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Determination of physico-chemical properties and agricultural potentials of soils in Tembaro District, KembataTembaro Zone, Southern Ethiopia

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Abstract

The objectives of this study were to classify the soils of Tembaro district, and to identify its potentials for crop production. Five pits representing a pedon each were opened and profile in each pit was described for its morphological, physical and chemical characteristics according to standard procedures. A total of 20 disturbed soil samples and 16 core ring samples were collected from five representative profiles. The samples were analyzed in the laboratory for texture, BD, FC, PWP, Soil pH, EC, OC, TN, av.P, av.K, exchangeable bases, free and active iron and CEC. The results showed that the proportions of soil separates varied among profile and depth however, soils were all in clay textural class. The BD varied from 1.02 in the surface profile 1 to 1.25 g.cm^{-3} in the profile 3. Soil pH ranged from 6.8 to 5.4 in the surface horizons of all profiles with further decrease with depth indicating that the soils in the watershed are slightly acidic to moderately acidic. The OM and TN contents ranged from 2.90 to 5.43 and 0.23 to 0.45% in the surface horizon and they were in the low, low to medium and high categories respectively. The corresponding values for the remaining subsoil horizons were in the low categories. In all cases the contents of these parameters decreased considerably with depths. Available P was below critical values for all profiles and depths except for profiles 1 and 4. Exchangeable K was above critical value in all profiles with increasing trend along with depth of all profiles. Exchangeable Mg varied from 2.47 in surface horizon of profile 3 to 3.98 cmolc kg^{-1} in the surface horizons of profile 4 and increased with depth in all profiles except in profile 1. The observation with exchangeable K and Mg implies that there is leaching phenomenon in the study area. Ca ranged from 4. 35 cmolc kg $^{-1}$ in profile 5 to 16.50 cmolc kg $^{-1}$ in profile 1 with inconsistent trend with depth. The CEC from 18.22 cmolc kg $^{-1}$ soil in surface horizon of profile 5 to 27.43 cmolc kg-1 soil in the surface horizons of profile 1 indicating they are in the medium to high ranges. But inconsistent trend in CEC distribution was observed with depth in all profiles. Based on the data collected from profile description study and soil physicochemical analytical data and according to FAO-WRD soil classification legend, the soil at Ambukuna watershed were classified as Haplic Nitisols (Endoeutric, humic), Haplic Nitisols (Hypereutric, humic), Haplic Nitisols (Endoeutric) and Haplic Nitisols (Epidystric, Humic). Most of the soil physical and some of the chemical characteristics studied could be ranked as good indicating that the area has high potential for agricultural production.

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Introduction

Sustainable agricultural productivity aims to produce components that are directly consumed by human beings and contribute to the satisfaction of human needs by producing quantity and quality products with little damage to the environment, such as soils. Thus the overall productivity and sustainability of a given

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agricultural sector are functions of fertile soils and productive lands. However, soil fertility depletion is the fundamental biophysical cause for declining per capita food production in sub- Saharan African countries in general (Sanchez et al., 1997, Sanginga and Woomer, 2009) and in southern Ethiopia in particular. The study and understanding of soil properties and their distribution over an area has proved to be useful for the development of soil management plan for efficient utilization of limited land resources. Moreover, it is very important for agrotechnology transfer (Buol et al., 2003).

Ethiopian agriculture accounted for 39% of GDP, 83.9% of export earrings and 80% of total employment in 2015/2016, compared to 44.9%, 76.9%, and 80%, respectively in 2002/2003 (CSA, 2017). As a result, agriculture remains to be Ethiopian economy's most important sector.

Ethiopia has great agricultural potential because of its vast areas of fertile land, diverse climate,

generally adequate rainfall, and large labour pool (CSA, 2017). The country has a total surface area of 111.8 million ha (Mabbutt, 1984); of which 62.81million ha are estimated agriculturally productive (Mishra et al., 2004). However, Ethiopia's agriculture is characterized by low production per unit area. Although the country has enormous potential for agricultural production (such as in terms of land, climate and water resources), it is not uncommon facing a serious and chronic problem of food crop shortage in the country (Yohannes, 1989). Ethiopia with its immense potential soil resource base suffers from food insecurity (Mishra et al., 2004). This is a paradox, which invites researchers to investigate the causes of the problem and suggest feasible solutions.

There is no adequate information on soil resources of Ethiopia mainly at catchment levels, whereas such information is important in providing base line data for wise use of the agricultural resources in general. As a result, decision makers and development workers usually give a blanket recommendation of agricultural technologies on agro-climatic basis in the effort of increasing crop productivity. The objectives of the present study were to investigate the major morphological, physical and chemical properties and classification of the soils and, to determine agricultural potentials and constraints for crop production of the soils of Ambukuna catchment.

Material and Methods

Description of the study area

The study area, Ambukuna catchment, is located at about 8 km south east of Mudulla town in the Kembata-Tembaro zone, Tembaro woreda, Southern Ethiopia. It is located just 392 km south of Addis Ababa and 172 km west of Hawassa town. Geographically, the catchment is located between latitude 79°83'79" and 80°09'79" N and longitude 34°32'70" and 34o20'96" E (Figure 1). The total area of the Tembaro woreda and Ambukuna catchment is about 27.917 ha and 341 ha, respectively (WAO, 2011). Land degradation and soil erosion are the main problems due to the prevailing landscape and high altitude in the study area. It is divided into three agro-ecological zones, namely highland (*dega*), mid highland (*woina dega*) and lowland (*kolla*). The recent ten years (2006–2018) mean annual precipitation of the study area was about 1095.6mm. The area has a bimodal rainfall pattern and about 30 and 40% fall during autumn (March-May) and summer (June-August) seasons, respectively. The mean monthly temperature for the last ten years (2005-2015) ranges from 18.95–21.75 °C with an average of 20.59 °C.

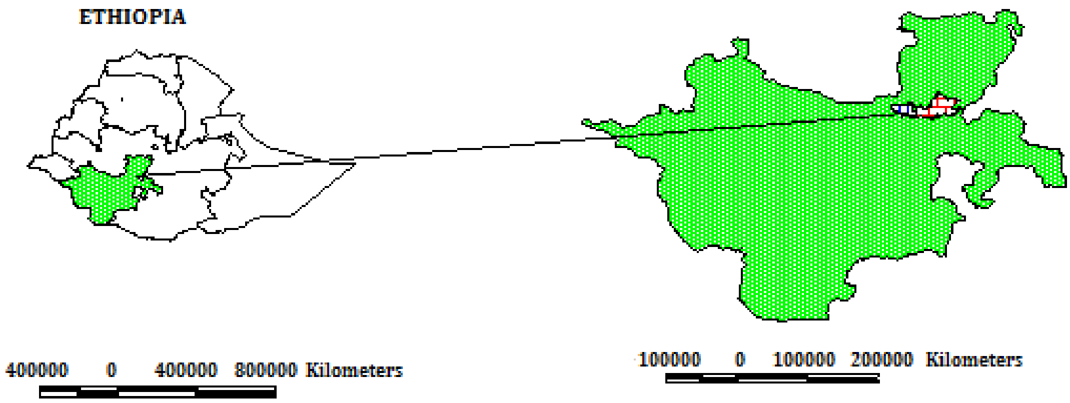

Figure 1. Ambukuna catchment map

Data Collection and Analysis

Two phases of field surveys were accomplished in studying the soil of the watershed. First, a preliminary or reconnaissance survey was performed with the help of 1:50,000 topo-sheet (EMLS, 1976) to acquire general information on soils and environment of the proposed study area. At this level tentative soil units and map were prepared on the same map based on landscape vegetation relationships and surface soil characteristics (e.g. colour, structure, texture) as field guide. Survey was conducted during the second phase. Using the tentative soil map as supplementary, soils were studied from auger holes, gully cuts and site observations. A number of auger holes observations were made and site characteristics and land use patterns were recorded on standard form. Then with this information, the tentative soil units were adjusted through manipulations of tentative soil boundaries. The final soil field boundaries were then delineated on the 1:50000 topo-sheet. In delineation of boundaries topographic factors, vegetation characteristics, surface colour and land use patterns were used in addition to auger hole and other observation points. A toposequence was selected along east-west facing slopes encompassing landform components from upper slope to bottom slope of the watershed. After a proper identification of soil mapping units, five soil pits were opened and profiles described according to procedures and criteria indicated in FAO (2006), for their environmental and morphological characteristics. Colours of the soils were determined using Munsell soil colour chart (Munsell colour company, 1975). The FAO (2014) classification legend was followed in the classification of the soils. Profile observation points were geo-referenced with the help of geographical positioning system (GPS) and located on the 1:50,000 scale base and then finally in the soil map. Total 20 disturbed and 16 undisturbed soil samples were collected from recognized genetic horizons of the 5 representative pits. From each recognized genetic horizon, disturbed soil samples using bag were taken, and from which 1 kg of soil was transferred into plastic bag and labeled. Then the soil samples were transported to National Soil Testing Center (NSTC), where they were analyzed for their physical and chemical characteristics.

The undisturbed core samples were used for the determination of bulk density and soil moisture contents at field capacity (FC at -0.33 bar) and permanent wilting point (PWP at -15 bars). The disturbed soil samples were air-dried, ground and passed through a 2 mm sieve and analyzed for physical and chemical parameters. The bulk density of undisturbed soil was determined by the core method as described by Gupta (2000). Total porosity was estimated using the following formula: Total Porosity (%) = 100-[(BD/Pd) x100] (Brady and Weil, 2002). The soil moisture contents at field capacity and at permanent wilting point were measured by the pressure plate apparatus. Finally, the available water holding capacity was determined from the difference between water content at FC and PWP (Hillel, 1980). The particle size distribution was determined by the hydrometer method (Van Reeuwijk, 2002). Electrical conductivity was measured by conductivity meter in 1:2.5 soil-water ratio (Okalebo et al., 2002). Soil pH was determined using pH meter with combined glass electrode at 1:2.5 (soil: water) ratio as described by Carter (1993). The organic carbon was determined by the Walkley and Black (1934) method and organic matter content was obtained by multiplying the OC content by a factor of 1.724. The total N content in soil was determined by using the Kjeldahl procedure (Gupta, 2000) and available P was determined by the Mehlich-III method (Mehlich, 1984). To determine available K in the soil, the soil samples were extracted with Morgan's solution and K was read by flame photometer (Morgan, 1941). Exchangeable bases (Ca, Mg, K and Na) and CEC in the soil were estimated by the ammonium acetate (1N NH_4OAc at pH 7.0) extraction method. Then, Ca and Mg were measured with the help of atomic absorption spectrophotometer (AAS), and K and Na by flame photometer in the ammonium acetate extract. Cation exchange capacity was determined through distillation and titration after leaching the ammonium saturated soil with 10% NaCl (Van Reeuwijk, 2002). Percent base saturation (PBS) was calculated by dividing the sum of exchangeable bases by the CEC of the soil and multiplied by 100. The CEC clay was obtained by dividing CEC of the soil by amount of clay of each horizon and expressed on the bases of percentage. The relative proportion of each exchangeable base was calculated by dividing the amount of respective cation by the CEC of the soil and multiplying by 100 for each horizon (Buol et al., 2003). The sample was shaken with a complexing acid ammonium oxalate solution dissolving the "active" or "short range-order" ("amorphous") compounds of Fe which were determined in the extract by AAS (Blakemore et al., 1987). The sample was heated in a complexing buffer of sodium citrate/bicarbonate to which solid sodium dithionite was added as a reducing agent and free iron was measured in the extract by AAS (Mehra and Jackson, 1960). Active Fe to free Fe ratio was calculated from Fe active and free iron data.

Statistical analysis

Simple linear correlation analysis was carried out to reveal the relationships between and among selected physicochemical properties of the soils according to the procedures described by Gomez and Gomez (1984) and used in the interpretations of data. Statistical Package for Social Science (SPSS) software model was employed in the statistical analysis procedure.

Results and Discussion

Site and morphological characteristics

Profiles had a depth of over 100 cm, which can be generally described as deep to very deep soils. The relatively less deep soil depth (124 cm) was recorded in profile 5, whereas all others have a depth of 200 cm. In the study area, surface soil colour patterns showed great variability. This may be related to position in the landscape, slope gradient and organic matter contents (Abate et al., 2014; Hailu et al., 2015, Fekadu et al., 2018). The soil colour patterns of the described profiles (profiles 1, 2, 3, 4 and 5) have become uniformly redder with depth. It changed from dark brown with moist hues of 7.5 YR in surface to dark reddish brown hues (5YR or 2.5YR, moist) in subsoil horizons (Table 1). The relatively dark brown surface soil colour could be attributed to a relatively high content of organic matter of the surface horizons. The redder hues (5 YR or 2.5 YR, moist) in subsoil horizons indicated the well drainage conditions of the profiles (hence described as well drained class soils) as well as organic matter decreased in subsoil suggesting the release of free iron to pigment the soils' reddish patterns. According to Foth (2003), reddish color is due to the presence of iron compounds in various states of oxidation.

Table 1. Selected morphological characteristics and classification

Depth (cm)	Horizon	Colour		Consistence	Structure	Boundary	Root	Cutanic
		Dry	moist	dry/moist/wet	grade/size/type	Distinctness/Topography	Abundance/Size	Feature
Profile 1: Haplic Nitisols (Endoeutric, humic)								
0-20	Ap	7.5YR4/4	7.5YR2.5/3	SHA/FI/SST/SPL	MO/ME/SB	G/S	M/M-C	None
20-75	Bt1	2.5YR3/6	2.5YR3/4	HA/FI/ST/PL	MO/ME/SB	D/S	C/F	Nitic
75-120	Bt2	2.5YR4/6	2.5YR3/6	HA/FI/ST/PL	MO/ME/SB	D/S	V/FV	Nitic
120-200	Bt3	2.5YR4/6	2.5YR3/6	HA/FI/ST/PL	MO/ME/SB	D	None	Nitic
Profile 2: Haplic Nitisols (Hypereutric, humic)								
0-24	Ap	7.5YR3/3	7.5YR2.5/3	SHA/FR/SST/SPL	MO/ME/SB	C/S	C/F-M	None
24-78	Bt1	7.5YR3/4	5YR3/4	HA/FI/ST/PL	MO/ME/SB	G/S	F/VF	Nitic
78-118	Bt2	2.5YR3/4	2.5YR3/4	HA/FI/VST/PL	MO/ME/SB	D/S	V/VF	Nitic
118-200	Bt3	2.5YR3/4	2.5YR3/6	HA/FI/LVST/PL	MO/ME/SB	D	None	Nitic
Profile 3: Haplic Nitisols (Endoeutric, humic)								
0-20	Ap	5YR4/4	5YR3/2	HA/FR/SST/SPL	MO/F/SB	C/S	C/M	None
20-50	Bt1	5YR4/6	5YR3/3	SHA/FI/ST/SPL	MO/F/SB	G/S	F/VF	Nitic
50-90	Bt2	5YR4/4	5YR3/2	SHA/FI/ST/PL	MO/F/SB	D/S	V/VF	Nitic
90-200	Bt3	2.5YR4/4	5YR3/3	SHA/FI/ST/PL	MO/F/SB	D	None	Nitic
Profile 4: Haplic Nitisols (Endoeutric								
0-15	Ap	5YR4/4	5YR3/2	SHA/FR/SST/SPL	ST/FI-ME/SB	C/S	M/F-M	None
15-58	Bt1	5YR3/3	5YR3/3	HA/FI/ST/PL	MO/ME/SB	G/S	F/F	Nitic
58-105	Bt2	5YR4/4	5YR3/2	HA/FI/ST/PL	MO/ME/SB	D/S	V/VF	Nitic
105-200	Bt3	2.5YR4/4	2.5YR3/2	HA/FI/ST/PL	MO/ME/SB	D	None	Nitic
Profile 5: Haplic Nitisols (Epidystric, Humic)								
0-21	Ap	7.5YR4/6	7.5YR3/3	SHA/FI/SST/PL	MO/FI-ME/SB	C/S	M/M	None
21-53	Bt1	5YR4/3	5YR3/3	HA/FI/ST/PL	MO/FI-ME/SB	G/S	C/VF	Nitic
53-97	Bt2	5YR4/6	2.5YR4/4	HA/FI/ST/PL	MO/FI-ME/SB	G/S	V/VF	Nitic
97-124	Bt3	2.5YR4/6	2.5YR3/6	HA/FI/ST/PL	MO/FI-ME/SB	G	None	Nitic

Abbreviations are as per FAO-WRB (2006).

Different degrees of nitic properties were observed in all of the subsoil horizons within 100 cm from the surface. This revealed a presence of nitic horizons as described in FAO (2014). The type, size and grade of structure in the surface horizons were uniformly described to have sub angular blocky, fine to medium and moderate, respectively. The development of blocky structure types could be related to the low level of organic matter, reduction in abundance of plant roots and higher clay percentage of subsoil horizons (Dengiz et al, 2013).

The change in consistence characteristics from surface to subsoil horizons reflects the high contents of clay and low contents of organic matter of subsoil horizons. Horizon boundary characteristics showed slight variations both among and within studied profiles. This is a typical characteristic of most tropical soils (Young, 1976).

Physical characteristics

Selected soil physical characteristics for representative profiles were described in Table 2. Clay content varied between 54% (profile 3) and 38% (profile 2) in surface soil and 84% (profile 1) to 42% (profile 3) in subsoil. This increasing pattern of clay content and a decreasing pattern in sand and silt contents with depth of profiles identify most subsoil horizons as argillic (Bt) (FAO, 2014). According to Boul et al. (2003), the accumulation of clay in the subsurface horizon could be due to the in situ synthesis of secondary clays and the weathering of primary minerals in the B horizon (Sekhar et al., 2014). However, most horizons have silt-clay ratio of below 0.15, as typical properties of tropical soils (Abayneh , 2005).

The bulk densities of the studied soils showed great variability with respect to contents of organic matter and position of horizons in a profile (Table 4). In most of the profiles, bulk density values were lower in the surface than in the underlying horizons. Bulk density varied from 1.02 g cm^{-3} (profile 1) to 1.23 g cm^{-3} (profile 3) in surface soil and 1.10 g cm^{-3} (profile 3) to 1.35 g cm^{-3} (profile 2) in subsoil horizons. This reveals that the high amount of organic matter and well structure characteristics of profile 1 resulted in low value of bulk density of surface soils. Hence, the unsystematic increasing pattern in bulk densities with depth of profiles could be related to a decrease in contents of organic matter and a presence of blocky type of soil structure. Higher OM content in the A horizon makes soils loose, porous and well aggregated, thereby reducing bulk density and bulk densities range for agricultural soils from values of the order of 1.0 g cm^{-3} to 1.7g cm^{-3} (Hillel, 1980). This implies that no excessive compaction and no restriction to root development (Werner, 1997). The bulk density of the study area was within the average range for good agricultural soils. According to Brady and Weil (2002), ideal total pore space values, which are acceptable for crop production, are around 50%. Hence, the soils of Ambukuna district have an acceptable range of total porosity values for crop production. According to rating Beernaert (1990), available water content values in the Ambukuna catchment were rated very low due to low organic matter in the study profiles.

Table 2. Some physical properties of the soils of Ambukuna catchment.

Depth (cm)	Particle size distribution			Textural Class	silt/clay	Water content			Bulk density (g cm^{-3})	Porosiy (%)
	Sand (%)	Silt (%)	Clay (%)			FC (%)	PWP (%)	AWC (%)		
Profile 1: Haplic Nitisols (Endoeutric, humic)										
0-20	23	37	40	C	0.93	27	25	2	1.02	62
20-75	19	15	66	C	0.23	33	28	5	1.24	47
75-120	7	11	82	C	0.13	33	28	5	1.23	46
120-200	5	11	84	C	0.13	31	29	2	1.28	48
Profile 2: Haplic Nitisols (Hypereutric, humic)										
0-24	33	29	38	CL	0.76	30	26	4	1.16	44
24-78	21	19	60	C	0.32	31	28	3	1.28	48
78-118	15	11	74	C	0.15	29	27	2	1.14	43
118-200	13	9	78	C	0.12	31	30	1	1.35	51
Profile 3: Haplic Nitisols (Endoeutric, humic)										
0-20	27	19	54	C	0.35	29	24	5	1.23	46
20-50	31	23	46	C	0.5	29	24	5	1.27	48
50-90	31	25	44	C	0.57	30	24	6	1.10	42
90-200	25	33	42	C	0.79	29	24	5	1.23	46
Profile 4: Haplic Nitisols (Endoeutric										
0-15	25	27	48	C	0.56	28	23	5	1.20	45
15-58	15	17	68	C	0.25	31	26	5	1.11	42
58-105	11	13	76	C	0.17	36	31	6	-	-
105200	9	9	82	C	0.11	37	33	3	-	-
Profile 5: Haplic Nitisols (Epidystric, Humic)										
0-21	29	25	46	C	0.54	-	-	-	-	-
21-53	29	25	46	C	0.54	-	-	-	-	-
53-97	15	15	70	C	0.21	-	-	-	-	-
97-124	19	7	74	C	0.09	-	-	-	-	-

C=Clay, CL= Clay loam, "-" not determined, FC=field capacity, PWP=permanent wilting point, AWC=Available water content

Chemical characteristics

Selected soil chemical characteristics of representative profiles are presented in Table 5. According to Churchman et al. (1983), these values reveal the absence of calcium carbonate in the study area, where values of pH-H_2O less than 6.5 are generally considered as non-calcareous. According to Brook (1983), the studied soils can be rated to range from moderately acidic to slightly acidic in reaction. Currently, it is estimated that about 40% of arable lands of Ethiopia are affected by soil acidity/Al^{3+} toxicity (Taye, 2007). According to Jones (2003), the soils of Ambukuna district of surface and subsoil horizons were rated as very low which considered as non-saline, mainly as a result of high rainfall of the area leaching much of salts in the profiles (Table 3).

According to Brook (1983), rating for soils of tropical and subtropical regions, organic matter content of the surface soils in the study area of profiles 1 and 2 was in medium level and profiles of 3, 4 and 5 was low class which is due to differing intensity of erosion, addition of organic material and level of the mineralization/decomposition of organic matter. According to Landon (1991), rating organic carbon content of the soils were low in all study profiles. According to Havlin et al. (1999), TN content of study area soils were categorized under the medium to high category. The results are in accordance with the findings of Wakene and Heluf (2003) and Tuma (2007) who reported that intensive and continuous cultivation forced oxidation of OC and thus resulted in reduction of TN. Moreover, a result from simple correlation analysis indicated that total nitrogen and organic matter are positively and significantly correlated (r =0.54*) and organic matter and clay content, water field capacity and permanent wilting point are negatively correlated r= -0.74**, -0.57* and -0.60, respectively.

Table 3. Some chemical properties of Ambukuna catchment

Depth (cm)	pH–H_2O	EC(ds/m)	OC (%)	OM (%)	TN (%)	C/ N	av. P (ppm)	av. K (ppm)
Profile 1: Haplic Nitisols (Endoeutric, humic)								
0-20	6.1	0 .11	3.17	5.46	0.41	8	6.52	383.18
20-75	6.0	0.04	1.09	1.88	0.10	11	1.46	668.61
75-120	5.4	0.03	0.87	1.50	0.13	7	1.54	383.18
120-200	5.0	0.04	0.46	0.79	0.06	8	1.00	465.29
Profile 2: Haplic Nitisols (Hypereutric, humic)								
0-24	6.2	0.04	2.77	4.77	0.30	9	3.58	559.13
24-78	6.4	0.04	1.44	2.48	0.25	6	2.24	574.77
78-118	6.0	0.03	0.87	0.50	0.15	6	1.80	430.10
118-200	5.9	0.03	0.63	1.10	0.13	5	0.90	484.84
Profile 3: Haplic Nitisols (Endoeutric, humic)								
0-20	5.6	0.03	1.72	2.96	0.30	6	4.58	359.72
20-50	5.6	0.03	1.34	2.31	0.25	5	2.64	164.22
50-90	5.8	0.02	1.49	2.57	0.16	10	3.04	160.31
90-200	5.9	0.03	1.48	2.55	0.29	5	3.50	168.13
Profile 4: Haplic Nitisols (Endoeutric)								
0-15	5.7	0.03	1.82	3.14	0.27	7	13.72	320.62
15-58	6.0	0.03	0.75	1.29	0.16	5	24.52	355.81
58-105	5.9	0.02	0.59	1.02	0.08	8	11.22	391.00
105-200	5.9	0.02	0.39	0.67	0.06	7	2.36	441.83
Profile 5: Haplic Nitisols (Epidystric, Humic)								
0-21	5.5	0.03	1.74	3.00	0.22	8	3.72	324.44
21-53	5.6	0.02	1.94	3.34	0.25	8	0.70	238.51
53- 97	5.5	0.19	1.01	1.72	0.13	8	0.68	301.07
97-124	5.1	0.03	0.67	1.16	0.11	6	0.56	340.00

EC = electrical conductivity, OC = Organic carbon, OM = organic matter, TN = total nitrogen, C/N = carbon/nitrogen, av .P = available phosphorus, av.K = available potassium

In general, a C/N ratio of about 10 suggests relatively better decomposition rate and indicates improved availability of nitrogen to plants and there will be possibilities to incorporate crop residues to the soil without adverse effect of nitrogen immobilization (Yerima, 1993). According to Yihenew (2002), optimum range of the C:N ratio is about 10:1 to 12:1 that provides nitrogen in excess of microbial needs. Accordingly, the C:N ratio of the surface soils across the sites may be considered to be below the optimum range in all soils for microbial needs.

According to the ratings for some tropical soils (Mehlich, 1984; Brook, 1983; Havlin et al., 1999), available P contents in the study Ambukuna district were low (soil indicates a crop response to P fertilizers) in the profiles of 2, 3 and 5, medium (indicates a probable response) in profile 1 and high (indicates a crop response is unlikely) in profile of 4 of the topsoils. Topsoil phosphorus is usually greater than that in subsoil due to sorption of the added phosphorus and greater biological activity and accumulation of organic material in the former. Moreover, Wakene and Heluf (2003) have suggested that the existence of low contents of available phosphorus is a common characteristic of most Ethiopian soils. The greater the proportion of clay minerals high in potassium, the greater will be the potential potassium availability in a soil (Tisdale et al., 2002). As Jones (2003) has suggested the index values for available potassium (K) in Morgan method, values of K in the study area was adequate. In most profiles, the available potassium content followed unsystematic variation with depth.

According to Brook (1983), rating of exchangeable Ca (in cmol(+) kg^{-1}), Ambukuna district was rated low in profile 5 and medium to high in profiles 1, 2, 3 and 4 in both surface and subsoil horizons. In the subsoil horizons, contents of exchangeable Ca showed an unsystematic decreasing trend in the other profiles, and varied from 2.90 cmol(+) kg^{-1} soil (profile 1) to 16.80 cmol(+) kg^{-1} soil (profile 2). In these subsoil horizons exchangeable Ca constituted 48 to 77 % of the exchange site of the soils. This revealed relatively low levels of exchangeable Ca in the profiles may suggest relatively advanced developed soils. According to Sims (2000), the range of critical values for optimum crop production for Ca are from 1.25 - 2.5 cmol (+) kg^{-1} soil and the exchangeable Ca content of the soils Ambukuna district were above the critical values. As Brook (1983) has suggested, exchangeable Mg (cmol(+) kg^{-1}) was rated medium to high in both surface and subsoil of the studied profiles of Ambukuna microcachment. A continuous cultivation and inorganic fertilizers application resulted in declining of soil pH that caused loss of basic cations and especially under intensive cropping of inherently poor soils, the deficiencies of calcium and magnesium are common (Wakene, 2001).

As Brook (1983) rating of exchangeable potassium (cmol(+) kg^{-1} soil), Ambukuna catchment exchangeable K was medium to high in both surface horizons and most of the subsoil horizons for crop cultivation. According to the same uother rating of sodium for tropical soil, amount of exchangeable sodium was very low to low or trace amount throughout the profiles and surface and subsoil horizons of the study watershed soils. In general, magnitude of exchangeable cations was in the order of Ca> Mg> K> Na. The ratios of K/Mg and Ca/Mg varied from 0.21 to 0.46 and 1.22-5.98 in the surface soil, respectively (Table 4).

According to Brook (1983), the CEC of Ambukuna catchment was rated as medium in the profiles 2, 4 and 5 to high in profiles 1 and 3 for surface horizons. In the subsoil horizons, CEC values varied between 13.38 cmol(+) kg^{-1} soil in profile 1 and 40.00 cmol(+) kg^{-1} soil in profile 2. There exists a strong relationship (r=0.81**) between CEC and sum of exchangeable cations and (r=0.76**) between CEC and available P of the soil profiles but sum of exchangeable bases and water field capacity have negative correlation (r=-0.71**) (Table 7). Accordingly, the increase in clay contents with depth of the profiles did not match with increase in CEC. The CEC/clay values were also found to be higher for the surface horizons than the subsoil horizons of the studied profile. Except for some profiles (profiles 1 and 4), CEC/clay showed an unsystematic decrease with depth of the profiles.

Table 4. Exchangeable bases, CEC and percent base saturation of soils of Ambukuna catchment

Depth (cm)	Exchangeable bases (cmol(+)/kg soil)				K/Mg	Ca/Mg	CEC (cmol(+)/kg soil)	PBS (%)	CEC/clay (%)
	Na	K	Ca	Mg					
Profile 1: Haplic Nitisols (Endoeutric, humic)									
0-20	0.00	0.98	15.59	3.35	0.29	4.65	26.35	76	66
20-75	0.00	1.71	8.75	3.40	0.50	2.57	18.72	74	28
75-120	0.00	0.98	5.14	3.24	0.30	1.59	17.47	54	21
120-200	0.00	1.19	2.90	1.96	0.61	1.48	13.38	45	16
Profile 2: Haplic Nitisols (Hypereutric, humic)									
0-24	0.00	1.43	15.30	3.12	0.46	4.90	23.13	86	61
24-78	0.00	1.47	16.80	3.53	0.42	4.76	40.00	55	67
78-118	0.00	1.10	13.09	3.75	0.29	4.49	22.35	80	30
118-200	0.04	1.24	10.55	3.20	0.39	3.30	20.88	72	27
Profile 3: Haplic Nitisols (Endoeutric, humic)									
0-20	0.00	0.92	14.76	2.47	0.37	5.98	25.70	71	48
20-50	0.00	0.42	4.01	3.50	0.12	1.15	19.02	42	41
50-90	0.00	0.41	7.63	4.05	0.10	1.88	20.27	60	46
90-200	0.00	0.43	11.41	4.47	0.10	2.55	23.57	69	56
Profile 4: Haplic Nitisols (Endoeutric									
0-15	0.00	0.82	11.50	3.98	0.21	2.89	21.08	77	44
15-58	0.00	0.91	10.04	4.70	0.19	2.24	24.28	64	36
58-105	0.13	1.00	8.47	4.02	0.25	2.11	23.46	56	31
105-200	0.13	1.13	7.36	4.77	0.24	1.54	22.40	60	27
Profile 5: Haplic Nitisols (Epidystric, Humic)									
0-21	0.00	0.84	3.37	2.77	0.30	1.22	17.16	41	37
21-53	0.00	0.61	3.88	3.82	0.16	1.02	17.64	47	38
53-97	0.00	0.77	6.49	4.17	0.18	1.56	21.48	53	31
97-124	0.00	0.87	5.63	3.09	0.28	1.82	16.84	57	23

Na=sodium, K=potassium, Ca=calcium, Mg=magnesium, CEC=cation exchangeable capacity, PBS=percentage saturation, EA=Exchangeable Acidity, K/Mg= ratio of potassium to magnesium, Ca/Mg=ratio of calcium to magnesium

The decline in total CEC or CEC/clay with depth of profiles reflects the role of clay mineralogy. The measured values of CEC from profile1, 2, 3, 4 and 5 may indicate presence of mixed clay mineralogy. These facts indicate that CEC could also be explained by stages of soil development. The percentage base saturation (PBS) was generally above 50% in most of the horizons and profiles. Although it still remained high, PBS showed a slight decreasing pattern with depth of almost all profiles, suggesting an existence of movement of bases from topsoil to subsoil horizons was unsystematic pattern probably due to differences in clay content in the subsoil horizons. PBS varied from 86 % of profile 2 to 41 % of profile 5 in the surface horizon. In the subsoil, PBS varied between 80 % of profile 2 and 42 % of profile 3 (Table 6). According to Brook (1983) suggestion for tropical soils (PBS %) of the Bejjo watershed has medium PBS for profile 5 and high PBS for profiles 1, 2, 3 and 4. PBS showed a slight increase in profile 5 with depth, suggesting an existence of movement of bases from topsoil to subsoil horizons. This variability in PBS is an indication of presence of variable levels of soil development in the study area.

Soil Classification

The studied morphological and physico-chemical characteristics were used in the classification of the soils of *Ambukuna* watershed. As described earlier, all profiles have variable degrees of shining faces in their subsoil horizons; indicating the presence of nitic properties and qualifying for nitic horizon as well.

According to FAO (2014), a nitic horizon needs to satisfy:

1. less than 20 percent change (relative) in clay content over 12 cm to layers immediately above and below; and
2. all of the following:
   a. 30 percent or more clay; and
   b. a water-dispersible clay to total clay ratio less than 0.10; and
   c. a silt to clay ratio less than 0.40; and
3. moderate to strong, angular blocky structure breaking to flat-edged or nut-shaped elements with shiny ped faces. The shiny faces are not, or are only partially, associated with clay coatings; and
4. all of the following:
   a. 4.0 percent or more citrate-dithionite extractable Fe (free iron) in the fine earth fraction; and
   b. 0.20 percent or more acid oxalate (pH 3) extractable Fe (active iron) in the fine earth fraction; and
   c. a ratio of active to free iron of 0.05 or more; and
5. a thickness of 30 cm or more.

Table 5. Free iron, Active iron and Active Fe/Free Fe Ratio for soils of Ambukuna Catchment

Depth (cm)	Free Fe (%)	Fe_2O_3 (%)	Active Fe (%)	Fe_2O_3 (%)	Active Fe/Free Fe
Profile 1: Haplic Nitisols (Endoeutric, Humic)					
0-20	6.90	9.90	1.41	2.01	0 .20
20-75	7.00	10.00	1.26	1.80	0.18
75-120	7.20	10.30	0.98	1.39	0.14
120-200	7.20	10.30	0.99	1.41	0.14
Profile 2: Haplic Nitisols (Hypereutric, humic)					
0-24	6.20	8.90	1.26	1.81	`0.20
24-78	6.70	9.60	1.18	1.69	0.18
78-118	7.40	10.50	1.14	1.63	0.15
118-200	6.90	9.90	0.96	1.38	0.14
Profile 3: Haplic Nitisols (Endoeutric, humic)					
0-20	8.40	12.00	1.43	2.04	0.17
20-50	6.60	9.50	1.51	2.15	0.23
50-90	4.80	6.80	1.28	1.83	0.27
90-200	5.10	7.20	1.39	1.98	0.27
Profile 4: Haplic Nitisols (Endoeutric)					
0-15	6.30	9.00	0.95	1.35	0.15
15-58	7.10	10.20	0.76	1.09	0.11
58-105	7.30	10.40	0.80	1.14	0.11
105-200	6.90	9.80	0.68	0.98	0.10
Profile 5: Haplic Nitisols (Epidystric, Humic)					
0-21	4.30	6.10	0.92	1.31	0.21
21-53	4.20	6.00	0.88	1.26	0.21
53-97	4.90	7.00	0.70	1.00	0.14
97-124	5.00	7.20	0.53	0.76	0.11

Many of these criteria are observed and measured in the field as well as determined in the laboratory. The subsoil horizon of all studied profiles have subangular to nutty structure and shiny faces, less than 20% clay content change, over 30% clay content with silt-clay ratio of less than 0.4 (except in nitic horizon profile 3), over 4% free iron and over 0.2% active iron with active to free iron ratio of >0.05 and a thickness of over 30 cm (Tables 3, 4 and 8). The surface horizon of these soils uniformly met the requirements for an ochric A horizon (FAO, 2006). Hence all the studied soils are classified as Nitisols, following the classification legend of FAO (2006). However, nitic horizon of profile 3 has silt/clay ratios of over 0.40 but clearly exhibited nitic properties as described by its shining faces in the field. The high silt content of profile 3 is related to the deposition of silty materials as it is located in the gentler lower slope position. Regardless of this, it is classified as Nitisols. In this study, none of the soils could qualify for prefix (2nd level) qualifier other than Haplic as suggested in the employed classification legend (FAO, 2006); thus, all the soils are classified as Haplic Nitisols. The present Nitisols were further mapped into detail mapping units on the basis of recognized unique suffix qualifiers depending on their specific morphological and physicochemical properties.

Accordingly, profile 1 and 3 had high base saturation status (greater than 50 percent) in all of its parts between 50 and 100 cm from the soil surface and qualified for endoeutric concept at the 3rd level. They also had a humic soil property which is having organic carbon content of greater than 1.4 percent as weighted average over a depth of 100cm from the soil surface and recognized meeting a humic qualifier at 4th unit level of classification. Therefore, soils represented by this profile (profile 1) were classified as Haplic Nitisols (Endoeutric, Humic) (FAO–WRB, 2006).

They are mapped as NT ha–ne, hu. Haplic Nitisols (Endoeutric, Humic) cover 3.5 % (12 ha) of the total area of the study watershed (Figure 2; Table 2,3,6).

Profile 2 experiencing high base saturation status (greater than 50 percent) between 20 and 100 cm from the soil surface and 80 percent or more in some layer within 100 cm of the soil surface qualified for hypereutric at the 3rd level. It also show a humic soil property as defined above and was a humic qualifier at 4th level. Accordingly, soils represented by profile 2 were classified as Haplic Nitisols (Hypereutric, humic) (FAO, 2006). They are mapped as NTha-he, hu. These soils covered about 18 % (61 ha) of the total area of the watershed (Figure 2; Table 2,3,6).

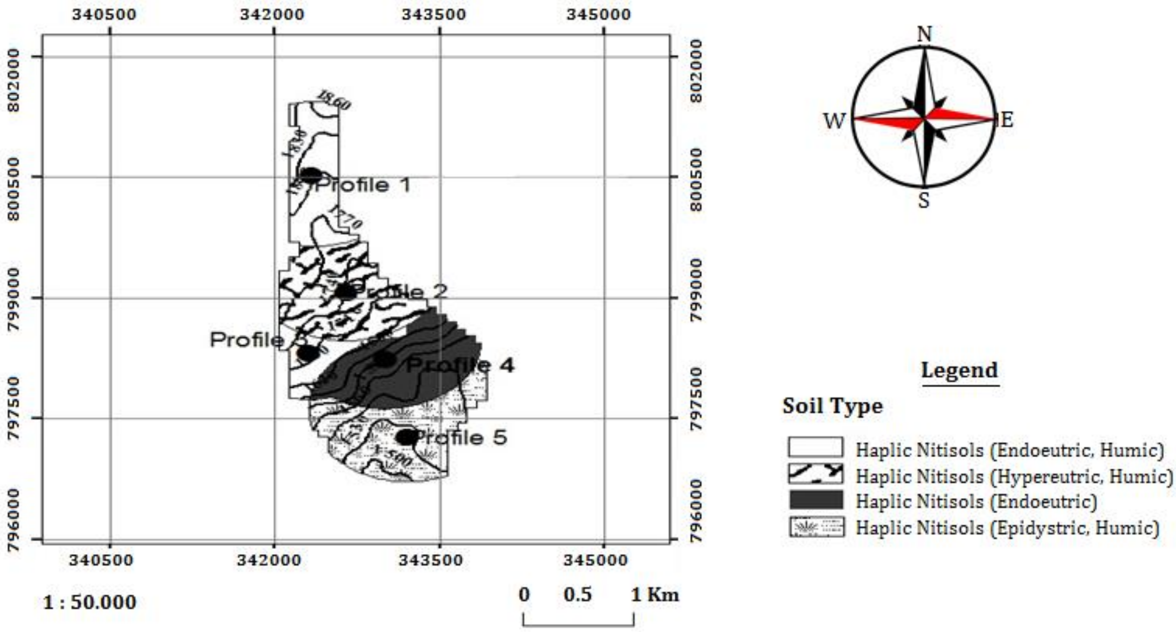

Figure 2. Soil map of Ambukuna catchment

Profile 4 showed high base saturation (greater than 50 percent) between 50 cm and 100 cm from the soil surface and qualified for endoeutric at 3rd level and as well does not qualify for humic as the others. It is mapped as Haplic Nitisols (Endoeutric) and (NT ha-ne) (FAO, 2006). The total area of these soils in the catchment is 141hectares i.e. 41.3 % of the total area of the study watershed (Figure 2; Table 2,3,6).

Profile 5 having medium base saturation (less than 50 percent) between 20 cm and 50cm from the soil surface qualified for Epidystric at 3rd unit level. It also showed a humic soil property as defined above and qualified for a humic qualifier. Accordingly, soils represented by profile 5 were classified as Haplic Nitisols (Epidystric, Humic) (FAO, 2006). They are mapped as NTha-ed, hu. The total area of these soils in the catchment is 127 hectare i.e. 37.2 % of the total area of the study watershed (Figure 2; Table 2,3,6).

Table 6. Description of soil mapping units and representative soil profile sites

Profile No.	Soil mapping units	Mapping units Symbol	Area	
			Ha	%
1 and 3	Haplic Nitisols (Endoeutric, humic)	NTha-ne, -hu	12	3.5
2	Haplic Nitisols (Hypereutric, humic)	NTha-he, -hu	61	18
4	Haplic Nitisols (Endoeutric)	NTha-ne	141	41.3
5	Haplic Nitisols (Epidystric, Humic)	NTha-ed, -hu	127	37.2
	Total		341	100

Agricultural constraints and potentials of the soils

Nitisols are among the most productive soils of the humid tropics and sub tropics (FAO, 2006). Nitisols are the extensively cultivated soils in the study area. Almost all identified units of the Nitisols had uniform characteristics with slight variation in physical properties (structure, texture, water holding, consistence, bulk density, colour); thus could have similar potentials and constraints for crop cultivation. The very deep solum, well drained condition, clay loam to clay texture, moderate - strong granular structure and relatively low bulk density values could form favourable soil conditions for agriculture. These properties allow free drainage, proper aeration, and ready infiltration of water and resist erosion- runoff processes. Furthermore, the friable to firm consistence, absence of a hard pan and/or of rock fragments imply that the soils are good for agriculture, as it is easy to cultivate and for penetration and development of plant roots.

Nitisols of the present study area are marked by low pH value (5.5 to 6.2) for surface soils. These values imply that the soil is moderately acidic to slightly acidic in reaction. According to Brook (1983) the most favourable pH for availability of most nutrients correspond roughly with the optimum range of 6-7 for most of the crop plants. This level of soil reaction of the soils may limit crop production and productivity by influencing availability of important nutrients as discussed above. Therefore, crops that are highly sensitive to acidity either cannot grow or their yield would be markedly reduced. Based on Table 10, profiles 1, 2, 3, 4 and 5 are commonly suitable for Carrot, Citrus-Lemon, Citrus-Orange, Coffee, Potato (sweet), Pumpkin and Sorghum. Soil acidity limits or reduces crop production primarily by impairing root growth there by reducing nutrient and water uptake (Marschner, 1995). Moreover, low pH or soil acidity converts some available soil nutrients in to unavailable form and also acidic soils are poor in their basic cations such as Ca, K, Mg and some micronutrients (e.g. Mo) which are as essential to crop growth and development (Wang et al., 2006).

According to the rating of Landon (1991), CEC of the surface horizons of Nitisols of the area can be rated as medium to high. Furthermore, such high CEC value provides the soil with high buffering capacity so that one can apply the required amount of fertilizer dosage without any immediate negative effects on the soils. On the other hand, the medium CEC values in the surface and subsoil horizons show the potential danger of nutrient losses due to leaching.

The percentage base saturation is frequently considered to be an indication of soil fertility. Soils with percentage base saturation of <20%, 20-60% and >60% are considered as low, medium, and high in fertility quality (Landon, 1991). Thus, the Nitisols of the present study area exhibited medium to high percentage base saturation levels (Table 6) which implies that basic cations were lost from the soil through the processes of leaching due to the high rainfall. Thus, as mentioned above low potential levels of basic cations could be the other major constraints of these soils. However, for profile 4 and 5, Mg may limit crop production predominantly as the Ca: Mg ratios between 4 and 6 are higher values that profiles 1, 2 and 3 are found in optimum range for agricultural production (Table 6; Brook, 1983). The exchange complex of the soils is dominated by Ca followed by Mg, K and Na (Table 6). According to Havlin and Tisdale (1999), the prevalence of Ca followed by Mg, K, and Na in the exchange site of soils is favourable for crop production. The exchangeable Na content of the soils is low and the exchangeable sodium percentage (ESP) of the soils was also less than 2%. This indicates that there is no sodicity problem in these soils. According to Brady and Weil (2002), ESP of 15% is considered as critical for most crops. According to Sims (2000), the range of critical values for optimum crop production for K, Ca and Mg are from 0.28 - 0.51, 1.25 - 2.5, and 0.25 - 0.5 cmol (+) kg^{-1} soil, respectively. Accordingly, the exchangeable K, Ca and Mg content of the soils are above the critical values. However, this does not prove a balanced proportion of the exchangeable bases. Potassium uptake would be reduced as Ca and Mg are increased; conversely uptake of these two cations would be reduced as the available supply of K is increased (Havlin and Tisdale, 1999). In addition, the ratio of exchangeable Ca/Mg should not exceed 10/1 to 15/1 to prevent Mg deficiency and also the recommended K/Mg are < 5/1 for field crops, < 3/1 for vegetables and sugar beets and < 2/1 for fruit and greenhouse crops (Havlin and Tisdale, 1999). The Ca/Mg ratio of the studied soils was in the range of 1.22 – 5.98 indicating that the response of crops to Mg is not likely. The K/Mg ratio of the studied soils varied from 0.21 to 0.46 and hence it is within the acceptable range for crop production.

Potassium (K) is one of the essential elements required by plants for their growth and development. It plays a very important role in activation of enzymes, photosynthesis, starch synthesis, nitrate reduction and sugar degradation (Askegaard et al., 2004). K availability would not be a limiting factor for crop production as the Nitisols of the present study area were rich according to the classification set by Landon (1991) and Jones (2003). Kapkiyai et al. (1998) indicated that soil organic matter (OM) content is a critical component of soil productivity and its maintenance is a sound approach to maintaining productivity of continuously cropped soils. The same publication showed that changes in soil OM results from imbalances between organic inputs and losses, and declining soil OM are frequently observed when lands are converted from natural vegetation to agriculture. The status of organic matter and total nitrogen of the Nitisols of the study area were low to medium and medium for agricultural use respectively (Landon, 1991).

In general terms, the available P content of Nitisols is below the critical limit for the growth of most crops based on Landon (1991) classification. According to Jones (2003) rating the available P content of the study area soil indicated low in profiles 2, 3 and 4 which indicates a crop response to P fertilizers; medium in profile 1 which indicates a probable response and high in profile 4 which indicates a crop response is unlikely. Thus, the available P content of most of these Nitisols appears to be the most limiting nutrient for crop production. According to Mishra et al. (2004), P in the Ethiopian soils poses different scenario wherein only a very low fraction of total P is available to plants. Phosphorus in soils of the highlands of Ethiopia is the limiting element in crop production, as a result 70 to 75% of the agricultural soils of the highland regions of the country are P deficient (Shiferaw, 2004). According to Anetor and Akinrinde (2006) report, with high rate of P fertilizer additions, soil sorption sites are satisfied and P level increases to sufficiency for crop production.

Conclusion

As Ethiopia is an agricultural country, its development is strongly linked with the agricultural resource base. The soil as one component is the basic resource that provides opportunities and constraints for agricultural development. Therefore, knowledge about the soils of the country is important for technology transfer, decision making and planning and policy formulation. However, the soil information currently available is very limited and derived from small scale studies. As a consequence, it is not possible to give site specific appropriate recommendation for agricultural problems based on spatial variability of soil properties. Hence, there is a need to conduct soil research that includes characterization and classification of soil at a watershed level, which is useful to determine the full production potentials of the country together with the identification of the factors, which are likely to limit production. The present soil study performed a field survey guided by 1: 50,000 topographic maps.

The soils showed variations in morphological, physical and chemical characteristics and one major soil unit namely, Nitisols were identified. Soil colour showed variability due to variations in elevation and topographic position. The colour of the soils in the gently sloping to moderately sloping land were dark brown (7.5YR, moist) in the surface and dark reddish (5YR to 2.5YR) in the subsurface. Surface soils structure was very similar in all the studied profiles but showed variations among the surface and subsurface soils of study profiles. The drainage condition in all profiles of study area was relatively the same and well drained. The texture of the soils in the surface horizons exhibited to be clayey in all the studied profiles. Bulk densities of the soil showed spatial variability among the soils in accordance with the level of organic matter.

Generally, the reactions of the soils were acidic in the studied profiles irrespective of their position in the landscape. Distribution of organic matter and total nitrogen varied among the studied profiles in response to differences in landscape position, elevation and management history. It was observed that the level of organic matter increases with increase in elevation and decreases with depth in the profiles. Distribution pattern of total nitrogen nearly resembled that of organic matter implying the major source of nitrogen for the soil system is organic matter. Therefore, preservation and maintenance of organic matter is essential for successful crop production. Available phosphorus shows irregular variability implying phosphorus availability is governed by complex processes. Besides, the level of available phosphorus was ranged from low (profile 1) to high (profile 4) in topsoil of the study soil; it is one of the major limiting nutrient elements in the study area. Therefore, management of phosphorus is essential to fully exploit the potential of the soils for crop production.

The concentration of exchangeable basic cations (Ca, Mg, K, Na) showed great variability among the soil profiles both in the surface and subsurface horizons. The contents of exchangeable and available K in the surface horizons of all soils was very high. Thus, K fertilization may not be needed for the presently grown crops of the study area. Exchangeable Na was low throughout the profiles and horizons of the studied soils. As a result, adverse effect of Na would not be expected in the study area. Generally, exchangeable cations increased downward with depth in most of the profiles. However, in a few cases it was observed that topsoil (A-horizon) contained higher exchangeable base than the upper B-horizon. The ratios of Ca/Mg in most cases were higher than 6:1 indicating the probable occurrence of an imbalance of Ca and Mg. In most of the cases, CEC of surface horizons was higher than that of subsoil horizons and generally decreased with depth of profiles. Accordingly, the increase in clay contents with depth of the profile did not parallel with increase in CEC. These suggest that CEC variations could not be explained by amount of clay and OM. The percentage base saturation was generally high in most of the soils in the studied profiles in the A-horizons.Based on this study finding, some specific recommendations are forwarded as follows:

- Organic matter was rated from low to medium in the soil of the watershed and these should be managed by application of crop residue, compost, green manure and farmyard manure in order to improve agricultural potential of soils of the watershed.

- The soil test of Bejjo watershed of P content was rated low which should be improved by applying organic materials and P-fertilizers (rock phosphate) to maximize agricultural production.
- There was less soil water conservation practice in the watershed. The soil water conservation practice should be improved by applying different farmer participatory SWC structure practice.

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