1}) and is considered adequate for the surface soils, according to Havlin et al. (1999). Relatively high content of available P found in soils of Zeway could be due to the continuous application of P fertilizer as was also reported by Whitebreed et al. (1998). In Zeway, extractable available Cu and Zn were found to be in marginal concentrations according to Havlin et al. (1999). The authors rated Cu as marginal, if the Cu content is between 0.4 and 0.6 mg kg^{-1} and Zn content ranges from 0.6 to 1 mg kg^{-1} soil. The available Fe and Mn contents were found to be in adequate amounts according to Havlin et al. (1999).

The CEC in Zeway soils ranged from 32.55 to 49.29 cmol kg^{-1} (Table 13). According to Landon (2014) this range is above the satisfactory value (15-25 cmol kg^{-1}) for agricultural lands. The Na content is found to be medium with ESP less than 15, which is usually taken as the critical limit for classification of sodic soils (Brady and Weil, 2002).

Classification of the study site soils

The soils of the study sites were classified according to Soil Taxonomy (Soil Survey Staff, 2014) and World Reference Base for Soil Resources (FAO, 2006) classification systems. The classifications were based on the morphological, physical and chemical characteristics observed in the field and the results obtained from

Table 13. Exchangeable cation composition ($cmol_c$ kg^{-1}) and total cation exchange capacity (CEC), and exchangeable sodium percentage (ESP) in soil profile of Zeway.

Profile	Ca	Mg	K	Na	CEC	ESP
Ap	30.51	5.46	1.91	3.59	48.21	8.66
Bw1	29.73	5.59	1.87	3.75	49.29	9.15
Bw2	25.36	4.26	1.29	4.63	40.12	13.03
Bw3	22.38	4.23	1.62	4.42	40.67	13.53
C1	20.24	4.39	1.43	4.84	32.55	15.65
C2	21.17	5.37	1.69	4.81	45.87	14.57
C3	16.27	4.27	1.03	5.55	37.71	20.47
C4	14.97	2.83	0.68	8.13	39.05	30.56

laboratory analyses.

Classification according to soil taxonomy

In Alage, the soil profile had an A, Bw1, Bw2, Bw3, Bw4 and Bw5 sequence of horizons. They have an ochric epipedon because it fails to meet the definitions for any of the other epipedons, as it has a high a color value and chroma. Although soil moisture was not measured at the time of sampling, from the available weather data it can be concluded that the area is characterized by aridic soil moisture regime. Due to the presence of high Na causing dispersion and movement of dispersed clay particles down the profile, the Alage soil has an argilic horizon. Thus, considering the morphological, physical and chemical properties of the surface and subsurfaces horizons, soils of Alage fall under the Aridisols Order of Soil Taxonomy (Soil Survey Staff, 2014). Aridisols are subdivided into seven suborders. These are Cryids, Salids, Durids, Gypsids, Argids, Cambids and Calcids (Soil Survey Staff, 2014). The profile has an argillic horizon and do not have a petrocalcic horizon within 100 cm of the soil surface. Therefore, the soils are classified under the Argids suborder. Under great group the profile is categorized as Natrargids and Typic Natrargids.

The profile at Hagerselam had an Ap, AB, Bt1, Bt2, and BC sequence of horizons. It has a clayey subsurface horizon and meets the properties described for an argillic horizon. Moreover, there is a clear evidence of clay illuviation in the form of clay films lining pores. The epipedon had a base saturation less than 50% (by NH_4OAC) and an OC content greater than 0.6%. According to Soil Survey Staff (2014), the epipedon with the above characteristics is umbric. Soils with these properties are classified as Ultisols (Soil Survey Staff, 2014). Using the mean annual and monthly temperature and moisture distributions of the region, the Hagereselam area is characterized by ustic moisture regime. Therefore, at the suborder level, the profile was differentiated as Ustults on the basis of the ustic moisture regime. Further, the pedon did not have a densic, lithic, paralithic, or petroferric contact throughout the mineral soil surface. As well, within 150 cm of the mineral soil surface, with increasing depth there was no clay decrease of 20% or more (relative) from the maximum clay content. Hence, they were classified as Paleustlts and Typic Paleustults under great groups and subgroups levels, respectively.

At Zeway, the soil profile had an Ap, Bw1, Bw2, Bw3, C1, C2, C3, and C4 sequence of horizons. It had higher color value, low OC content, and the Ca content was very high with high Ca:Mg ratio (> 5). The soil fails to satisfy the criteria listed for diagnostic epipedons other than ochric, as it has high color value for most of the horizons. Inferring to the weather data of the site it can be concluded that the area is characterized by an aridic soil moisture regime. Thus, considering the morphological, physical and chemical properties of the surface and sub surfaces horizons, soils of Zeway fall under the Aridisols soil Order of Soil Taxonomy (Soil Survey Staff, 2014). The profile does not have Cryic soil moisture regime, argillic, gypsic, natric, salic or gypsic horizon and therefore is classified under Cambids at the suborder level. Soil of Zeway is therefore classified as Haplocambids and Typic Haplocambids.

Soil classification according to world reference base

Soils of Alage had a texture of sandy clay loam or finer, a ratio of clay of the subsurface horizon to the surface greater than 1.2, a clay increment down the profile, an angular blocky structure at the surface horizons and prismatic structure for the subsurface horizons. The profile had ESP greater than 42 throughout the profile. Moreover, the color of the surface horizon ranged between brown and black. According to WRB (FAO, 2006) such characteristics are typically natric. The soil is classified under Solonetz with Haplic and Arenic prefix and suffix qualifiers. Therefore, soils of Zeway are Haplic Solonetz (Arenic).

Soil of Hagereselam had a clay content in the subsurface that was more than 8% compared to that of the surface horizon, a ratio of clay in the subsurface horizon to the surface greater than 1.2, a clay increment down the profile, does not have a natric horizon and a clay films on both vertical and horizontal surfaces of the soil aggregates. Accordingly, it satisfies the properties listed under argic horizon, which has CEC of 24 cmol kg^{-1}. It has also a base saturation of less than 50%. The above criteria qualify the soils to be classified under Alisols. It is further expressed by Haplic prefix qualifier and Chromin suffix qualifier. Therefore, soils of Hagereselam are Haplic Solonetz (Chromin).

In Zeway, the soils have salic horizons with average EC of the horizons more than 8.5 dS m^{-1} and hence could be classified as Solonchaks. They have mineral soil surface with reducing condition, in some parts, expressed as gleyic color pattern and therefore meet prefix qualifier as Glayic Solonchaks. They also have exchangeable sodium percentage greater than 6 within 100 cm and hence have suffix qualifier as Glayic Solonchaks (Hyposodic).

CONCLUSIONS AND RECOMMENDATIONS

Soil pits were used to provide characterization of soil profiles for soil morphological, physical and chemical characteristics in three areas of Southern Ethiopia with problem soils. The properties assessed enabled the productivity and fertility status of the soils to be assessed and to classify the soils according USDA and WRB systems of soil classification. In the study area, the soil profile opened was 200+ cm deep. Sodic soils of Alage are strongly alkaline (pH>10.10), with high Na and low OC, available P, $cmol_c$ kg^{-1}Cu and Zn contents that would limit production of many crops. The soils need reclamation to reduce sodicity and pH, and increase the availability of nutrients which are found in low amounts. According to USDA soil classification system, soils of Alage are classified as Typic Natrargids, whereas they are classified as Haplic Solonetz (Arenic) following WRB system.

In contrast to soils of Alagae, the soils of Hagereselam are found to be very acidic with pH less than 5. Clay content down the profile increases and available P was found to be low. Moreover, available Zn and Cu contents are at marginal levels and could also limit plant production. Therefore, reclamation especially liming could be a solution, but since increasing the pH tends to decrease the solubility and availability of micronutrients like Cu and Zn, it seems likely that addition of these micronutrients would be required. The soils of Hagereselam are classified as Typic Paleustults and Haplic Alisol (Chromin) following USDA and WRB classification systems, respectively. In Zeway, the soils are saline. They have high sand and Ca contents, but have low amount of OC. Available Cu and Zn contents are also found in marginal levels. The soils are classified as Typic Haplocambids and Glayic Solonchaks (Hyposodic) according to USDA and WRB classification systems, respectively. Removal of the salts from the soil profile through drainage and leaching would be needed to improve the productivity of these soils as the salt content will restrict growth of many crops. However, the feasibility of drainage is limited due to unavailability of fresh water for leaching and cost, and hence selection of salt tolerant crops may be more appropriate. Application of organic amendments including manures and crop residues may also be beneficial in increasing the fertility as well as organic carbon content.

Conflict of Interests

The authors have not declared any conflict of interests.

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