ORIGINAL ARTICLE

Pedological Characterization, Fertility Status and Classification of the Soils under Maize Production of Bako Tibe and Toke Kutaye Districts of Western Showa, Ethiopia

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ABSTRACT

Maize farm fields were selected in two districts of western Showa, Ethiopia. Four representative maize fields were selected based on landforms and other physiographic attributes in humid highland and sub humid mid altitude areas of Toke Kutaye and Bako Tibe Districts. The objective was to characterize and classify the soils under maize production in Toke Kutaye and Bako Tibe Districts of western Showa, Ethiopia. Four soil profiles were opened and characterized. Pedons are formed under udic and perudic moisture and iso-thermic temperature regimes for both districts. The soils were very deep, well-drained reddish brown to dark reddish brown loamy sand to sandy clay loams, with thick reddish brown loamy sand top and sub soil for Bako Tibe and Toke Kutaye. Three pedons had clayey top and sub soils. The pH of surface soil ranged from 4.48-5.52 which was very strongly acidic to strongly acidic. The soil organic carbon contents of the topsoil and subsoil of the four pedons ranged from 2.07 to 2.69% and 0.35 to 2.85 %, which were rated as medium to high, but very low to high respectively. Both two highland pedons had CEC ranging from 20.06 to 54.17 $cmol_c\ kg^{-1}$soil, which was rated as medium to very high, while in the two mid altitude pedons it ranged from 10.82 to 23.52 $cmol_c\ kg^{-1}$soil CEC, which was low to medium. The total nitrogen levels ranged from 0.19 to 0.23% for topsoils, which was low to medium, and from 0.03 to 0.07 % for subsoils, which was very low. According to USDA Soil Taxonomy, the four pedons were classified as *Typic Palehumults* (Acrisols and Alisols according to WRB). The four pedons were different in physicochemical properties, indicating the need to characterize soils to give site-specific fertilizer recommendations for maize production.

Keywords: Physico-chemical properties, fertility, pedons, maize

INTRODUCTION

Soil degradation and low rate of mineral fertilizer applications are a serious threat to food security in sub-Saharan Africa (Henao and Baanante, 1999). The major driving forces of land degradation include nutrient depletion, complete removal of crop residues, crop production with low levels of nutrient inputs and lack of adequate soil conservation practices in Ethiopia (Bojo and Cassels, 1995); longer cultivation (Wu *et al*., 2003). As a result, decline in soil fertility has a marked impact on plant growth and yield, grain quality, production costs and the increased risk of soil erosion. Conventional agriculture has certain limitations in terms of maintaining long-term soil fertility (Charpentier *et al*., 1999). A continental soil nutrient balance study in 38 sub-Saharan African countries for 35 crops reported negative soil nutrient balances for all three macro-nutrients (N, P, K) with mean annual losses of 22 kg N, 2.5 kg P and 15 kg K ha^{-1} (Stoorvogel and Smaling, 1990). The highest rate of nutrient depletion was observed in Ethiopia with aggregated national scale nutrient balances estimated to be -41kg N, -6kg P and -26kg K ha^{-1} (Stoorvogel and Smaling, 1990).

Inappropriate soil management practices such as low external inputs and internal nutrient cycles, and severe soil erosion contribute to soil and land degradation in Ethiopia. As a result, negative major plant nutrient balances are common problems in many parts of Ethiopia (Elias *et al*., 1998). Different soil types exhibit varying characteristics due to differences in micro-morphological, morphological, physical, chemical and mineralogical properties (Ukut *et al*., 2014). Variations in soil forming factors and processes operating on different parent materials, under different climatic, topographic, and biological conditions over varying periods would cause these variations (Soil Survey Staff, 1993). Fagbami (1990) reported the diversity of soils as a major reason behind allocation of land to wrong uses. Overall, human population pressure, climate change and lack of land capability classification are the major causes of soil fertility depletion in Ethiopia regardless of variations among agroecosystems.

To maintain agricultural land at optimum level of fertility and productivity, great attention has been given to assess the physical and bio-chemical properties of the soil resources under different famers' fields. Soil characterization and classification could provide information for the understanding of the morphological, physical, chemical, mineralogical and microbiological properties of the soil (Ogunkunle, 1986). Esu (2005) reported soil characterization as a major building block for understanding the soil, classifying it and getting the best understanding of the environment. Furthermore, monitoring of nutrient status for assessing the degree of nutrient mining in an agro-ecosystem is very crucial. The change in soil nutrient stocks over time has to be measured in order to quantify the extent of nutrient mining and maintaining the cropping system for sustainable crop production. Soil properties that change with duration and intensity of weathering provide vital clue toward the pedogenesis of the studied soil (Bera *et al*., 2015). According to Giessen *et al*. (2009) characterization and/or evaluation of soil properties is a master key for describing and understanding the status and qualities of the major nutrients in soils. Assessing soil physico-chemical properties is used to understand the potential status of nutrients in soils under different land uses (Wondowosen and Sheleme, 2011). Soil characterization provides information that helps to understand the physical, chemical, mineralogical and microbiological properties of the soils we depend on to grow crops, sustain forests and grasslands as well as support homes and society structures (Ogunkunle, 2005). Furthermore, soil characterization data helps in the correct classification of the soil to serve as a basis for more detailed evaluation of the soil as well as gather preliminary information on nutrient, physical or other limitations needed to produce a capability class for crop production (Eswaran, 1977). This knowledge can ascertain whether the specified land use types are useful for a given production system and used to meet plants requirement for rapid growth and better crop production (Shishir and Sah, 2003).

A detailed study of the soil characteristics and classification will provide baseline information on the physical, chemical and mineralogical properties of the soil for crop production, land use planning and management. Owing to the fact that Bako Tibe and Toke Kutaye Districts are intensive maize producing districts and no site-specific soil characterization and classification have been done on the soils of the area. Despite their importance for agricultural cropping and especially for intensive maize production, limited information is available for soils of the area. Soil characterization and classification of the Bako Tibe and Toke Kutaye Districts are very important in providing the needed basic information on soils of the area. Thus, this study aims to characterize the soils of the area based on their morphological characteristics, physico-chemical properties and their classification according to the "*United States Department of Agriculture (USDA) Soil Taxonomy*" (SSS, 2014) and the "*FAO-World Reference Base for Soil Resources*" scheme of classification (IUSS Working Group WRB, 2015). The results emanating from the study will provide information on the soil fertility trends and will serve to guide activities related to the management of the existing land resources for sustainable agricultural production in western Ethiopia. Therefore, the objective this study was to characterize the soils under maize production in Bako Tibe and Toke Kutaye Districts of Western Showa, Ethiopia and to recommend management practices required for sustainable crop production.

MATERIALS AND METHODS

Description of the study area

The soil characterization and classification study was conducted in Bako Tibe and Toke Kutaye Districts of West Showa zone of Oromia Regional National State, Ethiopia (Fig. 1). The study areas are located at Jato Dirki and Shakka in Bako Tibe with pedons designated as GTP-S01and TUP-S02, (opend from Gutu Tolera and Takele Uluma maize farm), and at Babichi and Kolba in Toke Kutaye with pedons named as SBP-S03 and GKP-S04, respectively (opend from Sisay Belete and Gutuma Kuma maize farm). The relevant site characteristics of the study areas are indicated in Table 1. The altitudes of the sites are 1727 and 1778 m.a.s.l. for Jato Dirki and Shakka in Bako Tibe; and 2322 and 2262 m.a.s.l. for Kolba and Babichi and in Toke Kutaye District. The soils are formed on flat plains with gradients ranging between 2.5 to 3; and 2 to 2.5%. The surface characteristics are moderate rill, inter-rill and sheet erosion. Soil profiles of all the study sites had well drained and slow run-off.

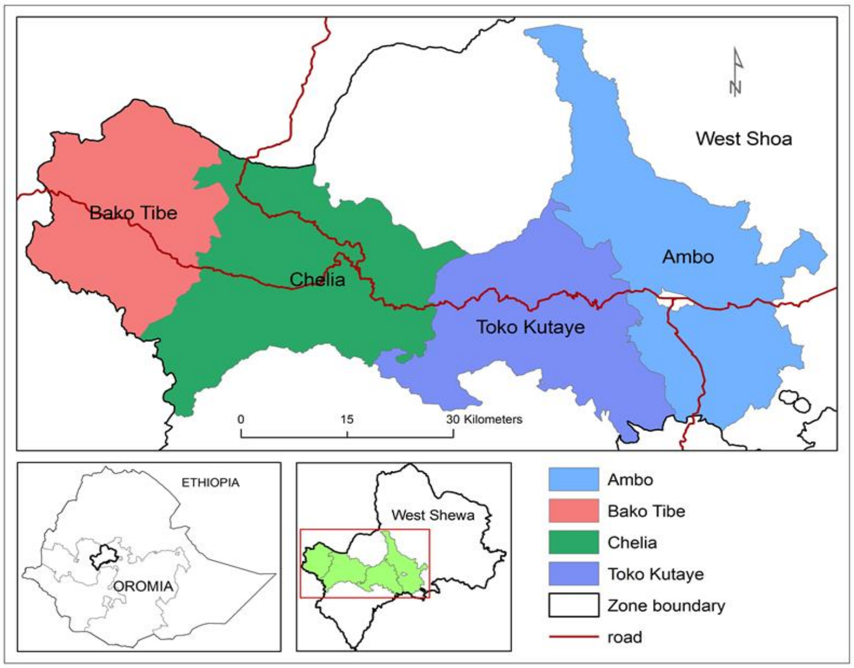

Figure 1. Study District In West Showa Zone Of Oromia Region, Ethiopia

The nearby weather data for both districts are presented in Figures 2-4. The long term weather station of Bako Agricultural Research Centre and National Meteorological Service Agency indicated that both study sites receive mean annual rainfall of 1265 and 1293 mm (MBARC, 2014 and NMSA, 2014b) for Bako Tibe and 1045 mm for Toke Kutaye (NMSA, 2014a) with unimodal distribution. Bako Tibe has warm humid climate with mean minimum, mean maximum and average air temperatures of 14, 28.5 and 21.2 ^{o}C for Bako; and 8.9, 13.2, 28 and 21^{o}C for Ilu-Gelan. However, Toke Kutaye has a cool humid climate with mean minimum, mean maximum and average air temperatures of 8.9, 27.4 and 18.1^{o}C, respectively

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Table 1. Site characteristics of the pedons

Pedon	Location	AEZ	Altitude	Land form	Slope %	Land use / Vegetation	SMR	STR
GTP-S01	N 9^{0}01'20 E 37^{0}13'29	Sub humid	1730	flat	2.5	Agriculture (Maize, tef, Sorghum, hot Pepper, sweet potato haricot bean, soybean, mango, sugarcane and banana) Dominant vegetation includes (Cordia tree, Acacia spp, *Eucalyptus spp,* Croton, Ficus tree)	Udic	Isothermic
TUP-S02	N 8^{0}59'31" E 37^{0}21'53"	mid altitude	1778	flat	3		Udic	Isothermic
SBP-S03	N 8^{0}71'21 E 37^{0}42'	Humid highland	2322	flat	2	Agriculture (Tef, wheat, barley, maize, faba bean, field pea and Niger seed) Dominant vegetation includes (Acaia spp, *Eucalyptus spp and* Croton tree)	Perudic	Isothermic
GKP-S04	N 8^{0}9'8 E 37^{0}72'		2262	flat	2.5		Perudic	Isothermic

Masl = metres above sea level, AEZ=Agroecological zone, SMR= soil moisture regime, STR= soil temperature regime

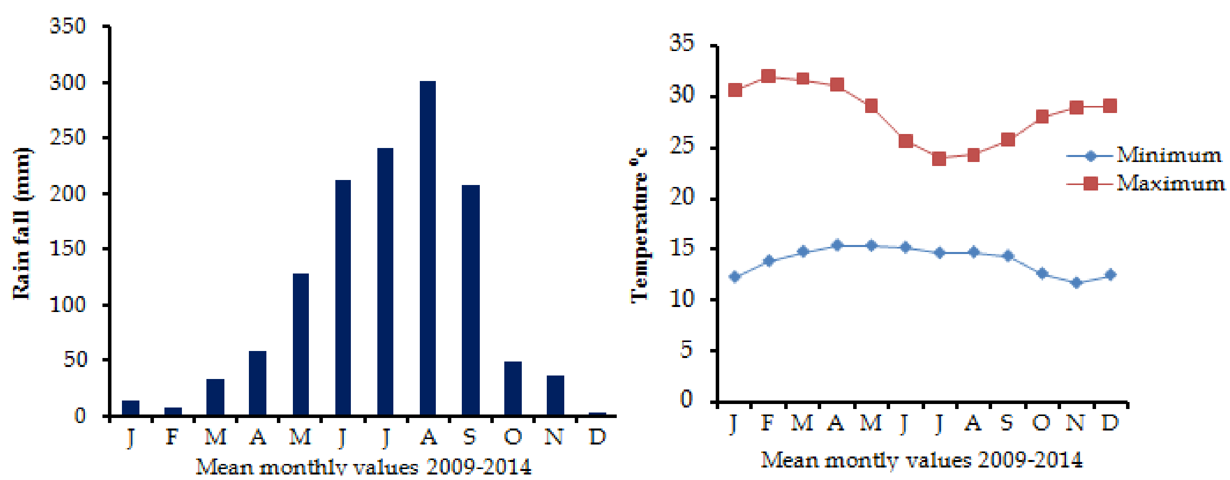

Figure 2. Mean monthly rainfall and temperature data for (GTP-S01) from 1961-2014

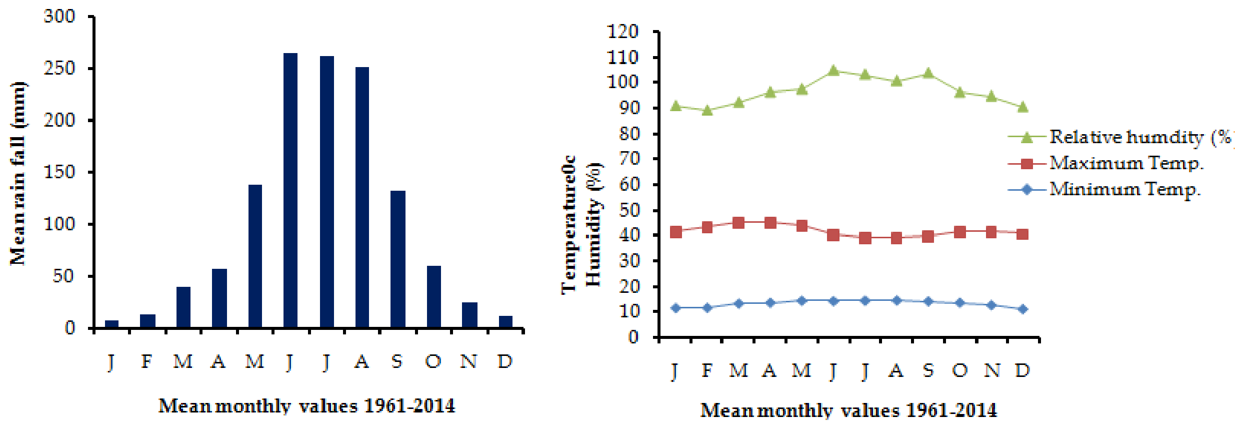

Figure 3. Mean monthly rainfall and temperature data for (TUP-S02) from 2009-2014

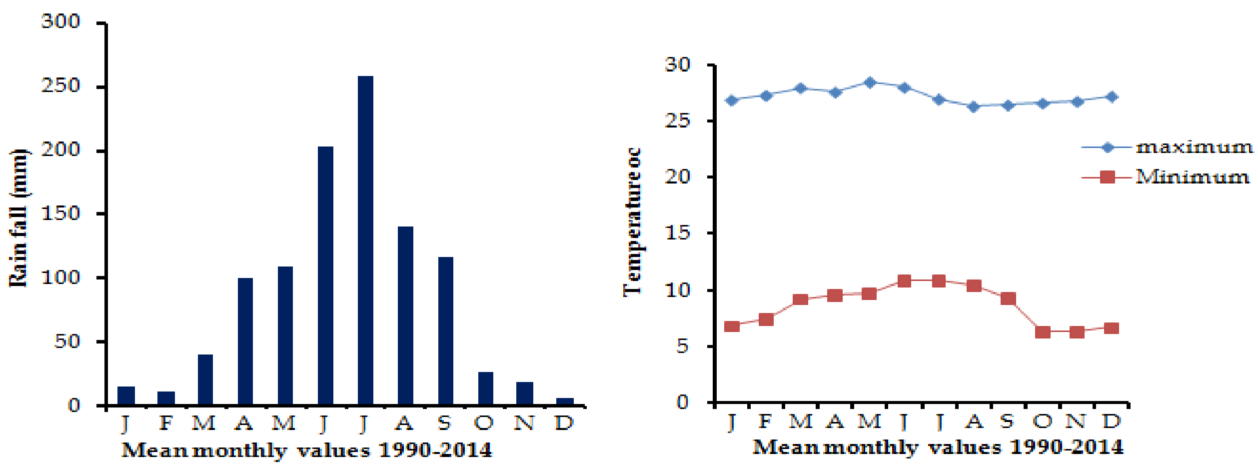

Figure 4. Mean monthly rainfall and temperature data for (SBP-S03 and GKP-S04) from 1990-2014

Land characteristics, geo-referencing, profile description and soil sampling

The representative sites for soil profile description and sampling were selected randomly around maize growing areas in mid altitude and highland areas using Ethiopian traditional system based on altitude and mean daily temperature (Dereje 2011; Gemechu, 1977; and Hurni, 1995). Data on landform, soil morphological characteristics, elevation, slope gradient, vegetation and land use or crops were collected from four observation sites that were selected to represent major landforms and soils of the selected maize fields. Four soil profiles, two from each district, were identified and opened for characterization. The opened soil profiles had 250 cm width, 150 cm length and 200 cm depth in the east to west direction using GPS compass. The soil profiles were studied, described and sampled according to FAO Guidelines for Soil Profile Description (FAO, 2006). The soil profiles were geo-referenced using Global Positioning System (GPS). The soil horizons were differentiated for each profile and soil samples collected from each horizon separately. The soil samples were air-dried and passed through 2mm sieve for determination of most soil physical and chemical properties.

Morphological Characteristics

Soil color (dry and moist) was determined using the Munsell color chart (Munsell Color Company, 2009). Other soil morphological features including field texture, structure and consistence were determined using the FAO Guidelines for Soil description (FAO, 2006).

Soil physical analysis

Undisturbed soil samples were taken by 144cc core samplers with 66 and 42 mm diameter and height respectively and dried at 105^{o}C for 24h for the measurement of bulk density. Bulk density was estimated by dividing the weight of the oven dried soil sample taken with core sampler to the volume of core sampler. Hydrometer method was used to determine the particle size distribution following the procedure FAO (1974).

Soil chemical Analysis

Soil pH was measured potentiometrically using digital pH meter in the supernatant suspension of 1: 2.5H_2O, 0.01M $CaCl_2$, and 0.1M KCl as described by McLean (1982). Cation exchange capacity (CEC) of the soil and exchangeable bases were determined by saturating soil with neutral 1M NH_4OAc (ammonium acetate) and the adsorbed NH^{4+} displaced by using 1M KCl and then determined by Kjeldahl distillation method for estimation of CEC of soil (Polemio and Rhoades, 1977; Rhoades, 1982). The exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+ and K^+) were determined by atomic absorption spectrophotometer (Anderson and Ingram, 1996). Percent base saturation was estimated from the sum of exchangeable bases as a percent of the CEC.

Exchangeable acidity was determined by saturating soil samples with potassium chloride solution and titrating with sodium hydroxide as described by Mclean (1965). Total nitrogen was determined following Kjeldahl procedure as described by Bremner and Mulvaney (1982). The available phosphorus was determined following Bray-II procedure as described by Bray and Kurtz (1945). Soil organic matter was determined following wet digestion methods as described by Walkley (1947) and FAO (1974).

Classification of soil

Field and soil physico-chemical laboratory analytical data were used for pedological characterization. The diagnostic epipedons and subsurface horizone were identified using the guidelines provides in the USDA Soil Taxonomy (SSS, 2006; 2014) and in the World Reference Base for Soil Resources (IUSS Working Group WRB, 2014; 2015). The soils were classified to the family level of the USDA Soil Taxonomy (SSS, 2014) and to tier-2 of the FAO World Reference Base for Soil Resources (IUSS Working Group WRB, 2014; 2015).

Statistical analysis

Pearson's simple correlation matrix was generated using Statistical Analysis Software 9.0 (SAS, 2004) to examine the relationship between different parameters.

RESULTS AND DISCUSSIONS

Soil Morphological Characteristics

The data for selected morphological properties are presented in Table 2. The soil depths of the profiles varied from 160 to 200 cm. There was a slight variation between the two mid altitude pedons in the soil horizon while the pedons on the highland were similar. The diagnostic epipedons of the two pedons (GTP-S01 and SBP-S03) are mollic and ochric for (TUP-S02 and GKP-S04) respectively. The subsurface horizons (Bt) were argillic and well developed in all the different maize fields under udic and isothermic for mid altitude and highland. Many distinct clay cutans were observed in the subsoils indicating that eluviation-illuviation processes have been dominantly active. The four soil profiles are gently sloping, very deep, clayey, very strongly acid (GTP-S01), strongly acidic (TUP-S02), very strongly to extremely acid (SBP-S03) and medium to strongly acid (GKP-S04).

The color of moist surface soil was very dark red (2.5YR3/2) and dark red brown (2.5YR2.5/4) for all pedons (Table 2) for the mid altitude and highland. The topsoils (plough layers) had a slight color variation among the pedons (Table 2). They had the same hue (2.5YR) with varying value/chroma ranging 2.5/4 to 3/6 when moist. Most colors of the subsurface soil horizons were dark reddish brown having similar hue 2.5 YR and with varying value/chroma ranging from 2.5/4 to 5/8. The subsurface horizons had a dominant color of red in moist soil condition because of the presence of high concentration of hematite. Murphy (1959) and Wakene (2001) reported that redness is due to the presence of iron oxide in the subsurface horizons.

Table 2. Morphological characteristics of pedons in different maize fields of mid altitude and highland areas of Western Showa, Ethiopia

Pedon	Horizon	Depth (cm)	Texture	Soil colour		structure	consistence
				Moist	dry		
GTP-S01	Ap	0-29	C	db (2.5YR3/2)	r(2.5YR2.5/6)	SCSB	Hd,fr,SP
	BA	29-78.5	C	drb(2.5YR 3/4)	rb(2.5YR4/4)	MCSB	Hd,fr,SP
	Bt1	78.5 – 119	C	r(2.5YR4/8)	r(2.5YR4/8)	MCAB	Hd,fr,SP
	Bt2	119 -1 63	C	rb(2.5YR4/4)	r(2.5YR4/6)	WCSB	Hd,fr,SSP
	BC	163-200	C	dr(2.5YR3/6)	drb(2.5 YR3/4)	nd	nd
TUP-S02	Ap	0-20	C	dr(2.5YR3/6)	drb(2.5YR2.5/4)	SCSB	Hd,fr,SP
	Bt1	20-54	C	rb(2.5YR 4/4)	r(2.5YR4/6)	MCSB	Hd,fr,SP
	Bt2	54 – 89	C	drb(2.5YR3/4)	r(2.5YR5/6)	MCAB	Hd,fr,SP
	Bt3	89 -1 29	C	rb(2.5YR4/4)	r(2.5YR4/6)	WCSB	Hd,fr,SSP
	BC	129-200	C	r(2.5YR4/6)	r(2.5 YR4/8)	nd	nd

SBP-S03	Ap	0-26	C	db(2.5YR3/2)	r(2.5YR4/6)	SCSB	Hd,fr,SP
	BA	26-48	C	drb(2.5YR 2.5/4)	drb(2.5YR3/4)	MFSB	Hd,fr,SP
	Bt1	48 – 94	C	db(2.5YR3/2)	r(2.5YR4/8)	MCAB	Hd,fr,SP
	Bt2	94 -1 42	C	drb(2.5YR2.5/4)	r(2.5YR4/6)	WMSB	Hd,fr,SSP
	BC	142-200	C	drb(2.5YR3/4)	drb(2.5 YR3/4)	nd	nd
GKP-S04	Ap	0-20	C	drb(2.5YR2.5/4)	drb(2.5YR2.5/4)	SCSB	Hd,fr,SP
	BA	20-63	C	drb(2.5YR 3/4)	dr(2.5YR3/6)	WFSB	Hd,fr,SP
	Bt1	63 – 102	C	yr(5YR 5/8)	yr(5YR4/6)	MCAB	Hd,fr,SP
	Bt2	102 -1 29	C	rb(5YR4/4)	rb(5YR5/4)	WMSB	Hd,fr,SSd
	BC	129-1 60	SCL	yr(5YR5/6)	rg(5 YR5/2)	nd	nd

C= clay, SCL= sand clay loam, WFSB = weak fine sub angular blocky, SCSB = strong coarse sub angular blocky, MCAB = moderate coarse angular blocky, WMSB = weak medium sub angular blocky, Fr =friable, Hd = hard, SP = sticky and plastic, Shd = slightly hard, SSP = slightly sticky and plastic, MMC = moderate medium crumb, nd= not determined.

Soil physical properties

Soil structure

The structure of the soil was from weak to strong sub angular blocky for the four pedons (Table 2). Similar results were reported by Wakene (2001). Soil consistence was similar among the different pedons of different soil surface horizons. The soils were sticky and plastic when wet, and friable when moist for all horizons of studied pedons. Soil consistence is an inherent soil characteristic and a reflection of the particle size composition of the soil, high organic matter content changed stickiness and plasticity of surface soil layer.

Soil texture

Clay was the predominant texture throughout soil horizons (Tables 2- 6). The silt to clay ratio of surface and subsurface soil profile in the maize farm fields was low which might be due to tillage practices in the topsoil and illuvation of clay minerals into the subsurface horizons. A similar result was reported by Achalu *et al*. (2012) stating that higher clay fraction and lower silt to clay ratio recorded in the cultivated land was attributed to the impacts of farming practices. The soil texture distributions varied among farms. The tillage practices could facilitate clay particle translocation within the different soil horizon.

Bulk density and moisture holding capacity

The bulk densities of the surface horizons ranged from 1.29 to 1.49 Mg/m^3 (Tables 3-6), whereas the bulk densities of sub surface horizons ranged from 1.30 to 1.55 Mg/m^3 (Tables 5-8). The higher soil bulk densities in the sub surface horizons than in the surface horizons can be attributed to the higher soil organic matter content in the latter (Gregorich *et al*., 1994; Wakene, 2001; Achalu *et al*., 2012). Soils having low or high bulk density, exhibit favourable and poor soil physical conditions, respectively (Hajabbasi *et al*., 1997; Patil and Prasad, 2004). The moisture holding capacity of the topsoils of studied maize fields ranged from 17.96 to 29.36% weight/weight (Tables 3-6). In subsoils, moisture holding capacities ranged from 10.77 to 33.88 % w/w (Tables 3-6). The soil moisture holding capacity decreased with increased soil depth. This can be attributed to the higher soil organic matter content in the topsoils than in the subsoils (Achalu *et al*., 2012).

Table 3. Important physico-chemical properties of soils at different horizons of GTP-S01 profile at Shaka, Bako Tibe district of West Showa, Ethiopia

Parameters	Soil depth (cm) and horizons				
	0-29(Ap)	29-78.5 (BA)	78.5 - 119 (Bt1)	119 -1 63(Bt2)	163-200 (BC)
pH(H_2O)	4.78	5.37	5.79	5.72	5.02
Organic carbon (%)	2.42	0.97	0.74	0.58	0.51
Organic matter (%)	4.17	1.67	1.28	1.00	0.88
CEC_{soil} ($cmol_c\ kg^{-1}$)	23.52	16.76	13.95	12.89	12.95
CEC_{clay} ($cmol_c\ kg^{-1}$)	38.40	19.43	15.72	14.13	17.56
Total N (%)	0.20	0.08	0.08	0.06	0.06
Available P ($mg\ kg^{-1}$)	52.67	7.24	4.94	4.12	28
C: N	12.10	12.13	9.25	9.67	8.50
EC µs/cm	44.5	47.1	53.0	73.6	70.8
Na ($cmol_c\ kg^{-1}$)	1.59	0.81	0.97	1.04	0.60
K ($cmol_c\ kg^{-1}$)	0.92	0.46	0.53	0.56	0.35
Mg ($cmol_c\ kg^{-1}$)	2.83	1.08	1.42	1.42	1.44

Ca (cmol$_c$ kg^{-1})	6.59	3.40	3.49	2.59	2.49
BS (%)	51	34	46	44	38
Clay (%)	61.25	86.25	88.75	91.25	73.75
Silt (%)	17.50	5.00	5.00	2.50	3.00
Sand (%)	21.25	8.75	6.25	6.25	23.0
Exc. Al^{3+} Acidity	0.23	0.14	0.17	0.14	0.21
pH (0.1MKCl)	3.45	4.97	4.26	4.20	4.60
pH (0.01$CaCl_2$. 6H_20)	4.52	5.00	5.56	5.55	4.91
Bulk density (Mg/m^3)	1.49	1.42	1.55	1.56	1.69
Moisture holding capacity (%)	17.96	25.27	12.00	11.43	18.29
Total sulfur	130.44	37.54	36.87	32.6	32.14

Table 4. Important physico-chemical properties of soils at different horizons of TUP-S02 profile at Jato Dirki, Bako Tibe District of West Showa, Ethiopia

Parameters	Soil depth (cm) and horizons				
	0-20(Ap)	20-54(Bt1)	54 – 89(Bt2)	89 -129 (Bt3)	129-200 (BC)
pH(H_2O)	4.56	4.66	5.57	4.69	5.2
Organic carbon (%)	2.69	1.40	1.17	0.97	0.58
Organic matter (%)	4.64	2.41	2.02	1.67	1.00
CEC$_{soil}$ (cmol$_c$ kg^{-1})	18.55	16.44	17.00	12.63	10.82
CEC$_{clay}$ (cmol$_c$ kg^{-1})	36.20	22.29	21.59	15.54	14.74
Total N (%)	0.23	0.12	0.09	0.08	0.07
Available P (mg kg^{-1})	50.2	0.69	0.47	0.39	2.67
C:N	11.70	11.67	13.00	12.13	8.29
EC µs/cm	114.3	76.0	52.6	52.5	46.5
Na (cmol$_c$ kg^{-1})	1.13	0.48	0.37	0.35	0.32
K (cmol$_c$ kg^{-1})	0.65	0.30	0.25	0.20	0.17
Mg (cmol$_c$ kg^{-1})	3.67	1.42	2.25	2..76	2.65
Ca (cmol$_c$ kg^{-1})	5.12	2.54	2.81	2.65	2.55
BS (%)	57	29	33	25	53
Clay (%)	51.25	73.75	78.75	81.25	78.75
Silt (%)	25.00	10.00	7.50	7.50	10.00
Sand (%)	23.75	16.25	13.75	11.25	11.25
Exch. Al^{3+} acidity	0.27	0.29	0.31	0.24	0.21
pH (0.1MKCl)	3.40	3.44	3.51	3.36	3.56
pH(0.01$CaCl_2$. 6H_20)	4.46	4.60	4.70	4.66	5.11
Bulk density(Mg/m^3)	1.29	1.30	1.43	1.46	1.35
Moisture holding capacity (%)	27.77	15.54	20.62	25.36	14.00
Total sulfur	151.00	56.31	42.85	42.67	23.13

Table 5. Important physico-chemical properties of soils at different horizons of SBP-S03 profile at Babichi, Toke Kutaye District of West Showa, Ethiopia

Parameters	Soil depth (cm) and horizons				
	0-26 (Ap)	26-48 (BA)	48 – 94 (Bt1)	94 -142 (Bt2)	142-200 (BC)
pH(H_2O)	4.48	4.72	4.84	5.32	5.32
Organic carbon (%)	2.07	1.44	2.85	0.66	0.39
Organic matter (%)	3.57	2.48	4.91	1.14	0.67
CEC$_{soil}$ (cmol$_c$ kg^{-1})	20.06	23.28	23.17	22.32	24.35
CEC$_{clay}$ (cmol$_c$ kg^{-1})	35.66	31.57	29.42	27.47	30.91
Total N (%)	0.19	0.13	0.1	0.08	0.04
Available P (mg kg^{-1})	80.26	11.04	7.52	6.27	25.32
C:N	10.89	11.08	28.50	8.25	9.75
EC µs/cm	54.4	52.6	71.4	52.4	53.4
Na (cmol$_c$ kg^{-1})	1.75	1.73	2.50	2.75	2.75

K ($cmol_c$ kg^{-1})	1.01	0.95	1.18	1.78	1.48
Mg ($cmol_c$ kg^{-1})	1.75	1.25	1.08	1.08	1.07
Ca ($cmol_c$ kg^{-1})	6.03	3.04	2.15	2.05	2.11
BS (%)	53	30	30	34	30
Clay (%)	56.25	73.75	78.75	81.25	78.75
Silt (%)	27.50	17.50	10.00	10.00	5.00
Sand (%)	16.25	8.75	11.25	8.75	16.25
Exc. Al^{3+} Acidity	0.41	0.33	0.29	0.22	0.15
pH (0.1MKCl)	3.26	3.41	3.53	3.77	3.98
pH(0.01$CaCl_2$. 6$H_2$0)	4.37	4.61	4.68	5.27	5.09
Bulk density (Mg/m^3)	1.42	1.52	1.42	1.49	1.46
Moisture holding capacity (%)	29.02	10.77	12.15	13.44	12.44
Total sulfur	123.91	60.99	54.33	43.47	13.21

Table 6. Important physico-chemical properties of soils at different horizons of GKP-S04 profile at Koleba, Toke Kutaye District of West Showa, Ethiopia

Parameters	Soil depth (cm) and horizons				
	0-20 (Ap)	20-63 (BA)	63 – 102 (Bt1)	102 -1 29 (Bt2)	129-1 60 (BC)
pH(H_2O)	5.52	5.48	5.62	5.69	5.83
Organic carbon (%)	2.49	1.36	0.86	0.70	0.35
Organic matter (%)	4.29	2.34	1.48	1.21	0.60
CEC_{soil} ($cmol_c$ kg^{-1})	28.84	29.91	29.18	34.08	54.17
CEC_{clay} ($cmol_c$ kg^{-1})	43.53	39.23	38.27	49.57	164.15
Total N (%)	0.21	0.11	0.08	0.06	0.03
Available P (mg kg^{-1})	30.51	4.20	2.86	2.38	16.22
C:N	11.86	12.36	10.75	11.67	11.67
EC µs/cm	93.0	84.2	69.7	166.7	86.3
Na ($cmol_c$ kg^{-1})	4.75	4.25	2	1.25	1.5
K ($cmol_c$ kg^{-1})	1.07	2.07	1.18	0.44	0.59
Mg ($cmol_c$ kg^{-1})	4.92	2.25	3.67	4.25	4.78
Ca ($cmol_c$ kg^{-1})	6.83	4.29	5.59	6.17	6.57
BS (%)	61	43	43	36	25
Clay (%)	66.25	76.25	76.25	68.75	33
Silt (%)	17.50	15.00	5.00	15.00	20.75
Sand (%)	16.25	8.75	18.75	16.25	46.25
Ex.Al^{3+} acidity	0.12	0.17	0.15	0.11	0.30
pH (0.1MKCl)	4.10	4.03	4.06	4.08	4.12
pH(0.01$CaCL_2$. 6$H_2$0)	5.45	5.42	5.43	5.57	5.72
Bulk density (Mg/m^3)	1.38	1.45	1.46	1.42	1.30
Moisture holding capacity (%)	29.36	28.48	21.12	22.54	33.86
Total sulfur	136.96	51.6	43.47	27.85	9.91

Soil chemical properties

Soil pH

The pH (H_2O) of topsoil ranged from 4.48 to 5.52 for the four pedons (Tables 3-6). The soil reaction of surface soils varied from very strongly acidic to strongly acidic (Jones, 2003; Landon, 1991). The results were in agreement with the findings of Achalu *et al.* (2012), who analysed the soil properties of cultivated field in western Ethiopia.

The lower value of soil pH under the cultivated land might be due to the depletion of basic cations in crop harvest and due to its highest microbial oxidation that produces organic acids, which provide H ions to the soil solution that lower its soil pH value (Achalu *et al.*, 2012). Moreover, Frossard *et al.* (2000) reported that the acidic nature with low soil pH obtained from all the representative land uses, might be attributed to the fact that soils were derived from weathering of acidic igneous granites and leaching of basic cations such as K, Ca and Mg from the surface soil.

Available Phosphorous

The available phosphorus for surface soil ranged from 30.51 to 80.26 mg kg^{-1}which is high relative to the P content of mineral soils (FAO, 1990 and Landon, 1991). However, the sub surface horizons had soil with lower amounts of available phosphorus than surface horizons of all the pedons. Tolessa (2006) and Wakene (2001) reported similar results in Alfisols of western Ethiopia. Varying amounts of phosphorus were observed among soil profiles, which might be due to continuous cultivation for prolonged period. Tekalign and Haque (1987) and Dawit *et al*. (2002) reported that the availability of P in most soils of Ethiopia vary due to fixation, abundant crop harvest and erosion. Similarly, Paulos (1996) found variations in available P contents in soils, which are related to the intensity of soil disturbance, the degree of P- fixation with Fe and cations.

Cation exchange capacity of the soil

The CEC levels of the surface soils were 23.52 and 18.55 $cmol_c$ kg^{-1} for GTP-S01 and TUP-S02, respectively, with low sub surface CEC concentration. The CEC of the four surface pedons studied ranged from 18.55 $cmol_c$ kg^{-1} for TUP-S02 to 28.84 $cmol_c$ kg^{-1} for GKP-S04, which is regarded as low to high CEC based on (FAO, 1990; Landon, 1991). Similar results were reported by Achalu *et al*. (2012) suggesting that soil CEC is expected to increase through improvement of the soil OM content.

Total base saturation and base saturation percentage

The total exchangeable bases (sum of Mg, Ca, K and Na) and percent base saturation for surface soil ranged from 10.54 to 17.57 $cmol_c$ kg^{-1} and 51 to 61 %, respectively for the four maize fields (Tables 3 to 6). The base saturation for surface soil was rated as medium (FAO, 1990; Landon, 1991). The studied soils had higher base saturation percentage (Tables 3 to 6). The percent base saturation for top soils for both mid altitude and highland was greater than 50%.

Organic carbon

The organic carbon contents of the surface soil ranged from 2.07 to 2.69%, indicating medium to high level of OC based on (FAO, 1990; Landon, 1991) (Tables 3-6). This might be due to frequent cultivation, which has increased soil aeration through enhanced decomposition of SOM. The results were in agreement with Achalu *et al*. (2012). Similarly, studies conducted by Lal (1996); Mandiringana *et al*. (2005) and Michel *et al*. (2010) indicated lower percentage of soil OC content in cultivated land. The organic carbon levels decreased with increasing soil depth starting from surface horizon to subsurface horizon, which is in agreement with the results of Tolessa (2006) and Wakene (2001). This is because the surface soil is biologically the most active parts of soil system because of high population of soil fauna and flora and receives different organic residues continuously.

Total nitrogen

The total nitrogen contents of the surface soil ranged from 0.19 to 0.23% (Tables 3-6). The total N levels were rated as low to medium according to FAO (1990) and Landon (1991). This might be due to continuous cultivation of the field that resulted to crop harvest and crop residue removal. Similarly, the lower total N in cultivated land was in agreement with the findings of Abbasi *et al*., 2007; Jaiyeoba, 2003; Heluf and Wakene (2006).

The low N fertility could be attributed to continuous monocropping (Wakene *et al*., 2004). Total nitrogen contents decreased with depth from surface soil through all sub surface horizons (Tables 3-6). The results were in agreement with those of Tolessa (2006) and Wakene (2001). The total N was of medium range (FAO, 1990) and (Landon, 1991) and the soil has a good potential for agricultural crop production.

C: N ratio

The C: N ratios of the surface soil ranged from 10.89-12.10:1 (Tables 3-6), found in medium range, which is good quality (Msanya *et al*., 2000). The C:N ratios of the subsurface soil ranged from 8.29 - 28.50:1 and were rated as low to very high (Tables 3-6), showing good to poor quality (Msanya *et al*., 2000; and Landon, 1991). C:N ratio is the traditional guide to the nature of the organic matter present in the soil (Brady and Weil, 2002). The C:N ratio of the surface soil was in narrow range. Similarly, Achalu *et al*. (2012) found cultivated land recorded narrow C:N ratio. This might be due to different tillage practices applied during land preparation, which enhance decomposition process in the soil system. Aeration during tillage and increased temperature that enhances mineralization rates of OC than organic nitrogen could probably be the causes for the lower level of C:N ratio in cultivated land (Achalu *et al*., 2012). Abbasi *et al*. (2007) found narrow C:N ratio in soil of cultivated land might be due to higher microbial activity and more CO_2 evolution and its loss to the atmosphere in the top (0 - 20 cm) soil layer which resulted to the narrow C:N ratio. Soil management practices are necessary for improving the narrow range of C:N ratio. Haney *et al.* (2012) reported introducing management schemes to improve the C:N ratio and increase microbial activity should result in increased soil fertility/soil biology and highly productive and sustainable systems. Therefore, it is important to sustain to restore intensively cultivated lands through best management practices, for instances improving soil properties by managing using crop rotation, composting, returning crop residues to the fields and cultivating no more than necessary and adding organic materials are very crucial.

Soil classification

On the basis of soil morphological and laboratory analytical data, the diagnostic horizons and other diagnostic features (Table 7), classification of the soils of the study area is as presented in Table 8. The diagnostic epipedons of the two pedons (GTP-S01 and SBP-S03) were mollic and ochric for (TUP-S02 and GKP-S04) according to USDA Soil Taxonomy (SSS, 2014) (Table 2.7). The diagnostic subsurface horizons of the four soil profiles were argillic USDA Soil Taxonomy (SSS, 2014) (Table 7). While according to WRB IUSS Working Group WRB (2015), the diagnostic horizons of surface epipedons and subsurface horizons of the four pedons were mollic and argic horizon, respectively. The soil names (taxa) are presented in Table 8. The soil order of Western Showa zone (from Toke Kutaye to Bako-Tibe) was Ultisols according to USDA Soil Taxonomy (SSS, 1993; 2014). According to WRB for Soil Resources (IUSS Working Group WRB, 2007; 2015), the tier-1 soil names were respectively Acrisols (GTP-S01 and TUP-S02) and Alisols (SBP-S03 and GKP-S04) (Table 8). In contrary, formerly it was Alfisols according to USDA Soil Taxonomy (SSS, 2014), corresponding to Nitisols with Soil Resources (IUSS Working Group WRB, 2015).

Table 7. Summary of the morphological and diagnostic features of surface epipedons and subsurface horizons Bako-Tibe and Toke Kutaye Districts, Western Showa, Ethiopia

Pedon No.	Diagnostic horizons, and other features: USDA Soil Taxonomy (SSS, 2014)		Diagnostic horizons, properties and materials: IUSS Working Group WRB (2015)
GTP-S01	Mollic epipedon, argillic horizon	Gently sloping, very deep, clayey, very strongly acid, udic SMR, isothermic STR	Mollic horizon, argic horizon
TUP-S02	Ochric epipedon, argillic horizon	Gently sloping, very deep, clayey, strongly acid, udic SMR, isothermic STR	Mollic horizon, argic horizon
SBP-S03	Mollic epipedon, argillic horizon	Gently sloping, very deep, clayey, very strongly to extremely acid, perudic SMR, isothermic STR	Mollic horizon, argic horizon
GKP-S04	Ochric epipedon, argillic horizon	Gently sloping, very deep, clayey, medium to strongly acid, perudic SMR, isothermic STR	Mollic horizon, argic horizon

Table 8. Details classification of the studied soils

USDA Soil Taxonomy (SSS, 2014)						World Reference Base for Soil Resources [IUSS Working Group WRB (2015)]			
Pedon No.	Order	Suborder	Greatgroup	Subgroup	Family	Reference Soil Group – Tier 1	Principal Qualifiers	Supplementary Qualifiers	Tier-2 soil name
GTP-S01	Ultisols	Humults	Palehumults	Typic Palehumults	*Gently sloping, very deep, clayey, very strongly acid, udic, isothermic, Typic Palehumults*	Acrisols	*Haplic*	*Clayic, Cutanic, Humic, Profondic*	*Haplic Acrisols (Clayic, Cutanic, Humic, Profondic)*
TUP-S02	Ultisols	Humults	Palehumults	Typic Palehumults	*Gently sloping, very deep, clayey, strongly acid, udic, isothermic, Typic Palehumults*	Acrisols	Haplic	Clayic, Cutanic, Humic, Profondic	*Haplic Acrisols (Clayic, Cutanic, Humic, Profondic)*
SBP-S03	Ultisols	Humults	Palehumults	Typic Palehumults	*Gently sloping, very deep, clayey, very strongly to extremely acid, perudic, isothermic, Typic Palehumults*	Alisols	*Rhodic, Haplic*	*Clayic, Cutanic, Humic, Profondic*	*Haplic Rhodic Alisols (Clayic, Cutanic, Humic, Profondic)*
GKP-S04	Ultisols	Humults	Palehumults	Typic Palehumults	*Gently sloping, very deep, clayey, medium to strongly acid, perudic, isothermic, Typic Palehumults*	Alisols	*Haplic*	*Clayic, Cutanic, Humic, Profondic*	*Haplic Alisols (Clayic, Cutanic, Humic, Profondic)*

Table 9. Pearson`s correlation coefficients (r) among selected soil physico-chemical properties of the surface soil of Bako Tibe and Toke Kutaye Districts of Western Showa, Ethiopia

	pH(H_2O)	OC	CEC	TN	TP	K	Mg	Ca	PBS	Ts
pH(H_2O)		-0.60	-0.41	-0.78	-0.87	0.16	0.086	-0.011	-0.48	-0.77
OC			0.22	0.96*	0.72	0.51	-0.53	-0.71	0.98*	0.95
CEC				-0.096	0.41	-0.92	0.30	0.48	-0.32	-0.075
TN					0.83	0.38	-0.39	-0.52	0.91*	0.99**
TP						-0.19	0.025	-0.091	0.68	0.86*
K							-0.61	-0.73	0.54	0.33
Mg								0.88*	-0.43	-0.29
Ca									-0.70	-0.45
PBS										0.92
Ts										

pH (H_2O) = soil pH, OC=organic carbon, CEC=Cation exchange capacity, TN=Total nitrogen, TP= Total phosphorous, K= potassium, Mg= Magnesium, ca=Calcium, PBS= Percent base saturation, and Ts= Total sulfur.

The relationships between soil nutrients of topsoils

Soil pH had non-significant negative association with total nitrogen and available phosphorous concentration of the soil (Table 9), indicating that as pH decreases, the amounts nitrogen and phosphorous increases in the soil. Significantly, higher and positive correlation coefficients were observed between organic carbon with total nitrogen (0.96) and base saturation percentage (0.98) (Table 2.9). This indicated that the higher the organic carbon concentration the higher would be the total nitrogen and base saturation percentage and vice versa. There were significantly positive association with correlation coefficients between total nitrogen and base saturation percentage (0.91). Significantly ($P<0.05$), perfect positive association was obtained between total nitrogen and total sulfur concentration (Table 9). The relationship among available phosphorous and total sulfur concentration of the soil was significant and positive with correlation coefficients of 0.86. Magnesium had significantly positive association with calcium with correlation coefficients of 0.88 (Table 9), indicating that soils with higher levels of Mg will also have higher levels of Ca concentration and vice-versa. In conclusion, some soil physicochemical properties had positive and negative relationship with other properties of the soil.

CONCLUSIONS AND RECOMMENDATIONS

Results of the study showed that soils of Bako Tibe and Toke Kutaye Districts of Western Showa, Ethiopia, are Ultisols. The surface soils contained higher organic carbon, total nitrogen and available phosphorous. The CEC of the surface soils were 23.52 and 18.55 cmolc kg^{-1} in Bako Tibe district maize farms field, decreasing as depth increases; whereas the CEC were 20.06 and 28.84 cmolc kg^{-1} for Toke Kutaye maize farmer's field increased with increasing soil depth. Significantly ($P = 0.05$) positive association was observed between total nitrogen and total sulfur concentration. The soil physico-chemical characteristics differed between and among pedons in the highland and mid altitude agroecology. Soil fertility variations were observed among four pedons of maize farmers' field based on nutrient concentrations. The total N and available P status of the soils were found to vary from low to medium and low to adequate range. There is a need for a more targeted approach soil fertility intervention that differentiates between maize farm field in highland and mid altitude of western Ethiopia. Soil test-based and integrated soil fertility management is recommended for sustainable maize production in highland and mid altitude areas of Western Ethiopia.

REFERENCES

Abbasi, MK, Zafar, M and Khan, SR. 2007. Influence of different land-cover types on the changes of selected soil properties in the mountain region of Rawalakot Azad Jammu and Kashmir. Nutr. Cycl. in Agroecosyst. **78**: 97-110.

Achalu, C, Heluf, G, Kibebew, K and Abi, T. 2012. Status of selected physicochemical properties of soils under different land use systems of Western Oromia, Ethiopia. J. of Biod. and Environ. Sci. **2 (3)**: 57-71.

Anderson, JM and Ingram, JSI. 1996. Tropical soil biology and fertility: A handbook of methods. CAB International. Walling ford. Oxon, England. 221pp.

Bera, R, Seal, A, Das, TH, Sarkar, D and Chatterjee, AK. 2015. Characterization of soils in terms of pedological variability under different physiography of Damodar command area (part), West Bengal, India. Cogent Food and Agric. **1:** 1-14.

Brady, NC and Weil, RR. 2002.The Nature and Properties of Soils, Prentice Hall, pp. 521-526.

Bray, RH and Kurtz, LT. 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. **59**: 39- 45.Bojo, J and Cassels, D. 1995. Land degradation and rehabilitation in Ethiopia: a reassessment. AFTES Working paper No. 17, World Bank, Washington DC, 48 pp.

Bremner, JM. and Mulvaney, CS. 1982. Nitrogen-total. In Page A.L, Miller R.H. and Keeney D.R. (Eds.) Methods of Soil Analysis Part 2. Chemical and microbiological properties. 2nd edition, American Society of Agronomy, Madison, WI 101. USA. pp. 595-624

Charpentier, H, Doumbia, S, Coulibaly, Z and Zana, O. 1999. Stabilizing agriculture in northern and central Cote d'Ivoire: what are the new farming systems? Agriculture-et-Développement**.** **21**: 4-70.

Dawit, S, Fritzsche, F, Tekalign, M, Lehmann, J and Zech, W. 2002. Phosphorus forms and dynamics as influenced by land use changes in the sub-humid Ethiopian highlands. Geoderma **105**: 21-48.

Dereje Gorfu. 2011. Agro-ecologies of Ethiopia and major crops grown; collaboration with EIAR.

Elias, E, Morse, S and Belshaw, DGR. 1998. Nitrogen and phosphorus balances of Kindo Koisha farms in southern Ethiopia. Agric. Ecosys. and Environ. **71**: 93-113.

Esu, IE. 2005. Soil characterization and mapping for food security. A Keynote Address In Salako, F.K., Adetunji, M.T., Ojanuga, A.G., Arowolo T.A. and Ojeniyi, S.O.(Eds.) Managing Soil Resources for Food Security and Sustainable Environment. Proceedings of the 29th Annual Conference of Soil Science Society of Nigeria (SSSN). December 6-10, 2004, University of Agriculture, Abeokuta, Nigeria.

Eswaran, H. 1977. Soil analysis for soil surveys. In: *Soil Resource Inventories*. A proceeding of a workshop held at Cornell University, Ithaca, USA. pp. 315-324.

Fagbami, A. 1990. Land use plan of Norbru farms. Keffi for Soil Conservation, Productivity Sustenance and Effective Farm Management. 7p.

FAO 1974. The euphrates pilot irrigation project. Methods of Soil Analysis, Gadeb Soil Laboratory (A laboratory manual). Rome, Italy.

FAO 1990. Guideline for Soil Description. Rome, Italy 193 pp.

FAO 2006. FAO World Reference Base for Soil Resources. World Soil Resources Report 103. FAO, Rome. 145 pp.

Frossard, E, Condron, LM, Oberson, A, Sinaj, S and Fardeau, JC. 2000. Processes governing phosphorus availability in temperate soils. J. of Environ. Quality **29**: 15-23.

Gemechu, D. 1977. Aspects of climate and water budget in Ethiopia. Addis Ababa University Press. 77 pp.

Giessen, V, Sánchez-Hernández, R, Kampichler, C, Ramos-Reyes, R, Sepulveda-Lozada, A, Ochoa-Goana, S, de Jong, BHJ, Huerta-Lwanga, E and Hernández-Daumas, S. 2009. Effects of land-use change on some properties of tropical soils: An example from Southeast Mexico. Geoderma. **15:** 87-97.

Gregorich, EG, Carter, MR, Angers, DA, Monreal, CM and Ellert, BH. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. J. of Soil Sci. **74:** 367-385.

Hajabbasi, MA, Jalalian, A and Karimazadeh, HR. 1997. Deforestation effects on soil physical and chemical properties, Lordegan, Iran. Plant and Soil. **190**: 301-308.

Haney. RL, Franzluebbers, AJ, Jin, VL, Johnson, MV, Haney, E.B, White, MJ and Harmel, RD.2012.Soil Organic C: N vs. Water-Extractable Organic C: N. Open J. of Soil Sci. **2**: 269-274.

Heluf, G and Wakene, N. 2006. Impact of land use and management practices on chemical properties of some soils of Bako area, Western Ethiopia. Ethiopian J. of Natu. Reso. **8:** 177-197.

Henao, J and Baanante, CA. 1999. An evaluation of strategies to use indigenous and imported sources of phosphorus to improve soil fertility and land productivity in Mali. (IFDC). International Fertilizer Development center. Muscle Shoals, USA. 75 pp.

Hurni, H. 1995. Ethiopia: Agroecological belts, three map sheets, scale 1:1 million. Ministry of Agriculture, Ethiopia, and Centre for Development and Environment, Berne.

IUSS Working Group WRB. 2007. World reference base for soil resources 2006, first update 2007. World soil resources reports No. 103, FAO, Rome.

IUSS Working Group WRB. 2014. World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.

IUSS Working Group WRB. 2015. World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome. 203pp.

Jaiyeoba, IA. 2003. Changes in soil properties due to continuous cultivation in Nigerian semiarid savannah. Soil and Tillage Res. **70:** 91-98.

Jones, JB. 2003. Agronomic Handbook: Management of crops, soils, and their fertility. CRC Press LLC, Boca Raton, Florida, USA. 482 pp.

Lal, R. 1996. Deforestation and land use effects on soil degradation and rehabilitation in western Nigeria. Soil physical and hydrological properties. Land Degradation and Develop.**7:** 19-45.

London, JR. (Ed.) 1991. Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman.

Mandiringana, OT, Mnkeni, PNS, Mkile, Z, Averbeke, V, Ranst, W and Verplanke, EV. 2005. Mineralogy and Fertility status of selected soils of the Eastern Cape province, South Africa. Commun. in Soil Sci. and Plant Analy. **36:** 2431-2446.

MBARC 2014. Meteorological data of Bako area for 1960-2014. Bako, Oromia, Ethiopia.

McLean, EO. 1965. Aluminum pp. 978-998. *In* Black, C.A. (Ed.) Methods of Soil Analysis. Agronomy No. 9. Part II. American society of Agronomy, Madison, Wisconsin, USA.

McLean, EO. 1982. Soil pH and Lime Requirement. In Page, A.L., Miller, R.H. and Keeney D.R.(Eds.) Methods of Soil Analysis Part 2. Chemical and microbiological properties. 2nd edition, American Society of Agronomy, Madison, 101. USA. pp. 199-234.

Michel, KY, Angui, KT, Souleymane, K, Jerome, T, Yao, T, Luc, A and Danielle, B. 2010. Effects of land use types on soil organic carbon and nitrogen dynamics in Mid-West Côte d'Ivoire. European J. of Sci. Res. 40: 211-222.

Msanya, BM, Kimaro, DN, Mbogoni, JDJ and Kimbi, GG. 2000. Soils and Land Resources Report of Morogoro Urban District, Tanzania. Sokoine University of Agriculture, Faculty of Agriculture, Department of Soil Science, Morogoro, Tanzania. Ministry of Agriculture, ARI- Mlingano, National Soil Service, Tanga, Tanzania.

Munsell Color Company. 2009. Munsell soil color charts. Munsell Color Company Inc., Batimore 18, Mary land, USA.

Murphy, HF. 1959. A report on the fertility status of some soils of Ethiopia. Experiment Bull. No. 1. College of Agriculture and Mechanical Arts, Alemaya, Ethiopia. 201pp.

NMSA 2014a. Meteorological data of Tokke Kutaye area for 1990-2014. National Meteorological Service Agency (NMSA), Addis Ababa, Ethiopia.

NMSA 2014b. Meteorological data of Ilu-Gelan area for 2009-2014. National Meteorological Service Agency (NMSA), Addis Ababa, Ethiopia.

Odeh, IOA, Todd, AJ and Triantafilis, J. 2003. Spatial prediction of soil particle-size fractions as compositional data. Soil Sci. **168 (7)**: 501-515.

Ogunkunle, AO. 1986. Spatial variability of some chemical properties in two mapping units in Southern Nigeria. Soil Survey Land Evalu. **6**:26-32.

Ogunkunle AO. 2005. Soil Survey and Sustainable Land Management. Invited paper at the 29th annual conference of SSSN 6- 10 December 2004, held at University of Nigeria, Abeokuta.

Patil, RB and Prasad, J. 2004. Characteristics and classification of some sale (Shorea robusta) supporting soils in Dindori district of Madhya Pradesh. J. of Indian Soc. Soil Sci. **52**: 119 -125.

Paulos, D. 1996. Availability of phosphorus in the coffee soil of southwest Ethiopia. pp. 119-1 29. *In* Tekalign, M. and Mitiku, H. (Eds.) Soil. The Resource Base for Survival. Proc. of the Second Conference of the Ethiopian Society of Soil Science. 23-24 September 1993, Addis Ababa, Ethiopia.

Polemio, M and Rhoades, JD. 1977. Determining cation exchange capacity: A new procedure for calcareous and gypsiferous soils. Soil Sci. Soc. Am. J. **41**: 524-528.

Posadas, AND, Gimenez, D, Bittelli, M, Vaz, CMP and Flury, M. 2001. Multifractal characterization of soil particle-size distributions. Soil Sci. Soc. of American J. **65:**1361-1367.

Rhoades, JD. 1982. Cation Exchange Capacity. In Page A.L., Miller, R.H. and Keeney, D.R.(Eds.) Methods of Soil analysis Part 2. Chemical and Microbiological Properties. Agronomy Monograph no. 9. 2nd Edition. Agronomy society America-Soil Science Society America, 677 S. Segoe Rd., Madison, WI 53711, USA. pp. 149-157.

Shishir, P and Sah, J. 2003. Physicochemical characteristics of soil in tropical sal forests in eastern Nepal. Himalayan J. of Sci. **1:** 107-110.

SAS 2004. SAS/STAT Software Syntax, Version 9.0. SAS Institute, Cary, NC. USA.

Soil survey Staff. 1993. Soil Survey Manual. Soil Conservation Service U.S. Department of Agriculture Handbook 18. U.S. Govt. Printing Office, Washington, D.C. 871.

Soil survey Staff. 2003. Keys to Soil Taxonomy.9th Ed. United States Department of Agriculture Natural Resources Conservation Service. Washington, DC 20250-9410. 332 pp.

Soil survey Staff. 2006. Keys to soil taxonomy. 11th edition. United States Department of Agriculture. NRCS, Washington DC. 346 pp.

Soil Survey Staff 2014. Keys to Soil Taxonomy. 12th edition. United States Department of Agriculture, Natural Resources Conservation Service. 372pp.

Stoorvogel, JJ and Smaling, EMA. 1990. Assessment of soil nutrient depletion in sub-Saharan Africa, 1983-2000, Report 28. DLO Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), Wageningen, Netherlands.

Tekalign, M and Haque, I. 1987. Phosphorus status of some Ethiopian soils. I. Sorption characteristics. Plant and Soil **102:** 261-266.

Tolessa, D. 2006 Effect of tillage system, residue management and nitrogen fertilization on maize production in western Ethiopia. Dissertation for

Award of PhD degree at the University of the Free State, Bloemfontein, South Africa.200 pp.
Ukut, AN, Akpan, US and Udoh, BT. 2014. Characterization and classification of soils in steep sided hills and sharp-crested ridges of Akwa Ibom State, Nigeria. Net J. of Agric. Sci. **2(2):** 50-57.
Wakene, N. 2001. Assessment of important physicochemical properties of dystric udalf (dystric Nitosol) under different management system in Bako area, Western Ethiopia. Dissertation for Award of MSc degree at Alemaya University, Ethiopia, 115 pp.
Wakene, N, Tolera, A, Friesen, DK, Abdenna, D and Berhanu, D. 2004. Evaluation compost for maize production under farmers' conditions. pp. 382-386. *In* Friesen, D.K. and Palmer, A.F.E. (Ed.) Integrated Approaches to higher maize productivity in the new millennium. Proc. of the Seventh Eastern and Southern African Regional Maize Conference, 5-11 February 2002, Nairobi, Kenya: CIMMYT. (International Maize and Wheat Improvement Center) and KARI (Kenya Agricultural Research Institute).
Walkley, A. 1947. An examination of Degtjareff method for determining soil organic matter and the proposed modification of the chromic acid titration method. Soil Sci. **37**: 29-38.
Wondwosen, T and Sheleme, B. 2011. Identification of growth limiting nutrients in Alfisols: Soil physicochemical properties, nutrient concentration and biomass yields of maize. Am. J. of Plant Nutr. and Fertilization Techn. **1:** 23-35.
Wu, TY, Schoenau, JJ, Li, FM, Qian, PY, Malhi, SS and Shi, YC. 2003. Effect of tillage and rotation on organic carbon forms in chernozemic soils in Saskatchewan. J. Plant Nutr. and Soil Sci. **166:** 385-393.