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Characterization and Classification of Soils of Selected Areas in Southern Ethiopia

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ABSTRACT
Characterization and classification of soils previously conducted in southern Ethiopia were not detail and could not give adequate information for further researches. Hence, this study was conducted in Taba, Huletegna Choroko, Tenkaka Umbulo, Kontela, Alage and Jole Andegna, southern Ethiopia, to make detail assessment of morphological and physicochemical properties and investigate the types of soils of the areas for research purpose. Two representative pits of 2 x 2 x 2 m were excavated at each location and the profiles were described *in situ*. Soil samples were collected from each identified horizon and analyzed for macro- and micro-nutrients status, organic carbon, pH, $CaCO_3$ and soil texture. The soils in all locations are very deep (>150cm), have well-developed structure and Bt subsurface (argic) horizons (except Alage and Kontela soils) indicating the occurrence of clay translocation within the profiles. Calcium carbonate accumulations were found in Kontela, Alage and Tenkaka Umbulo soils that resulted in occurrence of calcic subsurface horizons. The soils of the study areas have different textural classes varying from sand to clay. The soils in all locations had pH>7.4 and high base saturation (>60%). Generally, the soils contained medium organic carbon (1.5-2.5%) and medium to high total nitrogen (0.2-0.5%) at the surface and low at the subsurface horizons. The cation exchange capacity ranged from medium to very high (5-25 to >40 cmol (+)/kg soil), the medium range being dominant. Iron (Fe), zinc (Zn) and copper (Cu) were low in Tenkaka Umbulo and Huletegna Choroko soils, whereas manganese (Mn) was high at the surface and low in subsurface horizons. In Taba soils, Cu was deficient throughout the profiles, whereas Fe, Zn and Mn were high in the surface and low in subsurface horizons. Soils of Jole Andegna contained low Fe, and high Cu and Mn, whereas Zn content was high in the surface but low in the subsurface horizons. The soils were classified according to the World Reference Base for soil resources as Haplic Calcisols (Humic) in Tenkaka Umbulo, Haplic Lixisols (Siltic) and Haplic Lixisols (Humic) in Taba, Andic Lixisols (Humic) and Andic Cambisols (Humic) in Huletegna Choroko, Luvic Calcisols (Siltic) in Kontela, Haplic Calcisols (Chromic) in Alage and Haplic Luvisols (Humic) in Jole Andegna. The varying properties, fertility status and types of soils identified in the study areas provide adequate information to design soil management options and further researches on the soils of each site. Therefore, application of site specific soil fertility management practices and conducting researches, which can improve soil micronutrient status and nutritional quality of crops are essential.

Key words: soil properties, soils horizons, soil profiles, micronutrients, soil types

1. Introduction

Characterization and classification of soils previously conducted in southern Ethiopia were not detail and could not give adequate information for further researches. Agricultural land productivity in Ethiopia is declining over time due to a variety of factors; however, the degree to which productivity is declining is not known, largely due to the absence of reliable data on soil characteristics by which changes can be assessed. Engdawork (2002) reported that understanding the characteristics and types of soils is crucial when assessing the potential impact of intensification and/or expansion of cultivated land while maintaining the environment. Characterization and classification of soils are fundamental to all soil studies and help to document soil properties at research sites, which are essential for the successful transfer of research results to other locations (Buol et al., 2003). Braimoh (2002) and Shi et al. (2005) also reported that soil classification can present a basis for soil-related agro-technology transfer and links research results and their beneficial extension to field applications. Soil types and characteristics show great variations across the various regions of Ethiopia (Ali et al., 2010). Natural conditions, such as geology, climate, topography, biotic and land-use/land cover patterns are largely responsible for creating regional and local differences in soil characteristics, and hence variation in their agricultural potentials (Shimelis et al., 2007). Soil characterization studies carried out in different parts of the country revealed great diversity of soils due to variation in geographical and ecological conditions in the country (Ali et al., 2010; Mulugeta and Sheleme, 2010; Rabia et al., 2013). Accordingly, all Reference Soil Groups exist in different parts of the country, except for Cryosols, Podzols, Technosols, Plinthosols, Planosols, Ferralsols, Durisols, Anthrosols and Albeluvisols (Piccolo and Huluka, 1986; Fritzsche et al., 2007; Ali et al., 2010; Rabia et al., 2013; Jones et al., 2013).

Sustainable use of soil is required for successful agriculture to meet the increasing demands of food, fiber and fuel from the decreasing per head farm land. Sustainable management practices are essential to maintain soil fertility and thus ensure secured food supplies (Jones et al., 2013). Detail information on soil characteristics is required to make decision with regard to management practices for sustainable agricultural production, rehabilitations of degraded land (Dinku et al., 2014) and sound researches on soil fertility. Therefore, it is very useful to study and understand the properties of soil and their distribution over an area in order to develop management plans for efficient utilization of soil resources (Shi et al., 2005). Rabia et al. (2013) found the occurrence of different types of soils in the Tigray region and recommended a different management practice for each type of soil. Similarly, Ali et al.(2010), and Mulugeta and Sheleme (2010) indicated that different types of soils exist in Delbo Wegene and Kindo Koye watersheds of southern region, respectively, and these differences direct the requirement of applying different soil management practices for sustainable use of the resource.

The World Reference Base for Soil Resources (WRB) is universally accepted comprehensive soil classification system that enables people to accommodate their national classification system (FAO, 2006) and is widely adopted in Ethiopia. Soils of Taba, Huletegna Choroko, Tenkaka Umbulo, Kontela, Alage and Jole Andegna previously were not characterized and their properties were not known. Therefore, this study was carried out with the main objective of making detail assessment of morphological and physicochemical properties and investigating the types of soils of the areas for research purpose.

2. Materials and Methods

2.1. Description of the study areas

The study was conducted in Kontela, Taba, Jole Andegna, Tenkaka Umbulo, Alage and Huletegna Choroko. Kontela and Alage are located in Oromiya region, whereas Taba, Jole Andegna, Tenkaka Umbulo and Huletegna Choroko are in Southern Nations, Nationalities and Peoples Regional State of Ethiopia (Fig. 1).

2.1.1. Kontela

The Kontela site is located 5 and 120 km north of Zeway and Hawassa, respectively, and 155 km south of Addis Ababa. The site lies between 07°58’09.7” to 07°58’48.5” N latitude and 38°43’09.9”to 38°43’18.3” E longitude with altitude ranging from 1642 to 1646 m.a.s.l. (Table 1). According to the data from the nearby meteorological station at Zeway (2000 – 2013)**,** the mean annual rainfall at the Kontela village is 706 mm with the rainy season extending from March to September. The mean annual temperature is 21 ℃, whereas the mean annual minimum and maximum temperatures are 18 ℃ and 28 ℃, respectively (Fig. 2). The major crops and vegetation in the area include maize (*Zea mays* L.), barley (*Hordeum vulgare*), wheat (*Triticum aestivum*) and haricot bean (*Phaseolus vulgaris*), whereas the native vegetation is dominated by Acacia (*Faidherbia albida*).

2.1.2. Alage

The Alage site is located 60 km south of Zeway town and 220 km south of Addis Ababa. The coordinates of the pedon site are 07°32’21.8” N latitude and 38°24’51.3” E longitude with altitude of1600 m.a.s.l**.** (Table 1). The mean annual rainfall at Alage is 693 mm with the main rainfall season extending from March to September. The mean annual temperature is19.8 ℃ with mean annual minimum and maximum temperatures of 13 ℃ and 27 ℃, respectively (Fig.2). The major crops and vegetation in the area include maize, barley, wheat, haricot bean, sorghum (*Sorghum bicolor*), and hot pepper (*Capsicum frutescens* L.) with Acacia as the dominant vegetation.

2.1.3. Tenkaka Umbulo

Tenkaka Umbolu is located 21km west of Hawassa city within the geographical coordinates between 07°01’19.9” to 07°01’26.7” N latitude and 38°20’23.6”to 38°20’18.8” E longitude and altitude ranging from 1717 to 1727 m.a.s.l. (Table 1). The mean annual rainfall at Tenkaka Umbulo is 932 mm with the main rainy season extending from April to October. The mean annual temperature is 21 ℃ with mean annual minimum and maximum temperatures of 13 ℃ and 28 ℃, respectively (Fig.2). The major crops and vegetation in the area include maize, haricot bean, sugar cane (*Saccharum officinarum*), enset (*Ensete ventricosum*) and kale (*Brassica oleracea* L. var. acephala DC), Acacia sp. and Cordia (*Cordia africana*) are the dominant vegetation.

2.1.4. Huletegna Choroko

Huletegna Choroko is located 4 and 87 km northwest of Halaba and Hawassa towns, respectively, and 314 km south of Addis Ababa. Its lies between 07°20’34.5”to 07°20’21.9”N latitude and 38°06’30.0” to 38°06’31.1”E longitude with altitude ranging from 1807 to 1808 m.a.s.l. (Table 1). The mean annual rainfall at Huletegna Choroko village is 952 mm and the main rainfall season extending from March to October. The mean annual temperature is 19 ℃ with mean annual minimum and maximum temperatures of 13 and 26 ℃, respectively (Fig. 2). The major crops and vegetation in the area include maize, hot pepper, finger millet (*Eleusine coracana*), haricot bean, tef (*Eragrostis tef*) and sorghum, whereas Acacia sp., Cordia, Croton (*Croton macrostachyus*), and Erithrina (*Erythrina* spp.) are the dominant vegetation.

2.1.5. Taba

Taba site is located 8 and 24 km north of Bodity and Sodo towns, respectively, within the geographic coordinates between 07^{o}00’49.9” to 07^{o}01’01.9”N latitude and 037^{0}53’57.6” to 037^{o}54’03.1”E longitude, and altitude ranging from 1910 to 1915 m.a.s.l. (Table 1). The mean annual rainfall at Taba village is 1153.89 mm with the main rainfall season extending from March to September. The mean annual temperature is 15.5 ℃ with mean annual maximum and minimum temperatures of 20 ℃ and 10 ℃, respectively (Fig. 2). The major crops and vegetation in the area include maize, taro (*Colocasia esculenta* L. Schott & Endl.), kale, sweet potato (*Ipomoea batatas*), banana (*Saging Musa sapientum* L.), enset, yam (*Dioscorea alata*), sugar cane, and haricot bean. The vegetation is dominated by Cordia, avocado (*Persium americana*), mango (*Mangifera indica*), and caster bean (*Risunus cominis*).

2.1.6. Jole Andegna

The site is located 12.5 km north of Butajira town and 119.5 km south of Addis Ababa. Its geographical extent is between 08°12’25.9” to 08°11’19.8” N latitude and 38°27’33.2” to 38°27’22.9” E longitude with altitude ranging from 1896 to 1923 m.a.s.l. (Table 1). The mean annual rainfall at Jole Andegna was 937 mm and the main rainfall season extending from March to October. The mean annual temperature is 18.7 ℃ and mean maximum and minimum temperatures are 26.4 ℃ and 10.9 ℃, respectively (Fig. 2). The major crops and vegetation in the area include maize, haricot bean, faba bean (*Vicia faba*), hot pepper, tef, and sorghum, whereas the vegetation is dominated by Acacia and Croton.

2.2.Soil Profile Description and Sampling

Two representative pits of 2 x 2 x 2 m were excavated at each location, except for Alage site where only one pedon was used. The representative soil profiles of each site were described *in situ* following to the Guidelines for Field Soil Descriptions (FAO, 2006). Soil colour notation was described according to Munsell Color Chart (KIC, 2000). Soil samples were collected from each identified horizon and analyzed for macro- and micro-nutrients status, organic carbon, pH, $CaCO_3$ and soil texture.

2.3. Laboratory analysis

Particle size analysis was carried out by the modified sedimentation hydrometer procedure (Bouyoucos, 1951). The pH of the soils was determined in H_2O (pH-H_2O) 1:2.5 soil to solution ratio using a pH meter. Organic carbon content of the soils was determined following the wet combustion method of Walkley and Black as outlined by Sahlemedhin and Taye (2000). Soil total nitrogen was analyzed by wet-oxidation procedure of the Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was analyzed using the Olsen sodium bicarbonate (pH 8.5) extraction method and determined using a spectrophotometer at 882 nm. Exchangeable basic cations and the cation exchange capacity (CEC) of the soils were determined using the 1*M*NH_4OAc (pH 7) method as outlined by Sahlemedhin and Taye (2000). Exchangeable Ca and Mg in the leachate were determined using atomic absorption spectrophotometer (AAS), whereas K and Na were measured using aflame photometer. Available micronutrients (Fe, Mn, Zn, and Cu) contents of the soils were extracted by diethylene triamine pentaacetic acid (DTPA) method (Tan, 1996) and the contents in the extract were determined by AAS.

2.4. Soil Classification

Using field and laboratory data, the soils were classified according to the FAO World Reference Base for soil resources (FAO, 2006).

3. Results and discussion

3.1. Morphological properties

The soils of all locations were found to be very deep (>150cm) (Table 2). The number of generic horizons per pedon was two in Huletegna Choroko and Taba, three in Tenkaka Umbulo, Alage and Jole Andegna, and four in Kontela soils. The A-horizons, except in Alage, were formed due to the accumulation of organic matter from agricultural crops, which is in line with the findings reported by Dinku et al. (2014). The A-horizon in Alage was formed by deposition of sands from the surrounding area. The B-horizons are formed by wetting and drying cycles that aggregated clay-textured soil particles into granular and blocky peds. The development of B-horizon was observed between E-horizons in both pedons of Jole Andegna. The presence of Bt horizons in soils of Tenkaka Umbulo, Taba and one of the profiles at Huletegna Choroko indicated clay translocation and the presence of an argic subsurface diagnostic horizon. The second profile in Huletegna Choroko did not have a Bt horizon indicating the soils of the two profiles at this site are of different types. On the other hand, sub-soils of Tenkaka Umbulo, Kontela and Alage had accumulations of calcium carbonate (Table 3) indicating calcic diagnostic horizons, which qualify the soils to be grouped as Calcisols (Rabia et al., 2013). However, the first profile of Kontela soil contained accumulation of sodium (ESP>15%) showing the presence of natric horizon. Although two diagnostic horizons were present in soils of Tenkaka Umbulo and Kontela, the soils were classified as Calcisols due to the dominancy of calcic horizon.

Moist colors of the study soils were different within and between pits of the same and different locations (Table 2). The colour of Tenkaka Umbulo soils ranged from very dark grey (2.5Y3/1) to light reddish brown (2.5Y6/3). The moist colour of soils in Taba and Huletegna Choroko varied from dark bluish grey ($GLEY_2$ 4/5PB) to pale red (10R6/4), whereas in Kontela soils it varied among dusky red (10R 3/2), very dark grey (7.5YR 3/1) and pinkish white (10R 8/2). The profile description in Alage indicated that the soil colour ranged from very dark red (2.5YR2.5/2) to white (2.5YR8/1) when moist. Jole Andegna soil comprised a moist colour varying from dark reddish grey (2.5YR3/1) to dark greyish brown (10YR4/2). The above colours indicate that soils were well drained in Tenkaka Umbulo, Kontela, Alage and Jole Andegna as reddish and brownish subsoil colors are indicatives of well-drained and aerated conditions, whereas soils in Taba and Huletegna Choroko were poorly drained as water saturated soils tend to have grey-colored B-horizons (Foth, 1990).

The soils of all locations have well-developed granular and blocky structures throughout their profiles (Table 2). Both moist and wet consistencies of the soils in all locations varied within and between the pedons. The moist consistence of Tenkaka Umbulo soils was dominated by friable, whereas the wet consistence of most horizons was slightly sticky and slightly plastic. The soils of Taba and Huletegna Choroko had moist consistency of firm and wet consistency of slightly sticky and very plastic in most of their horizons. In Kontela and Alage, soils were dominated by moist consistency of friable and wet consistence of sticky and slightly plastic. On the other hand, friable, and very sticky and very plastic were the moist and wet consistencies of Jole Andegna soils, respectively. The friable, and non/slightly sticky and non/slightly plastic consistencies indicate the low clay contents of the soils and their ease to till. Ali et al. (2010) also reported that the friable consistency of the soils indicates workability of the soils at appropriate moisture content. In contrast, the sticky, very sticky, plastic and very plastic consistencies show the presence of high clay and low organic carbon contents and difficulty to till. The presence of very sticky and very plastic consistency could be indicative of presence of smectitic clays in the soils (Ali et al., 2010) of Jole Andegna. The friable and very friable consistency observed at the surface of the pedons (Table 2) could be attributed to the higher organic carbon contents as organic matter reduces the stickiness of clay soils making them easier to till (Morgan et al., 2008). Similar findings were also reported by Mulugeta and Sheleme (2010).

The soil horizon boundaries in Jole Andegna were diffuse with smooth topography. Tenkaka Umbulo soils consisted of diffuse, abrupt and clear horizon boundaries with smooth topography, whereas Taba soils had gradual, clear and diffuse horizon boundaries with wavy and smooth topography. Soils of Huletegna Choroko had clear and gradual horizon boundaries with wavy and smooth topography. The distinctness of the boundaries of soil horizons in Kontela were clear and abrupt with smooth topography, whereas the horizon boundaries were diffuse with smooth and wavy topography in Alage soils (Table 2). The variations in horizon boundaries indicate that the soils were formed by different soil-forming processes. The existence of abrupt boundaries in Kontela and Tenkaka Umbulo profiles is evidence for the presence of lithological discontinuities. The change in particle-size distribution between horizons of these profiles also indicates the difference in the material from which the horizons were formed (FAO, 2006). The lithological discontinuities were observed in pedon 1 of Tenkaka Umbulo and in both pedons of Kontela. Designations of the lithological discontinuities show that soil horizons in pedons 1 and 2 of Tenkaka Umbulo and Kontela, respectively, were formed from two contrasting materials, whereas the horizons in pedon 1 of Kontela was formed from three contrasting materials (Table 2).

3.2.Physicochemical properties of the soils

According to Hazelton and Murphy (2007), who rated all sand, silt and clay contents of soils into high (>40%), moderate (25-40%) and low (10-25%), the sand contents varied between low and high in soils of all locations, except in Taba that ranged from low to moderate (Table 3). The silt and clay contents also varied between low and high, and low and moderate in soils of all locations, respectively, but in soils of Taba and Huletegna Choroko. In soils of Taba and Huletegna Choroko the silt contents ranged from moderate to high, whereas clay ranged from low to high and moderate, respectively. Although the particle size distributions in most of the soils were under the same rating, their contents varied resulting in different textural classes. Accordingly, the textural classes of Tenkaka Umbulo, Taba, Huletegna Choroko, Kontela, Alage and Jole Andegna varied from loam to sandy loam, clay loam, loam to clay loam, silt loam, loam to sandy loam and clay to silt loam, respectively.

Higher sand content of up to 68, 79 and 66% was recorded in soils of Tenkaka Umbulo, Kontela and Alage, respectively, which could be attributed to the rhyolitic parent material that contains a common mineral of quartz. Soils in Taba, Huletegna Choroko and Andegna Jole had higher clay content that could be originated from the fine-grained basaltic nature of their parent materials. The silt content was more or less similar in soils of all locations. The high sand content of Tenkaka Umbulo, Kontela and Alage soils indicates that both moisture and nutrient retention is low, whereas the high clay content of Taba, Huletegna Choroko and Jole Andegna soils indicates relatively higher retention of moisture and nutrients in the soils. The textural classes were more or less the same when determined either by the hand texturing method in the field or in the laboratory indicating the field determination can give a good indication of the textural classes and be used when quick results are required and where there is no access to laboratory.

The soils of all locations had alkaline reactions with pH of more than 7.4 and electrical conductivity (EC) of <0.8 dS m^{-1} (Tables 3 and 4), which could be rated as low according to Landon (1991). Maria and Yost (2006) rated organic carbon content of <1.5%, 1.5-2.5% and >2.5% as low, medium and high, respectively. Landon (1991) also stated total N <0.2, 0.2-0.5, and >0.5% as low, medium and high, respectively. The organic carbon (OC) contents of soils in pedon 1 of Tenkaka Umbulo and Jole Andegna, and pedon 2 of Taba ranged from medium to high, the high contents being at the surface horizons of all pedons (Table 3). Pedon 2 of Tenkaka Umbulo, pedon 1 of Taba and Huletegna Choroko, and both pedons of Kontela had OC contents ranging from low to high, whereas the contents in Alage soils ranged from low to medium. Organic carbon contents in pedon 2 of Huletegna Choroko and Jole Andegna were high and medium, respectively, throughout the profiles. These results indicated that OC contents vary not only among soils of different locations but also between pedons of the same location showing accumulation of organic materials as well as farm management differ among fields or farms of the same location. The OC content of surface horizons in all locations, except Alage, was high and decreased with depth attributed to accumulation of more organic materials on the surface soils. These findings are in line with those reported by Getahun et al. (2014) and Maria and Yost (2006). The A-horizon in Alage soils contained lower organic carbon than the underlying horizon, which could be attributed to the prevalence of warm climate that enhances decomposition of organic matter in the surface layer (FAO, 2006). The A horizon contained 1.88% OC while the Bh horizon contained 2.43% due to which the suffix “h” was given. The total nitrogen (TN) in both pedons of Tenkaka Umbulo and pedon 1 of Huletegna Choroko ranged from low to high, whereas it ranged from low to medium in the rest of the pedons. It followed the trends of OC contents in all pedons indicating most of them were derived from OC. The TN contents in all locations, except Alage, were higher at surface horizons than sub-surface horizons attributed to the higher contents of OC on the surface soils. Similar findings were reported by Ali et al. (2010). The available phosphorus content varied among experimental sites mainly due to the difference in soil properties as reported by Sárdi and Csathó (2002). However, the available P content of soils was medium (5-15 mg kg^{-1}) in accordance with Landon (1991) throughout the profiles (Table 4) indicating its inadequacy for crop production, which could be attributed to fixation on both clay and lime surfaces (Leytem and Mikkelsen, 2005). Since a series of phosphorus fixation reactions occur in calcareous soils that decrease availability to plants, fertilizer recommendation should be adjusted to account for this condition.

According to FAO (2006), the $CaCO_3$ contents of soils of Taba, Huletegna Choroko and Jole Andegna were low (<2%), whereas it ranged from low to very high (>25%) in soils of Tenkaka Umbulo, Kontela and Alage (Table 4). The high $CaCO_3$ content of the latter soils could be attributed to the calcareous nature of the parent materials. Landon (1991) classified cation exchange capacity (CEC) <5, 5-15, 15-25, 25-40 and >40 cmolc (+) kg^{-1} soil as very low, low, medium, high and very high. Accordingly, the CEC of Tenkaka Umbulo, Taba and Huletegna Choroko soils were medium in most horizons, but high in Jole Andegna (Table 4). The CEC of Kontela soils ranged between very low and very high, whereas those of Alage ranged between medium and high.

In accordance with the ratings of Landon (1991), the exchangeable Ca in soils of Tenkaka Umbulo, Taba and Huletegna Choroko was classified as high, whereas the values ranged from very low to very high and medium to high in Kontela and Alage soils, respectively, and were very high in Jole Andegna (Table 4).The exchangeable Mg ranged from medium to high in soils of Tenkaka Umbulo and Jole Andegna, whereas it was low in soils of Taba and Huletegna Choroko. Soils in Kontela and Alage contained exchangeable Mg ranging from very low to high and low to medium, respectively. The ratio of Ca to Mg in most cases was above 3 indicating the balance between the two minerals (Engdawork, 2002). The percent base saturation (PBS) was >60 and rated as high (Hazelton and Murphy, 2007) in soils of all locations (Table 4) reflecting the large amount of weatherable minerals in the soils (Engdawork, 2002). The exchangeable K in soils of Tenkaka Umbulo, Taba, Huletegna Choroko and Alage was high, whereas the values in soils of Kontela and Jole Andegna ranged from low to very high and low to high, respectively. The exchangeable Na in soils of Tenkaka Umbulo and Taba ranged from high to very high and low to high, respectively. Huletegna Choroko, Kontela and Alage soils had high exchangeable Na, whereas it was medium in soils of Jole Andegna. The high contents of exchangeable bases in the surface layers of the soils resulted in high percent base saturation (CRI, 2012). Since the base saturation percentage directly affects the ratio of cations on the exchange sites to cations in soil solution, it should be considered for appropriate fertilizer application. Higher exchangeable bases were recorded in soils of Alage, Huletegna Choroko, Tenkaka Umbulo and Kontela, whereas lower values were recorded in soils of Taba and Jole Andegna (Table 4). The high exchangeable bases in soils of Alage and Kontela could be attributed to the low rainfall, and low rainfall plus high OC, respectively, whereas high OC could be the reason for high exchangeable bases in soils of Huletegna Choroko and Tenkaka Umbulo. On the other hand, the lower exchangeable bases in

Jole Andegna and Taba could be attributed to low OC and high rainfall that could cause leaching, respectively. In soils of Tenkaka Umbulo, the exchangeable Na percentages (ESP) of the lower three horizons of pedon 1 and the lower two horizons of pedon 2 were more than 15%, although only the last horizon of pedon 1 qualified for natric horizon. The others failed due to absence of clay increment and presence of lithological discontinuity (FAO, 2006).

Cation exchange capacity is related to amount and type of clay, and organic carbon content (Hamza, 2008). High CEC values were recorded in soils of Huletegna Choroko, Kontela and Jole Andegna, whereas low values were recorded in Tenkaka Umbulo, Taba and Alage soils. The higher CEC values in Huletegna Choroko and Kontela soils could be attributed to higher OC, whereas that of Jole Andegna is was likely due to the presence of smectitic clay. On the other hand, the lower CEC values in soils of Tenkaka Umbulo and Alage are the consequence of the lower contents of clay, whereas at Taba it could be attributed to leaching of basic cations caused by high rainfall. The CEC can determine appropriate fertilizer applications and amount of nutrients needed to correct imbalances. High CEC values indicate that a soil has a greater capacity to hold cations and requires higher rates of fertilizer that can increase its cation level to provide adequate crop nutrition. Whereas, low CEC soils hold fewer nutrients, and are likely subject to leaching of mobile "anion" nutrients that leads to the requirement for split applications of several nutrients (Hamza, 2008). Sonon et al. (2014) also reported that a single application of large quantities of fertilizers to sandy soils with low CEC can cause loss of nutrients via leaching.

According to Havlin et al. (1999), the available Zn level in Tenkaka Umbulo, Taba and Alage soils was low, whereas it varied from low to high in soils of Huletegna Choroko and Jole Andegna, and low to medium in soils of Kontela (Table 4). Available Fe was also low in soils of Tenkaka Umbulo, Taba, Jole Andegna and Alage while it ranged from low to medium in soils of Huletegna Choroko and Kontela. The available Cu was low in soils of Tenkaka Umbulo, Huletegna Choroko, Taba and Alage, whereas its values ranged from low to high in soils of Kontela, and high in Jole Andegna. Manganese contents varied between low and high in soils of all locations. Generally, availability of all micronutrients increased with depth but Cu decreased in all study sites. The values of all micronutrients were higher in B horizons of Kontela soils where $CaCO_3$ and humus were accumulated, which could be attributed to the higher competition by Ca for the adsorption site on the surface of CO_3 and release of the micronutrients upon decomposition of organic matter. In soils of Tenkaka Umbulo, all micronutrients were low in the surface horizon except Mn, indicating the availabilities of Fe, Zn and Cu were inadequate for crop production. The surface horizons of Taba soils contained high micronutrients except Cu suggesting the need for application of Cu fertilizer for crop production. Availability of Zn varied between medium and high in surface horizons of Jole Andegna and Huletegna Choroko soils indicating low crop response to Zn application on these soils. All micronutrients were low in surface horizons of Kontela and Alage soils, except for Cu at Alage, suggesting the need for application of fertilizers containing Zn, Fe and Mn for crop preproduction. Manganese was high in surface horizons of Jole Andegna and Huletegna Choroko soils indicating it was adequate for crop production on these soils.

3.3.Soil classification

The soils were classified based on both morphological and analytical data following the FAO World Reference Base for soil resources (WRB, 2006). The results revealed that there are differences in soil types (Table 5) within and between locations that might be attributed to diversity of geographical, morphological and ecological conditions (Piccolo and Huluka, 1986; Fritzsche et al., 2007; Shimelis et al., 2007; Ali et al., 2010; Rabia et al., 2013). The soils in Tenkaka Umbulo area were classified as Haplic Calcisols (Humic). Calcisols accommodate soils in which there is substantial secondary accumulation of lime and are common in highly calcareous parent materials and widespread in arid and semiarid environments (WRB, 2006). The soils of Tenkaka Umbulo area contained substantial accumulation of lime, which is designated by Ck horizon (Table 4). Rhyolitic volcanic could be the parent material of these soils (Geological Survey of Ethiopia, 2005). The soils contained more than 1 per cent organic carbon in the fine earth fraction to a depth of 50 cm from the mineral soil surface and hence considered as humic suffix qualifier.

The soils of Kontela and Alage areas also had an accumulation of lime and were grouped as Calcisols, but with different prefixes and suffixes (Table 5). Accordingly, the soils of Kontela and Alage areas were determined to be Luvic Calcisols (Siltic) and Haplic Calcisols (Chromic), respectively. The Kontela soils qualified for siltic suffix due to silty clay texture within 100 cm of the soil surface, whereas the Alage soils qualified for chromic since because of Munsell hue redder than 7.5 YR within 150 cm of the soil surface. According to Geological Survey of Ethiopia (2005) and Ministry of Water resources (2008), the parent material of Kontela soils is rhyolitic, whereas that of Alage soil is sub-alkaline basalt with minor rhyolite.

Soils of Taba were grouped as Haplic Lixisols (Siltic) and Haplic Lixisols (Humic). Lixisols comprise soils that have higher clay content in the subsoil than in the top soil as a result of pedogenetic processes (especially clay migration) leading to an *argic* subsoil horizon. An argic horizon is a subsurface horizon with higher clay content than the overlying soil as a result of illuviation, the destruction of clay in the overlying horizon, the selective erosion of clay, and sedimentation or biological activities (Jones et al., 2013). Lixisols have a high base saturation and low-activity clays at certain depths. The soils of Taba area having argic subsurface horizon, CEC<24cmol (+) kg^{-1} of soils and base saturation of up to 96% qualified Lixisols with parent material of ignimbrite (Geological Survey of Ethiopia, 2005). The presence of slickensides in the bottom horizon (Bti) of pedon 1 indicates soils of Taba have vertic property (FAO, 2006) at bottom horizon. The soils of Huletegna Choroko area were classified as Andic Lixisols (Humic) and Andic Cambisols (Humic). The soils grouped as Cambisols did not have appreciable quantities of illuviated clay and did not qualify for argic horizon. The parent material of these soils is ignimbrite (Geological Survey of Ethiopia, 2005).

The soils of Jole Andegna contained appreciable quantities of clay translocation and fulfilled the criteria of argic horizon. They contained CEC of >24Cmol (+) kg^{-1} soils and had high base saturation (up to 83%) and hence were classified as Haplic Luvisols (Humic). Luvisols are soils that have a higher clay content in the subsoil than in the surface as a result of pedogenetic processes (especially clay migration) leading to an *argic* sub-soil horizon. Luvisols have high-activity clays throughout the *argic* horizon and a high base saturation at certain depths. The higher clay content in the subsoil at Jole Andegna could be attributed to the basaltic parent material, which gives rise to fine-textured soils (Jones et al., 2013). In line with this, the Ministry of Water resources (2008) reported that the parent material of soils around Butajira area is basalt. Geological Survey of Ethiopia (2005) also indicated that the parent material of these soils is alkaline basalt.

4. Conclusion

Four different Reference Soil Groups with varying morphological and physicochemical properties were identified in the study sites. The physicochemical properties indicated that organic carbon and macronutrients were moderate, whereas micronutrients, especially, Fe, Zn and Cu were low in most of the studied soils. The varying properties, fertility status and types of soils identified in the study areas provide adequate information to design soil management options and further researches on the soils of each site. Therefore, application of site specific soil fertility management practices and conducting researches, which can improve soil micronutrient status and nutritional quality of crops are essential.

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Table 1**.** Location and physiographic settings of the pedons.

Location	Pedon	Geographic location		Slope (%)	Altitude (m.a.s.l)	Hierarchy of major landform
		Latitude	Longitude			
Taba	1	07^{o}01’01.9”	37^{0}53’57.6”	3	1915	Plain
	2	07^{o}00’49.9”	37^{o}54’03.1”	7	1910	Plain
Huletegna Choroko	1	07^{o}20’34.5”	38^{o}06’30.0”	1	1807	Plain
	2	07^{o}20’21.9”	38^{o}06’31.1”	1	1808	Plain
Jole Andegna	1	08^{o}12’25.9”	38^{o}27’33.2”	9	1923	Plain
	2	08^{o}11’19.8”	38^{o}27’22.9”	2	1896	Plain
Kontela	1	07^{o}58’09.7”	38^{o}43’09.0”	4	1646	Plain
	2	07^{o}58’48.5”	38^{o}43’18.3”	9	1642	Plain
Alage	1	07^{o}32’21.8”	38^{o}24’51.3”	9	1600	Plain
Tankaka Umbulo	1	07^{o}01’19.9”	38^{o}20’23.6”	10	1717	Medium-gradient escarpment zone
	2	07^{o}01’26.7”	38^{o}20’18.8”	1	1727	Plain

Table 2. Morphological properties of the soils of the study sites

Location	Pedon	horizon	Depth (cm)	Moist color	Textural class	Structure	Consistence		HB	CO_3 rxn	Pores
							moist	wet			
T. Umbulo	1	Ap	0-26	2.5Y3/1	SiL	ST, FI, G	VFR	SST, SPL	D,S	SL	M, M
		B	26-69	2.5Y4/2	L	ST, FI, G	VFR	SST, SPL	D, S	SL	M, M
		C	69-116	2.5Y5/2	SL	ST, FI, G	FR	SST, SPL	D, S	EX	M, C
		Ck	116-156	2.5Y6/3	US	ST, FI, G	VFR	NST, NPL	A, S	EX	F, F
		2B	156-176	2.5Y6/1	US	WE, VFI, G	FI	NST, NPL	C, S	ST	F, V
		2Bn	176-209	2.5Y3/2	SL	ST, CO, G	VFI	SST, SPL	-----	MO	F, F
	2	Ap	0-25	2.5Y3/3	SiL	MO, FI, G	FR	ST, PL	D,S	SL	M, C
		B1	25-69	2.5Y5/3	SL	MO, FI, G	FR	ST, SPL	D, S	SL	M, C
		B2	69-115	2.5Y4/3	US	MO, CO, G	FR	SST, NPL	D, S	SL	F, C
		Bt	115-131	2.5Y4/3	US	ST, CO, G	FI	SST, NPL	D, S	MO	M, C
		Ck	131-157	2.5Y6/5	SL	WE, CO, SB	VFI	NST, SPL	D, S	ST	F, F
		C	157-187	2.5Y7/5	SL	WE, FI, SB	FI	SST, SPL	-----	MO	F, F
Taba	1	Ap	0-33	7.5YR3/1	SCL	-------	LO	NST, SPL	G,W	SL	M, C
		AB	33-73	7.5YR4/2	SCL	-------	FR	NST, SPL	C, S	SL	F, F
		ABg	73-94	GLEY1 6/ 10Y	C	M, M, G	FI	SST, VPL	C, S	SL	V, F
		Bti	94-157	GLEY14/N	C	ST, Platy	VFI	VST, VPL	------	SL	N
	2	Ap	0-47	GLEY2 4/10B	SiL	WE, M, G	VFR	SST, PL	D,W	SL	M, C
		E	47-94	10R3/2	Si	MO, FI, G	FI	SST, PL	C,W	SL	M, C
		Bt	94-170	10R5/6	C	ST, VFI, G	VFI	ST, VPL	------	SL	F, V
H. Choroko	1	A	0-52	GLEY2 4/5PB	C	WE,FI,G	VFR	ST, VPL	G, S	SL	M, C
		AB	52-67	GLEY2 4/10B	L	WE,FI,G	VFR	SST, SPL	C, W	SL	M, F
		Btg	67-98	GLEY2 6/10G	SL	ME,FI,G	FI	SST, SPL	C, W	SL	M, V
		B	98-170	10R6/4	C	WE,FI, B	FI	VST, VPL	------	SL	N
	2	A	0-60	2.5YR 2.5/1	C	WE, FI, G	VFR	SST, VPL	G, S	SL	M, M
		CB	60-87	2.5YR 5/1	SC	WE, FI, G	FI	VST, VPL	C, W	SL	F, F
		C	87-187	2.5YR 3/1	C	ST, FI, B	VFI	ST, VPL	-----	SL	N

Horizon boundary (HB): D=diffuse; S=smooth; Texture: SiL=silt loam, L=loam, SL=sandy loam, US=sand unsorted, SG=single grain; Carbonate reaction: SL= slightly calcareous (0-2%), EX=extremely calcareous, ST= strongly calcareous, MO= moderately calcareous; Soil structure: ST=strong, FI=fine, G=granular; WE=weak, VFI=very fine, CO=columnar, SB=sub-angular blocky

Consistency: Moist: VFR=very friable, FR=friable, FI=firm, VFI=very firm, Wet: SST=slightly sticky, SPL=slightly plastic, NST=non-sticky, ST=sticky, NPL=non-plastic, PL=plastic, Pores: MM=medium many, MC=medium common, FF=fine few, FV=fine very few, N=none

Table 2. Morphological properties of the soils of the study sites *(cont'd)*

Location	Pedon	horizon	Depth (cm)	Moist color	Textural class	Structure	Consistence		HB	CO_3 rxn	Pores
							moist	wet			
Kontela	1	Ak	0-67	10R 3/2	C	WE, FI, G	FI	ST, VPL	C, S	EX	M, C
		E	67-76	10R 8/2	SC	WE, FI, G	VFI	ST, SPL	C, S	EX	M, F
		Bkn	76-100	10R 7/1	C	ST, FI, SB	FR	ST, VPL	C, S	EX	M, F
		C	100-107	GLEY2 6/5B	VFS	MO, VF, B	FR	NST, NPL	A, S	EX	N
		2Bh	107-133	10R 8/2	SC	ST, CO,SB	VFR	VST, SPL	C, S	MO	N
		2C	133-143	GLEY2 4/10G	S	SG	LO	-----	A, S	MO	C, M
		3C	143-169	10Y 7/1	SC	ST, ---, PL	VFR	SST, SPL	------	MO	None
	2	A	0-50	7.5YR 3/1	C	WE, FI, G	FR	SST, PL	C, S	MO	M, M
		B	50-80	GLEY2 7/5B	C	WE, FI, G	FR	VST, VPL	C, S	EX	M, F
		Bk	80-109	10R 8/2	SC	WE, FI, G	FR	VST, VPL	C, S	EX	M, F
		Ck	109-140	GLEY2 6/5B	S	SG	LO	-----	A, S	ST	C, M
		2B	140-151	5Y 7/2	SC	PL	VFI	ST, SPL	C, S	MO	N
		2C	151-187	GLEY2 7/5GY	SC	WE,VFI, G	EFI	ST, SPL	------	MO	N
Alage		Ap	0-20	2.5YR3/3	S	MO, ME, G	FI	ST, PL	D, W	MO	C, C
		Bh	20-48	2.5YR2.5/2	SiC	MO, ME, G	FR	VST, VPL	D, W	MO	M, C
		BC	48-87	2.5YR6/2	L	MO, FI, G	VFR	ST, SPL	D, W	MO	F, C
		Ck	87-137	2.5YR8/1	SL	MO, FI, G	FI	NST,SPL	D, S	EX	F, F
		C_1	137-175	2.5YR6/3	SL	MO, FI, G	FR	NST, SPL	D, S	ST	F
		C_2	175-197	2.5YR7/1	SL	ST, VFI, G	FR	SST, SPL	-------	EX	F
J. Andegna	1	Ap	0-30	2.5YR3/1	C	WE,ME,G	FR	ST,VPL	D,S	SL	M,M
		B	30-60	2.5YR4/4	SC	WE,FI,G	VFR	NST,PL	C,S	SL	M,C
		E	60-92	2.5YR5/8	SiC	WE,FI,G	FR	SST,PL	C,S	SL	M,F
		Bt	92-165	10YR2/1	C	WE,ME,G	VFR	ST,VPL	C,S	SL	F,F
		E'	165-205	10YR4/2	SC	MO,ME,G	FR	VST,VPL	_____	SL	F,F
	2	Ap	0-23	10YR3/2	C	MO,ME,G	FR	VST,VPL	G, S	SL	M,C
		E	23-52	10YR4/2	SiL	ST,C,SB	FI	ST,SPL	C, S	SL	C,F
		Bt_1	52-92	10YR4/3	SiL	ST,C,SB	FI	ST,SPL	D, S	SL	F,F
		Bt_2	92-146	10YR4/4	C	MO,FI,B	FI	VST,VPL	C, S	SL	N

E'	146-175	10YR4/4	C	WE,FI,G	FI	VST,VPL	C, S	SL	N
Bt_3	175-200	10YR3/3	SC	ST,C,SB	FI	VST,PL	------	SL	N

Table 3. Selected physical and chemical characteristics of soils of the study sites

Location	pedon	Horizon	Depth	Particle size distribution			Textural class*	pH (H_2O)	EC (dS/m	OC (%)	TN (%)	C/N ratio	AvP[@] (mg/kg)	$CaCO_3$ (%)
				Sand	Silt	Clay								
T.Umbulo	1	Ap	0-26	48	34	18	L	8.08	0.06	4.1	0.41	10	12.98	1.2
		B	26-69	8	64	28	SiL	8.3	0.08	2.54	0.24	10.6	13.96	1.82
		C	69-116	62	26	12	SL	8.74	0.18	1.71	0.15	11.4	13.26	26
		Ck	116-156	68	20	12	SL	9.4	0.33	1.40	0.12	11.7	14.13	27
		2B	156-176	60	24	16	SL	9.5	0.39	1.29	0.10	12.9	12.59	18
		2Bn	176-209	36	40	24	L	9.7	0.47	1.63	0.13	12.5	14.23	7.6
	2	Ap	0-25	40	38	22	L	7.3	0.03	4.33	0.42	10.3	13.24	1.3
		B1	25-69	40	36	24	L	7.4	0.07	2.40	0.22	10.9	13.97	1.5
		B2	69-115	44	30	26	L	8.25	0.21	2.58	0.23	11.2	12.10	1.7
		Bt	115-131	34	34	32	CL	8.74	0.51	2.54	0.21	12.1	10.51	6.2
		Ck	131-157	50	40	10	L	9.6	0.62	1.25	0.11	11.4	15.65	17
		C	157-187	36	54	10	SiL	9.6	0.81	0.17	0.84	10.5	15.09	11
Taba	1	Ap	0-33	30	38	32	CL	7.72	0.06	3.90	0.35	11.1	8.5	0.51
		AB	33-73	38	34	28	CL	7.03	0.03	3.10	0.26	11.9	6.8	0.54
		ABg	73-94	32	40	28	CL	7.8	0.06	1.01	0.11	9.2	9.27	0.53
		Bti	94-157	24	42	34	CL	7.6	0.11	1.03	0.15	6.9	9.9	0.64
	2	Ap	0-47	28	40	32	CL	7.58	0.17	3.60	0.30	12.0	9.8	0.68
		E	47-94	32	60	8	SiL	7.8	0.21	2.20	0.26	8.5	8.9	0.72
		Bt	94-170	26	30	44	CL	7.9	0.16	1.80	0.14	12.9	10.2	0.81
H. Choroko	1	A	0-52	41	34	25	L	8.24	0.08	4.26	0.50	8.52	13.53	0.61
		AB	52-67	36	40	24	L	8.36	0.31	2.56	0.32	8.00	11.45	0.73
		Btg	67-98	32	36	32	CL	8.5	0.25	1.55	0.16	9.69	14.84	0.67
		B	98-170	30	36	34	CL	8.2	0.5	1.17	0.13	9.00	10.89	0.76
	2	A	0-60	41	30	29	CL	7.5	0.07	6.30	0.47	13.4	15.08	0.52
		CB	60-87	28	46	26	L	8.47	0.2	3.52	0.27	13.0	13.17	0.63
		C	87-187	11	62	27	SiCL	7.6	0.25	2.42	0.25	9.68	13.64	0.70

*: L = loam, C = clay, CL = clay loam; SiCL = silt clay loam; SCL = sand clay loam; SL= sandy loam; LS = loamy sand; [@]AvP = available P.

Table 3. Selected physical and chemical characteristics of soils of the study sites *(cont'd)*

Location	pedon	Horizon	Depth	Particle size distribution			Textural class	pH (H_2O)	EC (dS/m	OC (%)	TN (%)	C/N ratio	AvP (mg/kg	$CaCO_3$ (%)
				Sand	Silt	Clay								
Kontela	1	Ak	0-67	25	56	19	SiL	7.94	0.58	3.51	0.45	7.80	13.29	30
		E	67-76	29	64	7	SiL	9.05	0.29	1.00	0.15	6.67	14.22	25
		Bkn	76-100	23	60	17	SiL	9.41	0.72	3.20	0.38	8.42	9.20	28
		C	100-107	29	62	9	Si	9.95	0.24	1.66	0.24	6.92	7.63	22
		2Bh	107-133	29	58	13	SiL	9.25	0.23	4.00	0.47	8.51	3.36	5.3
		2C	133-143	79	12	9	LS	9.8	0.69	1.53	0.21	7.29	1.82	7.4
		3C	143-169	25	66	9	SiL	9.12	0.84	3.70	0.41	9.02	9.84	8.1
	2	A	0-50	32	49	19	L	8.32	0.12	4.46	0.48	9.29	9.29	8.7
		B	50-80	25	56	19	SiL	8.5	0.20	1.96	0.28	7.00	14.02	26
		Bk	80-109	23	55	22	SiL	9.2	0.26	1.63	0.22	7.40	3.25	29
		Ck	109-140	78	12	10	LS	9.7	0.24	0.46	0.08	5.75	1.85	23
		2B	140-151	15	54	31	SiCL	9.55	0.24	0.19	0.02	9.50	3.58	5.1
		2C	151-187	47	42	11	L	9.54	0.36	0.16	0.02	8.00	0.67	5.8
Alage		Ap	0-20	66	12	22	SCL	6.9	0.15	1.88	0.21	8.95	12.62	4.6
		Bh	20-48	34	36	30	CL	7.65	0.13	2.43	0.31	7.84	9.94	6.9
		BC	48-87	42	38	20	L	8.22	0.11	1.17	0.17	6.88	9.81	7.4
		Ck	87-137	62	32	6	SL	8.46	0.14	0.71	0.11	6.45	10.06	28
		C_1	137-175	36	56	8	SiL	9.3	0.28	0.37	0.08	4.63	9.81	21
		C_2	175-197	44	48	8	L	9.5	0.41	0.28	0.05	5.60	10.86	26
J. Andegna	1	Ap	0-30	26	56	18	SiL	7.61	0.11	2.86	0.36	7.94	13.69	0.32
		B	30-60	66	12	22	SCL	7.66	0.10	1.66	0.23	7.21	12.81	0.41
		E	60-92	40	44	16	L	7.70	0.10	1.61	0.21	7.67	13.21	0.56
		Bt_1	92-165	27	40	32	CL	7.46	0.12	1.87	0.24	7.72	11.59	0.99
		E'	165-205	30	44	26	L	8.01	0.11	1.54	0.19	8.11	8.78	0.84
	2	Ap	0-23	34	34	32	CL	7.6	0.15	2.42	0.35	6.91	12.19	0.57
		E	23-52	22	60	18	SiL	7.43	0.09	1.61	0.22	7.32	13.14	0.62
		Bt_1	52-92	32	34	34	CL	7.33	0.12	1.70	0.23	7.39	12.87	0.66
		Bt_2	92-146	14	50	36	SiCL	8.02	0.15	2.18	0.32	6.81	9.12	0.73

E'	146-175	12	70	18	SiL	7.59	0.04	1.95	0.26	7.50	9.78	0.70
Bt_3	175-200	16	50	34	SiCL	8.19	0.14	1.78	0.24	7.42	10.42	0.78

Table 4. Exchangeable cations, cation exchange capacity, and available micronutrients of soils in Tenkaka Umbulo, Taba and Huletegna Choroko

Location	pedon	Horizon	Depth	Na	K	Mg	Ca	CEC	Sum of base	PBS	ESP	Fe	Cu	Zn	Mn
						cmol (+)/kg of soils					%		mg/kg soil		
T. Umbulo	1	Ap	0-26	1.8	2.1	2.1	13.0	21.6	19.0	87.7	8.3	2.08	0.23	0.42	1.54
		B	26-69	1.3	2.0	2.5	13.9	23.2	19.5	84.2	5.6	0.66	0.30	0.33	1.08
		C	69-116	1.5	2.1	3.1	8.6	16.3	15.3	93.7	9.2	0.28	0.27	0.13	0.06
		Ck	116-156	2.5	2.3	3.2	6.4	14.9	14.4	97.2	16.8	0.64	0.23	0.14	0.05
		2B	156-176	3.6	2.6	1.8	8.2	17.3	16.2	93.4	20.8	0.7	0.28	0.12	0.01
		2Bn	176-209	3.8	2.2	2.5	12.5	22.4	21.1	93.8	17.0	2.58	0.43	0.36	0.34
	2	Ap	0-25	1.5	2.0	3.1	15.3	23.5	22.0	93.6	6.5	2.44	0.27	1.04	4.18
		B1	25-69	1.7	3.0	3.2	14.7	24.6	22.6	91.9	7.0	1.13	0.09	0.20	2.57
		B2	69-115	2.7	3.7	5.5	10.9	25.2	22.7	90.2	10.7	0.68	0.12	0.30	0.87
		Bt	115-131	3.6	4.9	3.2	14.6	29.3	26.3	89.8	12.3	1.18	0.28	0.33	0.18
		Ck	131-157	4.6	7.6	4.2	6.6	15.5	13.3	85.5	29.6	1.35	0.16	0.20	0.14
		C	157-187	4.1	5.6	2.5	9.0	16.3	14.0	85.5	25.1	2.50	0.42	0.16	0.14
Taba	1	Ap	0-33	0.8	0.9	1.2	15.3	23.6	18.2	77.1	3.22	4.60	0.16	1.07	1.03
		AB	33-73	0.6	1.0	0.4	10.7	16.5	12.6	76.6	3.64	1.63	0.07	0.68	1.66
		ABg	73-94	0.3	1.1	0.1	7.10	10.9	8.61	78.9	2.84	0.68	0.25	0.38	0.41
		Bti	94-157	0.6	1.8	3.5	12.1	18.8	18.0	96.0	3.25	0.17	0.54	0.36	0.30
	2	Ap	0-47	1.2	1.8	1.1	14.8	22.7	18.9	83.1	5.28	1.11	0.39	2.06	1.32
		E	47-94	0.8	0.8	1.1	10.3	15.9	13.0	81.8	4.79	1.39	0.28	1.67	1.35
		Bt	94-170	1.3	1.1	0.5	14.1	23.5	16.9	71.9	5.52	1.12	0.07	0.44	1.76
H. Choroko	1	A	0-52	3.2	0.7	0.8	15.4	23.7	20.0	84.7	13.5	0.69	0.16	0.71	1.05
		AB	52-67	2.0	2.0	0.2	12.9	19.8	17.0	85.8	10.2	0.93	0.19	0.47	0.71
		Btg	67-98	1.8	0.9	0.4	8.93	13.7	12.0	87.5	13.1	0.84	0.10	0.04	0.24
		B	98-170	1.2	1.8	1.0	9.15	14.1	13.2	93.7	8.53	0.29	0.52	0.70	0.29
	2	A	0-60	0.8	1.6	1.2	17.3	26.6	20.8	78.3	3.01	3.27	0.39	1.88	5.24
		CB	60-87	2.0	1.5	0.1	8.01	15.2	14.5	95.7	12.8	1.08	0.20	0.16	1.29
		C	87-187	0.6	4.5	1.5	14.5	23.3	21.1	90.5	2.57	0.43	0.50	0.24	0.22

Table 4. Exchangeable cations, cation exchange capacity, and available micronutrients of soils in Kontela, Alage and Jole Andegna *(cont'd)*

Location	pedon	Horizon	Depth	Na	K	Mg	Ca	CEC	Sum of base	PBS	ESP	Fe	Cu	Zn	Mn
				Cmol (+)/kg of soils							%	Mg/kg soil			
Kontela	1	Ak	0-67	0.6	0.9	1.5	16.3	26.4	19.3	73.1	2.38	0.27	0.41	0.15	0.22
		E	67-76	3.2	1.5	2.2	7.01	16.8	13.8	82.6	18.8	0.23	0.66	0.19	0.61
		Bkn	76-100	6.2	1.0	2.2	6.21	16.4	15.7	95.3	37.7	0.31	0.81	0.18	1.27
		C	100-107	1.9	0.4	0.6	5.57	10.3	8.49	82.6	18.5	0.37	0.31	0.08	0.23
		2Bh	107-133	6.4	3.4	0.4	20.5	34.1	30.7	90.1	18.8	4.29	0.66	0.61	0.75
		2C	133-143	0.1	0.1	0.2	0.71	1.21	1.08	89.3	5.79	1.19	0.27	0.17	0.20
		3C	143-169	5.6	2.4	0.2	12.7	24.4	20.9	85.6	22.9	1.35	0.66	0.52	1.26
	2	A	0-50	1.8	1.8	1.2	37.6	47.7	42.3	88.6	3.69	0.31	0.43	0.20	0.63
		B	50-80	6.2	1.5	3.4	33.3	42.3	39.4	93	14.7	0.33	0.21	0.05	0.08
		Bk	80-109	2.3	3.7	0.4	22.4	37.3	28.8	77.1	6.27	4.35	0.70	0.70	0.73
		Ck	109-140	0.1	0.1	0.2	0.72	1.20	1.09	90.8	5.83	1.21	0.26	0.16	0.22
		2B	140-151	1.3	1.6	2.0	30.9	40.5	35.7	88.2	3.09	5.20	0.71	0.60	0.22
		2C	151-187	6.1	3.3	0.2	21.1	32.4	30.6	94.4	18.7	0.75	0.31	0.32	0.18
Alage		Ap	0-20	1.2	1.9	1.1	12.1	18.6	16.2	87.4	6.46	0.57	0.34	0.28	0.1
		Bh	20-48	1.6	2.8	2.5	20.2	32.7	27.1	83.1	4.93	0.41	0.25	0.18	0.01
		BC	48-87	0.7	3.0	2.0	16.0	25.0	21.7	86.8	2.80	0.33	0.30	0.09	0.16
		Ck	87-137	0.9	3.8	1.7	6.28	12.6	12.4	99.0	6.77	0.17	0.10	0.09	0.02
		C_1	137-175	3.4	5.2	2.2	3.52	14.6	14.3	98.4	23.4	0.39	0.25	0.02	0.04
		C_2	175-197	3.0	3.6	0.8	9.30	16.9	16.7	98.8	17.8	0.67	0.07	0.05	3.44
J. Andegna	1	Ap	0-30	0.5	0.5	1.9	30.7	45.7	33.51	73.1	1.12	1.79	1.67	0.90	8.89
		B	30-60	0.3	0.6	2.2	21.9	33.8	25.04	74.2	0.95	1.46	1.07	0.32	1.28
		E	60-92	1.0	0.9	3.0	22.1	32.4	26.97	83.1	3.11	0.51	1.06	0.28	1.27
		Bt_1	92-165	0.6	0.5	3.2	31.5	50.4	35.67	70.8	1.11	0.95	1.68	0.77	3.42
		E'	165-205	0.8	0.7	3.2	26.1	40	30.8	77	1.89	1.21	0.87	0.19	1.41
	2	Ap	0-23	0.2	0.2	1.0	29.1	47.8	30.51	63.8	0.44	0.82	0.33	1.33	12.1
		E	23-52	1.0	0.4	2.1	19.3	29.7	22.77	76.7	3.37	0.42	1.40	0.7	4.46
		Bt_1	52-92	0.2	0.2	2.0	25.4	39.3	27.88	70.9	0.56	0.88	1.43	1.15	4.97
		Bt_2	92-146	0.6	0.2	3.6	27.1	48.3	31.33	64.8	1.18	0.21	1.50	0.18	0.63
		E'	146-175	0.6	0.2	3.3	24.7	40.2	28.84	71.8	1.59	0.36	1.51	0.23	0.32
		Bt_3	175-200	0.6	0.1	3.0	18.9	31.0	22.58	73.0	2.07	0.07	1.21	0.28	0.17

Table 5**.** Diagnostic horizons and soil unit at different locations according to WRB (2006).

Location	Pedon	Diagnostic horizons		Soil unit
Tenkaka Umbulo		Surface	Subsurface	
	1	Mollic	Calcic	Haplic Calcisols (Humic)
	2	Mollic	Calcic	Haplic Calcisols (Humic)
Taba	1	Mollic	Argic	Haplic Lixisols (Siltic)
	2	Anthraquic	Argic	Haplic Lixisols (Humic)
Huletegna Choroko	1	Anthraquic	Argic	Andic Lixisols (Humic)
	2	Mollic	Cambic	Andic Cambisols (Humic)
Kontela	1	Mollic	Calcic	Luvic Calcisols (Siltic)
	2	Mollic	Calcic	Luvic Calcisols (Siltic)
Alage	1	Mollic	Calcic	Haplic Calcisols (Chromic)
Jole Andegna	1	Mollic	Argic	Haplic Luvisols (Humic)
	2	Mollic	Argic	Haplic Luvisols (Humic)

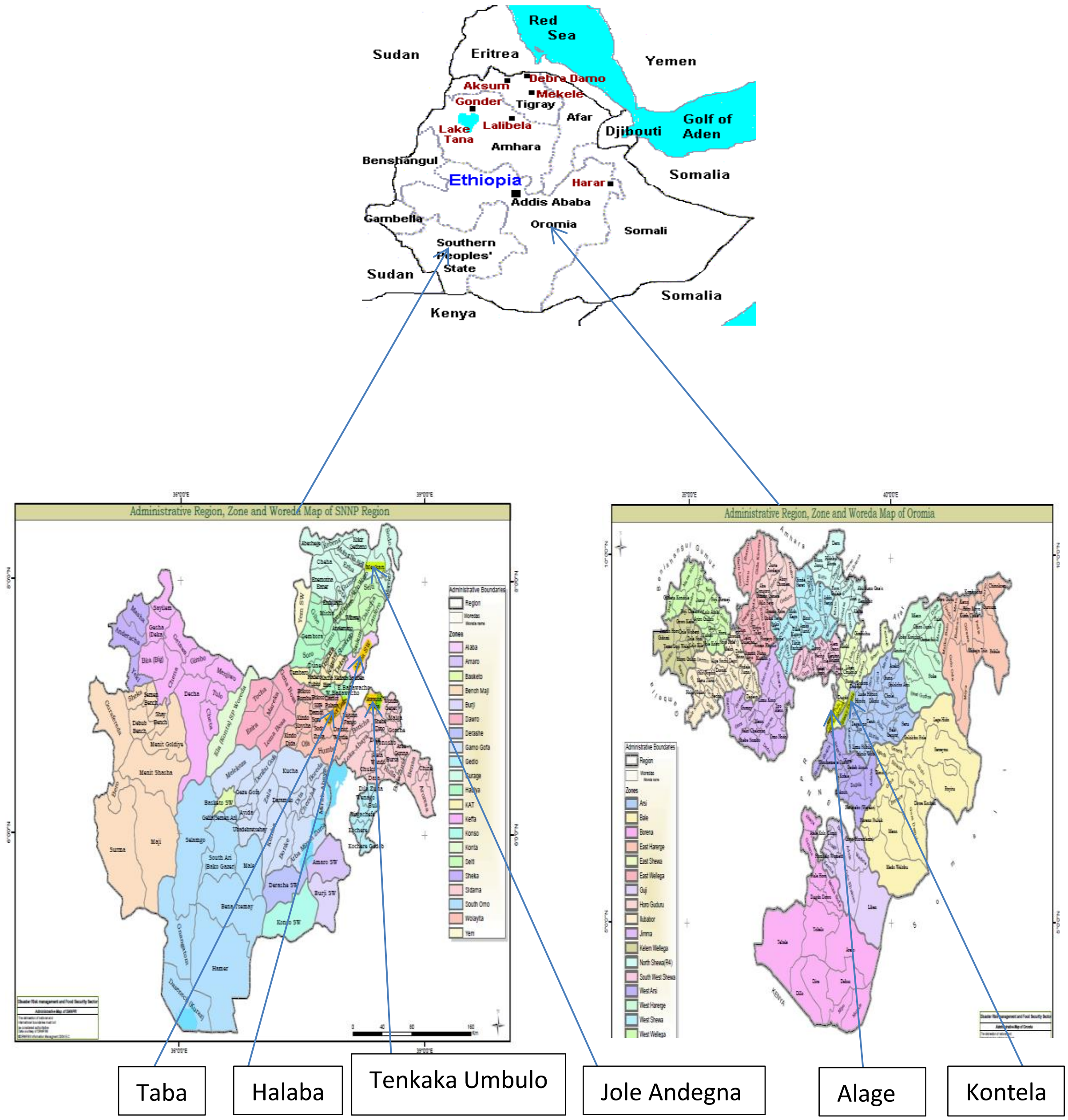

Fig.1 Maps showing location of the study sites

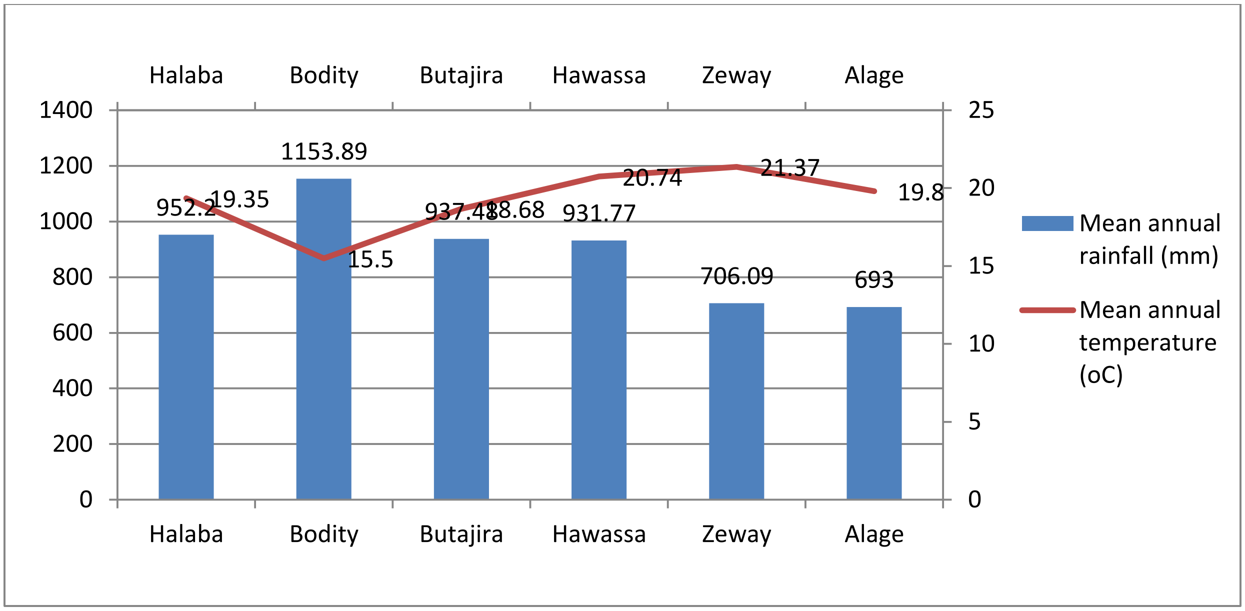

Fig. 2. Mean annual rainfall and temperatures of the study sites (2000-2013)