Soil Fertility in Koka Nagawo Area of Lumme District in East Shoa Zone of Oromia Region, Ethiopia

Haile Negash[1] and Muktar Mohammed[2]*

[1] Mizan-Tepi University, Department of Plant Science, P O Box 260, Mizan Teferi, Ethiopia
[2] Haramaya University, College of Agriculture & Environmental Sciences, P O Box 138, Dire Dawa, Ethiopia

Abstract: For designing proper soil fertility management interventions, locally specific information on physical, chemical, and biological properties of soils is indispensable. Therefore, a study was conducted to assess the spatial variability in the fertility status of soil of Koka Nagawo area of Lumme District in East Shoa Zone of Oromia Regional State, Ethiopia, based on selected soil physico-chemical properties. Eleven land units were delineated and mapped based on their soil color, slope, drainage, and soil management practices which were assumed to cause variability in soil fertility status among the land units. Eleven composite surface (0-20 cm) soil samples were collected randomly from each land unit and selected soil physico-chemical properties determined in the laboratory. The results of the study revealed that the soils of all land units on rain-fed agriculture (land units 1, 2, 3, 7, 8, and 11) had a clay loam texture but the soil of all land units on irrigated agriculture in floodplain (land units 4, 5, 6, 9, and 10) had a clay texture. The highest bulk density (1.38gcm^{-3}) was recorded for land units 1 and 3 and the lowest (1.16gcm^{-3}) was recorded for land units 4 and 10. The percent total porosity of all the land units was found to be very high. The pH values ranged from slightly alkaline to moderately alkaline for all land units. Land units 4 and 10 had high organic matter contents and land units 5, 6, 7, 8, and 9 had moderate organic matter contents whereas the remaining land units had low organic matter contents. Available P contents of the soils from land units 1, 2, 3, 7, 8 and 11 were medium whereas those of the soils from land units 4, 5, 6, 9, and 10 were high. The cation exchange capacity of the soils of the area ranged from 28.66 to 52.26 cmol(+)/kg soil, which is rated as high and very high, respectively. Exchangeable Ca was very high in irrigated floodplain land units but high in land units of rain-fed agriculture. Exchangeable Mg was high in the land units 4, 5, 6, 9 and 10, medium in land units 7 and 8, low in land units 1, 2, and 11, and very low in land unit 3. All the land units of the area revealed very high exchangeable K contents. Exchangeable Na contents of soils were high in all land units except for land unit 8, which was medium. The values of percent base saturation ranged from high to very high except for land unit 3 which was medium. Generally, the extractable micronutrient cations (Cu, Zn, Mn, and Fe) contents of the soils were found to be at critical levels, below which crops may suffer from deficiency of the nutrients, and low for all land units except land unit 7 which had a high Fe content. The soils of the study area showed potentially rich physical fertility and exchangeable bases except for Mg in some land units of rain-fed agriculture but poor chemical fertility such as alkalinity and low availability of most of the micronutrients. In addition, all land units of rain-fed agriculture low contents of soil organic matter and total N except land units 7 and 8. It could be concluded that the soils of the study areas have no limitation in terms of physical condition as well as availability of cations, but are constrained by low contents of micronutrients and soil organic matter. Therefore, soil fertility management practices in the areas should focus on improving mitigating the high soil pH and increasing the availability of micronutrients and the content of soil organic matter.

Keywords: Floodplain; Physico-chemical Properties; Soil Fertility Assessment

1. Introduction

Soil fertility is a complex quality of soil that is closest to plant nutrient management. It is a component of overall soil productivity that deals with its available nutrient status and its ability to provide nutrients out of its own reserves (FAO, 2006). Soil fertility management for food and livelihood security is a major concern in the face of persistent poverty and rampant environmental degradation in Sub-Saharan Africa (SSA) including Ethiopia. Socioeconomic, policy, and biophysical constraints, in general, and soil-related constraints and management practices, in particular, are factors identified as major causes of low crop production, soil fertility decline, and, ultimately, degradation of the agricultural land in most countries of Africa. Inadequate replenishment of removed nutrients and continued loss of organic matter from the soils are contributing to increasing erosion rates and the decline in the fertility of the soils.

*Corresponding Author. E-mail: muktarmoha@yahoo.com

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In Ethiopia, declining soil fertility presents a major challenge to bring about increased and sustainable productivity in order to feed the ever-increasing population of the country. As a result, millions are suffering from poverty and malnutrition. Eyasu (2002) indicated that under increasing demographic pressure, cultivation becomes a permanent lead to the mining of the natural soil fertility. Data on soil fertility in Ethiopia is largely out-of-date at the national level and is very locally specific, fragmented, and difficult to access at the local level; meaning that it would take significant time and efforts to obtain an actionable view of the current soil fertility status. What is more, much of this available information is specific to particular areas selected for specific studies or generalized for wider areas that cannot be assessed at a national level to enable policymakers and other stakeholders to draw conclusions on the status of soil at local level and its implications for food production. In addition to that soil types and characteristics show great variation within a short distance in Ethiopia (Mesfin, 1998; Ahmed, 2002; Mohammed, 2003).

The turning point to solve the problem is systematic application of scientific methods to assess the fertility status of soils through their physical, chemical and biological properties at local levels. A study by Wakene and Heluf (2003) also indicated that periodic assessment of important soil properties and their responses to changes in land management is necessary to improve and maintain the fertility and productivity of the soils. Success in soil management depends on understanding of the properties of a given soil. Therefore, more research needs to be carried out at a granular and actionable level. Not much research has been done on the fertility status of soils in Ethiopia. This kind of research would generate locally important specific information that can help to manage agricultural soils judiciously and to improve their productivity. Therefore, the objective of this study was to assess the spatial variability in soil fertility status at a local level based on selected soil physico-chemical properties.

2. Material and methods

2.1. Descriptions of the study area

2..1.1. Location

The study was conducted in Lumme District, East Shoa Zone of Oromia region, Ethiopia. It is located at the distance of about 88km away from the capital city, Addis Ababa, in south direction on the main road to Hawassa. The study area is part of the central rift valley of the country. Its grid reference is 8°24'43.25" and 8°27'57.11" North and 39° 0'11.46" and 39° 5'18.94" East and with an average altitude of 1,608 meters above sea level.

2.1.2. Climate

Agro-ecologically, the area is classified as semi-arid region with quite high variability in climate conditions. Rainfall mainly occurs in July and August (Figure 2), which is for a very short duration. This short duration of rainfall leads to a long period of dry season, with minimum temperature of 11^0C. The annual mean daily maximum and minimum temperatures of the area are 11^0C and 33^0C, respectively. The area is characterized by unimodal distribution of rainfall pattern ranging from 9.0 - 250.9 mm for monthly mean rainfall and mean annual rainfall of 896.3mm. Rainfall and temperature data recorded from 1997 to 2011 were obtained from National Meteorological Service Agency of Ethiopia.

2.1.3. Land use and land cover

Mixed farming system that comprises crop and livestock production is practiced in the area. Fishing is also a common practice in Koka lake side. During recession of flood water, as it happens slowly, a few farmers do fishing following the edge of the flood. Crop production is practiced under rain-fed and irrigated conditions. Crop production is the main agricultural activity in the area. Both non-flooded and flooded areas are used for crop production. In non-flooded areas, Teff (*Eragrostis teff*), is produced under rain-fed condition. However, in flooded areas, vegetables are the most predominantly grown crops. The natural vegetation is native grasses, sparsely growing *Acacia species* such as *Acacia tortilis, Acacia nilotica, Acacia seyal* and bushes. The main water resources for irrigation agriculture are river water and hand-dug wells.

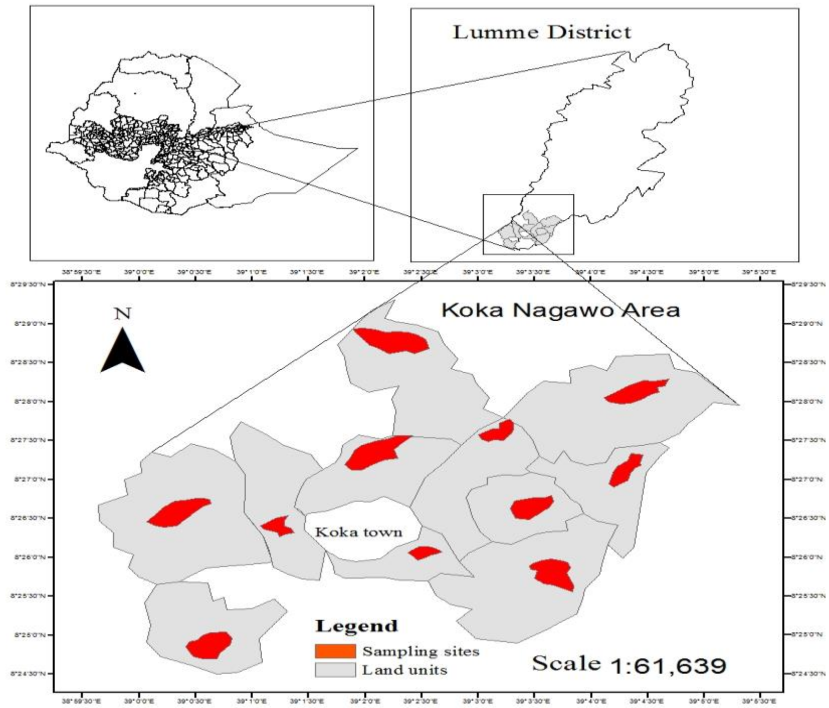

Figure 1. Map of the study area.

2.1.4. Geology and soil

As the study area is part of the central rift valley system of Ethiopia, the geology is complex (UNDP and FAO, 1984). Thirteen major units and six sub-units in the FAO/UNESCO soil classification are of importance in the Rift Valley. The major soil units in terms of area covered are: Vertisols (19.2%), Cambisols (17.9%), Fluvisols (16.2%), Regosols (15.8%), Lithosols (9.5%), Andosols (7.1%) and Acrisols (6.1%) (King and Birchall, 1975). The soils of the Rift Valley are largely derived from recent volcanic rocks and, in comparison to soils of other African countries, their base status is generally good. The main parent materials of the Rift Valley soils are basalt, ignimbrites, lava, gneiss, volcanic ash, alluvium, pumice, reverine and lacustrine alluvium. Some of the problems of these soils include low availability of phosphorus, micronutrient imbalances, and in some cases poor physical structure (Makin *et al*., 1975).

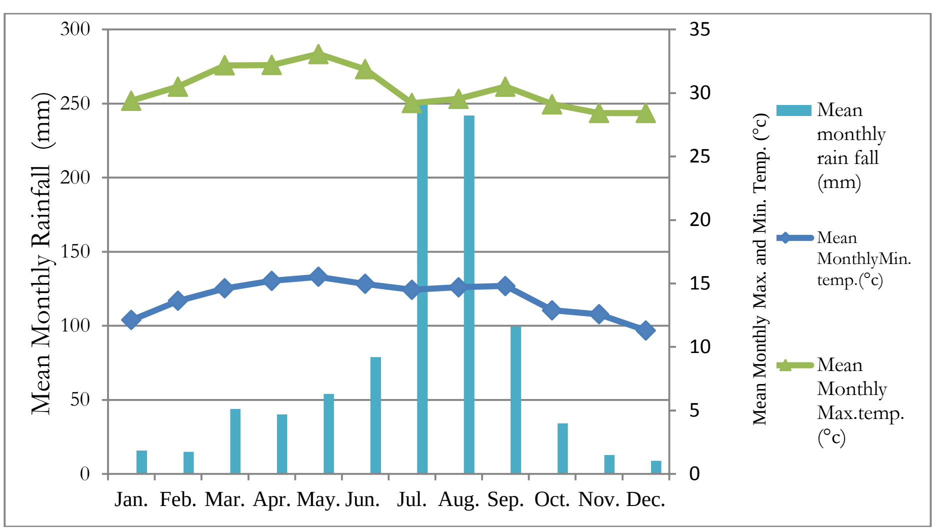

Figure 2. Mean monthly weather condition of the study area.

2.2. Land unit delineation and mapping

Preliminary soil survey and field observation were carried out using the topographic (1:50000) map (EMA, 1975) of the study area. Prior to the actual fieldwork, tentative land units were fixed on the base map. Eleven land units were fixed on the base map to represent the final respective land units (Figure 1). A total of eleven land units were demarcated differing from each other in surface soil color, slope, drainage, and management practices like fallowing and fertilization. Based on the field observation and soil survey, similar land of the study area was demarcated on the ground using geographic positioning system (GPS). A land unit map was developed using topographic (1:50000) map (EMA, 1975) as a base map and point data collected using geographic positioning system was overlaid on the topographic map using ArcGIS 10.1 geographic information systems' software.

2.3. Soil sampling, preparation and analysis

After crop harvest, one composite soil sample was augured at 0-20 cm depth from each of the rain-fed cultivated lands (six land units) for which teff is the major crop grown and another composite soil sample was taken in a similar way from irrigated lands of periodically flooded floodplain farms (five land units) for which vegetables are the predominant crops. To make one composite soil sample, 20 to 25 subsamples were augured using a zigzag sampling pattern and well mixed in a bucket. One kilogram of the mixed sub-samples (composite samples) was properly labeled and was taken to the laboratory for analysis.

2.3.1. Analysis of soil physical properties

The particle size distribution of the soils was analyzed according to the procedure outlined by Bouyoucos (1962) with the help of the hydrometer method. The bulk density of the soil was estimated from undisturbed soil samples which were collected by using a core sampler following the procedures used by Blake (1965). The core samples was oven-dried and the bulk densities were calculated by dividing the masses of the oven dry soils by their respective volumes as they existed naturally under field conditions. The generally used average value of 2.65 gcm^{-3} was used for the particle density of the soil. Total porosity was estimated from the values of bulk density (BD) and particle density (PD) as:

$$\text{Total porosity (\%)} = \left(1-\frac{BD}{PD}\right) \times 100$$

2.3.2. Analysis of soil chemical properties

Measurement of soil pH was conducted using a pH meter in the supernatant suspension of 1:2.5 soils to water ratio. The electrical conductivity of soils was measured from 1:2.5 soil water suspensions by electrical conductivity meter as described by Jackson (1973). The Walkley and Black (1934) wet digestion method was used to determine soil organic carbon content and percent soil organic matter was obtained by multiplying percent soil organic carbon by a factor of 1.724 following the assumptions that organic matter is composed of 58% carbon. Total Nitrogen was determined using the Kjeldahl digestion, distillation and titration method as described by Black (1965) by oxidizing the organic matter in concentrated sulfuric acid solution (0.1N H_2SO_4). Since pH of the soil in the study area ranges from 7.77 to 8.35, available soil P was analyzed according to the standard procedure of Olsen *et al.* (1954) extraction method. Cation exchange capacity and exchangeable bases (Ca, Mg, K and Na) were determined after extracting the soil samples by ammonium acetate (1NNH_4OAc) at pH 7.0. Exchangeable Ca and Mg in the extracts were determined using atomic absorption spectrophotometer while Na and K were determined using a flame photometer (Chapman, 1965; Rowell, 1994). Cation exchange capacity was thereafter estimated titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution (Chapman, 1965). Percent base saturation was calculated by dividing the sum of the charge equivalents of the base-forming cations (Ca, Mg, Na and K) by the CEC of the soil and multiplying by 100. Finally available micronutrients (Fe, Cu, Zn and Mn) were extracted by DTPA extraction method (Lindsay and Norvel, 1978) and all these micronutrients were measured by atomic absorption spectrophotometer.

2.4. Statistical analysis

A simple linear correlation analysis was carried out by calculating correlation coefficients (r) among and within soil physicochemical properties by using Statistical Analysis System (SAS) software version 9.00. Land units were compared with each other by referring critical values for the selected physico-chemical properties.

3. Results and discussion

3.1. Land surface configuration and soil color of the area

The studied land units were within slope range between 0.5 to 3.0%. Slope is one of the components of the land surface that influences drainage, runoff and erosion processes. Through these processes, the slope of a given area imposes its impact on soil physical and chemical properties in different intensities based on the configuration of the land surface (FAO, 2006b). Soil color reflects the composition as well as the past and present oxidation and reduction reactions of the soil (FAO, 2006b). The moist soil colors of the soils ranged from very dark gray (5YR3/1) under land unit 10 and 4 to light brown (7.5YR6/3) under land unit 3. Color characteristic of any soil varies with the organic matter contents, drainage conditions and other soil properties such as texture (FAO, 2006b).

Depending on the degree of saturation and land configuration, the drainage properties of soils affect the top soil by bringing about the reductive-oxidative conditions which vary from place to place (FAO, 2006b). As described in the field, it was found that the drainage properties of the soil varied from poorly drained to well drained. Soil management practices were also assumed to be the causes of soil variability among the land units.

3.2. Soil physical properties

3.2.2. Soil texture

The results of the study revealed that there were no textural differences within the land units used for rain-fed agriculture (LU1, 2, 3, 7, 8 and 11) also there were no textural differences within the land units on periodically inundated irrigated floodplain (LU4, 5, 6, 9 and 10). However, there were slight variations among the absolute values of sand, silt and clay contents of the soils. Accordingly, all the land units on rain-fed agriculture had a clay loam textural class and all the land units on irrigated floodplain had a clay textural class. Slope is one of major factors that may bring about differences in soil texture (Mohammed A., 2003). However, the results of this study indicated that the slope differences were not strong enough to bring about significant differences in particle size distribution within land units of rain-fed agriculture and within land units of floodplain areas.

But there were textural differences among land units of rain-fed agriculture and land units of floodplain areas which had clay loam and clay textural classes, respectively (Table 1). The sand, silt and clay contents ranged from 9-43 %, 23-36% and 30-57%, respectively, with high variation in the sand and clay fraction. The highest sand fraction (43%) was recorded for LU1, 3 and 11 and the lowest sand fraction (9%) was recorded for LU5 and 6, on rain-fed agriculture and periodically flooded floodplain irrigated land units, respectively. On the other hand, the highest clay content (57%) was obtained in LU5 and the lowest clay fraction (30%) was recorded in LU1 and LU2, which were land units devoted to rain-fed agriculture. This textural variation between the land units of rain-fed agriculture and land units of floodplain could be due to deposition and sedimentation of the suspended fine grained materials on the flood plain areas during inundation by Modjo river and Koka lake in the rainy season.

Table 1. Selected soil physico-chemical properties across different land units.

Land unit	Particle size (%)				Bulk density (gcm^{-3})	Total porosity (%)
	Sand	Silt	Clay	Textural Class		
LU1	43	27	30	CL	1.38	48.00
LU2	41	29	30	CL	1.34	49.40
LU3	43	25	32	CL	1.38	48.00
LU4	14	36	50	Clay	1.16	56.23
LU5	9	34	57	Clay	1.20	54.71
LU6	9	35	56	Clay	1.21	54.33

3.2.2. Bulk density and total porosity

The values of bulk density and total porosity for the land units are presented in Table 1. The results of this study revealed variation in soil bulk density among the land units. The highest bulk density (1.38 gcm^{-3}) was observed for LU1 and LU3 and the lowest (1.16 gcm^{-3}) was observed for LU4 and LU10, which are found on rain-fed agriculture and periodically flooded irrigated floodplain, respectively. The variation among the land units could be due to the differences in clay content, organic matter, and total porosity. This means that land units with high contents of clay and organic matter have lower bulk density than those with low OM and clay contents because of greater pore space associated with high OM and clay. Werner (1997) reported that lower soil bulk density implies greater pore space and improved aeration, creating a favorable environment for biological activity. Furthermore, OM makes the soil loose, porous, or well aggregated. Thus, the density of organic matter is very low as compared to that of mineral particles, thereby lowering the soil bulk density.

Based on the critical level given by Hazelton and Murphy (2007), the soil bulk density observed in the current study was generally low to moderate. The acceptable range of bulk density is 1.3 to 1.4 gcm^{-3} for mineral agricultural soils (Bohn *et al*., 2001). The average soil bulk density obtained in this study was within this range and less. In view of this, bulk density values of the soils in the study area optimum for proliferation and ramification of plant roots thereby favoring good crop growth as a result of good supply of water and air. This indicates the existence of loose soil conditions in the upper 20 cm of the soil depth in all the land units and, hence, good structure. Bulk density is one of the major physical parameters used to evaluate the physical fertility status of soils.

The percent total porosity of all the land units was very high according to FAO (2006c), that rated total porosity values as very low (<2%), low (2-5%); medium (5-15%), high (15-40%), and very high (>40%). However, there was variation in the real numerical value of total porosity among the land units ranging from 48% to 56.23 % (Table1). The relatively higher total porosity under land units of irrigated floodplain corresponds to the relatively higher OM that improves aggregation, clay content, and the lower BD, whereas the lower total porosity under the land units of rain-fed agriculture corresponds to the higher BD value, the relatively lower organic matter and clay content of the land units. Wakene (2001) reported that the low total porosity was the reflection of the low organic matter content around Bako area.

3.3. Soil chemical properties

3.3.1. Soil reaction and electrical conductivity

The soil pH (H_2O) values ranged from 7.77 to 8.35 (Table 2). As per the ratings of Foth and Ellis (1997), these pH values can be rated to range from slightly alkaline to moderately alkaline. The highest and the lowest pH values in water were recorded for LU10 and 7 with values of 8.35 and 7.77, respectively. These high soil pH values may have resulted from the soil management practice such as irrigation, high evapotranspiration, and low precipitation, which reduces the the loss of the base forming cations from the soil as a result of leaching. The agroecology of the study area is categorized under semi-arid zone, with characteristic low rainfall. High pH values of soils are typical characteristics of this agroecology in relation to the low amount of rainfall (Foth, 1990). The relatively higher pH value on land units of periodically inundated irrigated flood plain could be related to the basic properties of the Modjo river which is used as a source of irrigation water. Behailu (2007) found that the pH of most of the water samples from around Modjo river varied from 7.7 to 8.3, with the dominant content of bicarbonates. Furthermore, the transportation and deposition of exchangeable basic cations by erosion as most of the irrigated floodplain land units are located at the lower slope could also contribute to the high pH (Abdenna *et al*., 2007). The pH (H_2O) values in all of the land units were higher than the values obtained using KCl solution (Table 2). Consequently, delta pH values remained positive, suggesting that these soils have net negative charge and are cation exchangers (Uehara and Gillman, 1981).

Electrical conductivity ranged from a minimum of 0.24 dSm^{-1} to a maximum of 1.25dSm^{-1} on land units 11 and 5 of rain-fed agriculture and irrigated floodplain, respectively (Table 2). The observed generally low EC value in all the land units in the present study indicate a non-saline condition despite the aridity of the climate and limited rainfall to leach away base forming cations from the surface soil in the area in general and the study site in particular. However, the actual numerical EC value of the soils under land units of irrigated floodplain is greater than the EC values of the soil under land units of rain-fed agriculture. This could be due to the addition of soluble salt with irrigation water.

3.2.2. Organic matter, total N, and C:N ratio

The organic matter content was low to high according to Tekalign (1991), which ranged from 1.4% to 5.87% (Table 2). With respect to OM status of the study area, LU4 and 10 had high OM contents and LU5, 6, 7, 8 and 9 had moderate OM contents whereas other land units had low OM contents. The highest OM content was recorded for LU10 and the lowest was recorded for LU3. The low levels of OM in the soil of LU1, 2, 3 and 11 (land units of rain-fed agriculture) except LU7 and 8, which have moderate OM contents, is attributed to high temperature of the area that increases the rate of organic matter decomposition, continuous cultivation with complete removal of crop residue, limited application of farmyard manure, and zero crop rotation**.** This suggestion is in line with the findings of several authors (Duff *et al*., 1995; Grace *et al*., 1995).

LU7 and 8 were the land units of rain-fed agriculture that had moderate OM. From the history of these land units, it was observed that short-term fallowing, cropping sequences (teff-fallow-teff) and organic fertilizer applications were practiced, which resulted in moderate OM compared to the remaining land units of rain-fed agriculture with low OM. Corroborating this result, Taye *et al.* (2003) also reported that the incorporation of high proportion of OM containing decomposed materials as a major component appreciably increased the organic carbon and total N contents of soil.

The relatively high contents of OM under land units of periodically flooded irrigated lands could be due to the higher clay content of the land units. This is apparent because the clay particles, unlike the sand particles, have substantial exchange surface areas, which adsorb and stabilize OM and soil nutrients (Saggar *et al*., 1994; Saggar *et al*., 1996). Besides, the high values of organic matter could be because of poor drainage of the soil and the seasonal inundation by Modjo river and Koka lake, on which the water stays for about two to four months after the rainy season, which reduces the rate of organic matter decomposition. In addition, the high soil organic matter content could be due to the production of considerable biomass of water hyacinth, which rapidly decomposes after the water recedes and the land dries up in the off-season.

Similar to the organic matter content, variations were observed also in soil total nitrogen content among the land units (Table 2). The total soil nitrogen content varied from 0.08% to 0.31% where the lowest and highest values were recorded for LU3 and 4, respectively. According to Havlin *et al.* (1999), soil total N contents of less than 0.15, 0.15-0.25 and > 0.25% are categorized as low, medium and high, respectively. Therefore, land units 4 and 10 were found to have high contents of total N whereas LU5, 6, 7 and 9 were found to have medium contents of total N. However, the remaining land units had low total N contents. The highest total N contents on land units 4 and 10 could be attributed to the relatively highest OM contents of the respective land units.

Carbon to nitrogen ratio is an index of nutrient mineralization and immobilization whereby low C:N ratio indicates higher rate of mineralization and higher C:N ratio indicate high rate of immobilization across land use (Brady and Weil, 2002). All land units except LU1, 6 and 11 had C:N ratios within the range (10:1–12:1) which is commonly cited as the average C:N ratio of mineral soils world-wide (FAO, 2006b). Similar findings were reported by Taye *et al.* (2003). According to the rating given by Hazelton and Murphy (2007), C:N less than 25 indicate decomposition proceeds at the maximum rate possible under hot conditions which is true for the semi-arid environment.

Table 2. Soil pH, EC, OM, total N, C:N ratio, and available phosphorus (P) soils in the different land units.

Land units	pH(H_2O)	EC(dS/m)	OM (%)	TN (%)	C:N	Available P (mg kg^{-1})
LU1	7.91	0.31	1.90	0.12	9.17	12.14
LU2	8.02	0.31	2.13	0.11	11.18	10.57
LU3	7.87	0.42	1.4	0.08	10.12	11.78
LU4	8.34	0.84	5.62	0.31	10.51	19.83
LU 5	8.16	1.25	3.89	0.19	11.89	16.20
LU6	8.14	0.71	3.22	0.20	9.35	21.92
LU7	7.77	0.50	2.97	0.15	11.46	13.6
LU8	7.82	0.48	2.63	0.14	10.85	12.18
LU9	8.21	0.75	4.12	0.20	11.95	25.59
LU10	8.35	0.83	5.87	0.29	11.72	20.66
LU11	7.98	0.24	2.12	0.13	9.46	10.04

Where, LU=Land unit; EC=Electrical conductivity; OM=Organic Matter; TN= Total nitrogen; Available P=Available phosphorous

3.3.3. Available phosphorous

The highest and the lowest concentrations of available P were recorded for LU9 and 11 with values of 25.59 and 10.04 mg kg^{-1} soil, respectively (Table 2). This variability could be the reflection of different soil management practices, that is, amount and type of organic and/or inorganic fertilizers utilized, fallowing, and crop rotation. Birru (1999) reported that availability of P varied considerably with land use pattern, soil reaction, total P reserves and the particle size distributions of the soils. Paulos (1996) also reported that variations in available P contents in soils are related with the intensity of soil weathering or soil disturbance, the degree of P-fixation with Fe and Ca and continuous application of mineral P fertilizer sources.

Based on the critical values for the Olsen extractable P (8.5 mg kg^{-1}) established by Tekalign and Haque (1991) for some Ethiopian soils, the available P contents of the soils in the present study area were above the critical values for all the land units. According to Landon (1991) soils with Olsen P level of < 5 mg kg^{-1}arerated as low, 5-15 mgkg^{-1}as medium and > 15mg $kg^{-1}$is rated as high. Thus, the available P of the soils of LU1, 2, 3, 7, 8 and 11 (land units of rainfed agriculture) were medium and the available P of the soils of the remaining land units (land units of irrigated floodplain) were high. The high available P could be due to the application of diammonium phosphate fertilizer twice a year on the same plot of land in the irrigable floodplain lands but once in a year on the land units of rain-fed agriculture. That is, when farmers cultivate their irrigable farm land twice a year, they would apply considerable amounts of DAP twice a year on the same farm plot. It could also be due to the possibility that irrigation/flooding in the land units that are found on the floodplain that had increased contents of available phosphorus since irrigation promotes greater diffusion of phosphorus and solubility of calcium phosphate under flooded conditions (Ponnamperuma, 1972; Richards *et al.*, 1995; Juo *et al.*, 1996 and Havlin *et al.*, 1999).

3.3.4. Cation exchange capacity

The recorded CEC of the soils in the study area ranged from 28.66 to 52.26 (cmolc/kg) (Table 3) in land unit 3 and 10, respectively, and rated as high to very high according to Landon (1991), who rated CEC values as very low (<5), low (5-15); medium (15-25), high (25-40), and very high (>40). The very high CEC values were found in soil of all the land units of irrigated floodplain areas (LU 4, 5, 6, 9 and 10) and high CEC values were found in soil of all land units of rain-fed agriculture (LU 1, 2, 3, 7, 8 and 11). The variation could be attributed to the differences in OM and type and amount clay contents of the land units (Table 3). The amount and type of clay might have been very important in contributing to CEC values. Shrinking swelling type clay has extensive internal and external surfaces. These surfaces can attract or adsorb many cations. This is in line with the findings of Mebit (2006) who reported very high CEC on Eutric Vertisols and that varied inconsistently with soil depth. Both clay and colloidal OM have the ability to absorb and hold positively charged ions (Foth, H.D. 1990). Thus, soils containing high clay and organic matter contents have high cation exchange capacity. CEC represents the primary soil reservoir of available K, Ca, Mg and several micronutrients. It also helps to prevent nutrients from leaching. The larger the CEC, the more nutrients the soil can supply, and it is directly related to the inherent fertility (exchangeable nutrient contents) of the soils (Bandel *et al*., 2002). Moreover, high CEC values imply that the soil has high buffering capacity against the induced changes.

Table 3. Exchangeable bases, CEC, percent base saturation, and ESP of the soils in different land units.

Land units	Exchangeable bases (cmolc/kg)				CEC (cmolc/kg)	PBS	ESP
	Na	K	Mg	Ca			
LU1	0.81	3.56	0.56	13.73	28.91	64.54	2.80
LU2	0.77	3.81	0.72	14.43	32.05	61.56	2.40
LU3	0.76	3.34	0.24	12.01	28.66	57.04	2.60
LU4	1.62	4.23	5.19	35.31	51.41	90.15	3.10
LU5	0.94	3.92	4.49	29.50	45.12	86.10	2.10
LU6	1.01	3.90	5.04	26.93	44.46	82.95	2.30
LU7	0.86	4.11	1.13	19.96	35.69	73.01	2.40
LU8	0.68	4.40	1.25	18.33	34.49	71.49	1.80
LU9	0.96	4.05	4.12	28.49	45.73	82.26	2.10
LU10	1.25	4.18	5.29	34.39	52.26	86.31	2.30
LU11	0.73	4.40	0.64	14.76	29.99	68.45	2.40

Where, CEC= cation exchange capacity; PBS= percent base saturation; ESP=exchangeable sodium percentage

3.3.5. Exchangeable bases and percent base saturation

Exchangeable Ca followed by exchangeable K was the predominant cation in the exchange sites of soil colloidal materials for the land units used for rain-fed agriculture while exchangeable Ca followed by exchangeable Mg was the predominant cation in the exchange sites for the land units of irrigated floodplain (Table 3). The predominance of Ca and K in the exchange site over the exchangeable Mg and Na in land units of rain-fed agriculture might be related to the parent material from which the soils have been developed and to minimum soil leaching and arid nature of the study area. On the other hand, the predominance of Ca and Mg over the exchangeable K and Na on land units of irrigated floodplain could also be related to the parent material from which the soils have been developed *i.e.* basalt rock. This soil type was transported and deposited in the study area by inundation of Modjo river during the wet season. Consistent with these suggestions, Heluf and Wakene (2006) revealed that, variations in the distribution of exchangeable bases depends on the mineral present, particles size distribution, degree of weathering, soil management practices, climatic conditions, degree of soil development, the intensity of cultivation and the parent material from which the soil is formed.

The highest and the lowest values of exchangeable Ca were 35.31 and 12.01cmolc kg^{-1} for LU4 and 3, and of Mg were 5.29 and 0.24 cmolc kg^{-1} for land units 10 and 3, respectively. The highest contents of exchangeable K were observed in LU8 and 11 with values of 4.40 and the lowest contents of exchangeable K were observed in land unit 3 with values of 3.34 cmolc kg^{-1}, while exchangeable Na had its highest and lowest mean values of 1.62 and 0.68 (cmolc kg^{-1}) in LU4 and 8, respectively (Table 3). Exchangeable Ca was rated as very low (<2), low (2-5), medium (5-10), high (10-20) and very high (>20) by FAO (2006a) and the recommended threshold level of Ca^{2+} for most crops is 5-10 cmolc (+) kg^{-1}. Accordingly, LU4, 5, 6, 9 and 10 (land units of irrigated flood plain) were observed to contain very high exchangeable Ca and the remaining land units contained high levels of exchangeable Ca.

Exchangeable Mg was high in the land units 4, 5, 6, 9 and 10, medium in land units 7 and 8, low in land units 1, 2 and 11 and was very low in land unit 3 based on the rating of FAO (2006a). The low and very low contents of exchangeable Mg in LU1, 2, 11 and 3 could be attributed to intensive cultivation, abundant crop harvest, limited recycling of dung and crop residue in the soil and declining fallow periods or continuous cropping. Similar results were reported by other researchers (Singh *et al.* 1995; Baker *et al.*, 1997; Saikh *et al.*, 1998b and He *et al.* 1999). Besides, all the land units were observed with very high exchangeable K contents. Exchangeable Na could be rated high in all land units except land unit 8 which was medium and the exchangeable sodium percentage of all land units was less than 15% (Table 3). These high value of exchangeable bases could be attributed to high evapotranspiration and soil management practice like fallowing. It may also be attributed to high contents of organic matter, clay, and CEC as well as high transportation and deposition of exchangeable cations by erosion (since most of the irrigated floodplain land units are located at the lower slope), high pH value, nature of the parent material, minimum soil leaching and arid nature of the study area. Similar findings were reported by other researchers (Mesfin, 1996; Abdena *et al.*, 2007; Debela *et al.*, 2011; Wondimagegne and Abere, 2012).

Percent base saturation values are presented in Table 3. The highest and the lowest values of PBS were 90.15 and 57.04 % for LU4 and 3 of irrigated floodplain and rain-fed agriculture, respectively. Based on the ratings of Hazelton and Murphy (2007), PBS is very high when its values are > 80, high when 60-80, medium when 40-60, low when 20-40 and very low when 0-20%. According to this rating, the values of PBS in LU4, 5, 6, 9 and 10 (land units of irrigated flood plain) could be categorized into very high and the remaining land units could be categorized into high percent base saturation except LU3 which was medium. The trends of the distribution of PBS showed similarity with the distribution of CEC and exchangeable cations since factors that affect these soil attributes also affect the percentage base saturation.

3.3.5. Micronutrients

In this study, the values of extractable micronutrients in the soils of the study area ranged from 1.09 to 6.43 mg kg^{-1} for Fe; 3.60 to 11.84 mg kg^{-1} for Mn; 0.40 to 1.03 mg kg^{-1} for Zn and 1.32 to 3.03 mg kg^{-1} for Cu (Table 4). According to the rating of Jones (2003), the contents of Fe and Zn in all the land units under rain-fed agriculture were medium except LU7 and 11 which were high in Fe and low in Zn, respectively. In contrast to that, the contents of Fe and Zn were low in all the land units under irrigated floodplain except LU6 and5 which were medium in Fe and Zn, respectively. The lower contents of Fe and Zn under land units of floodplain area could be attributed to the relatively higher pH of the soils and ample phosphate availability. Concurrent with the results of this study, Regis (1998) also reported that increase in pH and high amounts of phosphorus in soils decrease and borderline the availability and/or uptake of micronutrient by plants. In addition, Wondimagegne and Abere (2012) reported that high soil alkalinity or ample phosphate availability led to deficiency of Zn in the Middle Awash area.

On the other hand, the contents of Cu was medium in all the land units under irrigated floodplain and low in all the land units of rain-fed agriculture except LU7 and 8 which are medium, and the contents of Mn was medium in all the land units. The relatively higher Cu contents in land units of irrigated flood plain area could be related to the higher organic matter contents that have greater availability of chelating agents and higher clay contents of the respective land units. These findings are in agreement with the results of Chhabra *et al.* (1996); Khalifa *et al.* (1996) and Yadav (2011) who reported positive associations between Cu and clay contents as well as between Cu and soil OM contents. Similarly, Fisseha (1992) also reported that solubility and availability of micronutrients is largely influenced by clay content, pH, OM, CEC and phosphorus levels in the soil and tillage practices. As indicated above, the contents of Mn was medium in all land units of the study area, indicating that this nutrient adequately available in the soil for crop production at least for the time being. Concurrent with this result, Singh and Sekhon (1993) also reported that the effect of soil pH, EC, organic carbon and clay was least on Mn availability.

Table 4. Extractable soil micronutrient cations of the different land units.

Land units	Micronutrients ($mgkg^{-1}$)			
	Fe	Mn	Zn	Cu
LU1	3.37	10.66	0.59	1.32
LU2	2.97	8.62	0.51	1.72
LU3	3.35	9.50	0.63	1.58
LU4	1.09	9.15	0.48	2.99
LU5	1.43	5.54	0.52	3.03
LU6	2.96	5.83	0.43	2.69
LU7	6.43	6.61	1.03	2.65
LU8	4.88	3.60	0.72	2.61
LU9	1.96	11.84	0.41	2.76
LU10	1.35	7.58	0.40	2.87
LU11	3.01	10.28	0.42	2.05

3.4. Correlation analysis of selected soil properties

Sand was positively and significantly ($r = 0.92^{**}$) correlated with the bulk density and negatively with total porosity (r= -0.93**) and CEC ($r = -0.94^{**}$) of the soils. While clay was positively and significantly ($r= 0.90^{**}$) correlated with the CEC and total porosity (r= 0.89**) and negatively ($r = -0.89^{**}$) with the bulk density. That means bulk density of the soil increase with increasing in sand content and the reverse is true for CEC. This may be because sand contains low total porosity even though it has high large pore distribution and very low exchange sites. On the other hand, bulk density of the soil decrease with increase in clay content but CEC increase with increase in clay content due to high total porosity and high exchange site on clay particles. The correlation analysis also indicated that bulk density was found to be significantly and negatively correlated with OM (r = -0.93**) and total porosity (r = -0.99**). This is because OM makes soils loose, porous, or well aggregated, thereby lowering bulk densities. Besides, the density of organic matter is very low as compared to mineral particles and hence higher organic matter content results in lower density.

Organic matter was significantly and positively correlated with total N (r = 0.97**) and available P (r= 0.74**). As the amount of OM increases in the soil, N also increases and vice versa indicating the strong influence of organic matter on TN content. This was also significantly and positively (r = 0.77**) correlated with clay content because clays have substantial surface areas, which adsorb & stabilize OM. CEC was significantly and positively correlated with OM (r=0.96**) and clay (r= 0.90**). SOM is an important fraction of the soil because of its high CEC and retaining nutrients against leaching losses. EC is positively and significantly correlated with pH (r = 0.66*), CEC (r = 0.82**), and OM (r = 0.72*). EC value of the soils was also positively correlated (r= 0.84**) with Ca and Mg. Changes in conductivity are highly related in soil solutions with the Ca and Mg bicarbonate concentrations in alkaline soils (FAO, 1995). In this study, pH was found to be significantly and positively ($P \leq 0.01$) correlated with exchangeable Ca, Mg and Na. However, pH was negatively and significantly ($P \leq 0.01$) correlated with Fe (r = - 0.89**) and Zn (r = -0.75**). This is because the solubility and availability of the base forming cations increased as the pH values of the soils increase. Reversibly, Fe and Zn. Ca and Mg was positively and significantly ($P \leq 0.01$) correlated with clay, OM and CEC and Na was also positively and significantly ($P \leq 0.01$) correlated with OM and CEC and positively ($P \leq 0.05$) with clay.

Cu was positively correlated with clay (r= 0.77**) which indicates that the availability of Cu increased as clay content increased in the soil. These findings are in agreement with that of Chhabra *et al*., (1996) who reported positive correlation between Cu and clay contents. The Cu content was also positively correlated with total nitrogen and OM (r= 0.77** and 0.81**), respectively and positively ($P \leq 0.05$) correlated with available phosphorus. Thus, the availability of Cu increased as phosphorus, nitrogen and OM contents increased in the soil. These results are in line with that of Yadav (2011) and Khalifa *et al.* (1996) who found positively significant correlations between Cu and OM. Thus, the availability of Cu increased with OM content which might be ascribed to greater availability of chelating agents through OM.

Cation exchange capacity was significantly ($P < 0.01$) and positively associated with the exchangeable bases (Ca, Mg and Na). Exchangeable bases increased with increase in CEC. Fe was positively and significantly correlated with Zn (r = 0.87**) and negatively (r = -.67*) with Mg and (r = -0.61*) with Na and Ca. Fe is also negatively (r= -32 and -0.27) but not significantly correlated with Mn and Cu, respectively. Generally, these results are in line with that of Regis (1998) who reported that applications of iron and zinc may reduce manganese availability in the soils.

4. Conclusions

The physical and chemical properties of soils may vary from place to place due to slope gradient, drainage conditions and management practices. Variation in soil color could also indicate variation in soil chemical and physical properties as it was the case in the present study area. The soils of the study area showed potentially desirable physical fertility and exchangeable bases except for Mg on land used for rain-fed agriculture. However, the soils had poor chemical fertility particularly in terms of alkalinity. In addition, extractable micronutrient cations contents were at critical levels for most land units. Furthermore, the soils of most of the land units of rain-fed agriculture showed low contents of OM and TN.

Therefore, management practices such as crop rotation, increase input of plant residues and nitrogen rich organic materials like manure and compost are required for sustainable crop production especially on the land units being used for rain-fed agriculture. Moreover, application of micronutrients based fertilizers should be introduced in order to boost crop productivity of the study area. In addition, proper extension service should be given indicating the economic loss and environmental pollution that may result from over application fertilizers on irrigated flood plains. To make a conclusive recommendation, similar research should be done over seasons and locations with the inclusion of plant tissue analysis.

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6. References

Abdenna, D., Fite, G., and Wakene, N. 2007. Influence of small scale irrigation on selected soil chemical properties. Proceedings of the second conference of utilization of diversity in land use systems: Sustainable and organic approaches to meet human needs. October 9 - 11, 2007 Witzenhausen, Germany.

Ahmed, H. 2002. Assessment of Spatial Variability of Some Physcio-chemical Properties of Soils under Different Elevations and Land Use Systems in the Western Slopes of Mount Chilalo, Arsi. (Unpublished MSc thesis), Alemaya University, Alemaya, Ethiopia.

Baker, M. R., C. Nys and J. F. Picard, 1997. The effects of liming and gypsum application on a sessile oak (*Quercuspetraea*) stand at Larcroix- Scaille (French Ardennes). I. Site characteristics, soil chemistry and aerial biomass. *Journal of Plant and Soil.* 150: 99-108.

Bandel, V. A., James, B., Meisinger, J. J. 2002. *Basic Principles of Soil Fertility. II. Soil properties.* University of Maryland, MD, USA: College of Agriculture and Natural Resources.

Behailu, B. 2007. Impact of Industries and Urbanization on Water Resource in Modjo River Catchment (Published M.Sc thesis). Addis Ababa University, Addis Ababa, Ethiopia.

Birru, Y. 1999. Phosphorus Status and Sorption Characteristics of the Soils of the North-western Highlands of Ethiopia. (Unpublished MSc. thesis) Alemaya University, Alemaya Ethiopia.

Black, C. A, 1965. *Methods of soil analysis*. Madison, Wisconsin, USA: Part I, American Society of Agronomy. 157p.

Blake, G. R. 1965. Bulk Density. pp. 374-399. C.A. Black (Ed). Methods of soil analysis Agron. Part I, No. 9.Am. Soc. Agron. Madison, Wisconsin, USA.

Bohn, H. L., B. L. McNeal and G. A. O'Connor, 2001. *Soil Chemistry 3rd Edition*. New York USA: John Willey and Sons Inc.

Bouyoucos, G. J. 1962. Hydrometer method improved for particle-size analysis of soils. *Agron. J*. 53: 464-465.

Brady, N. C. and R. R. Weil, 2002. The Nature and Properties of Soils 13th*Edition*. New Jersey, USA: Prentice-Hall. Inc.

Chapman, H. D., 1965. Cation exchange capacity by ammonium saturation. In C.A. Black (Ed.) *Methods of soil analysis* pp. 891-901. Wiscisin, USA: Agron, Madison.

Chhabra, G., P. C. Srivastava, D. Ghosh and A. K. Agnihotri. 1996. Distribution of available micronutrient cations as related to soil properties in different soil zones of Gola-Kosi inter basin. *Journal of Crop Research-Hisar*. 11(3): 296-303.

Debela, H. Feyissa, Jasse T. Njoka, Zemede, A. and M.M. Nyangito. 2011. Soil physico-chemical properties of semiarid Ethiopia in two land use system: implication to crop production. *International Journal of Agricultural Research*. 6(12):840-847.

Duff, B., P. E. Rasmussen and R. W. Smiley, 1995. Wheat/fallow systems in semi-arid regions of the Pacific, north-west America. In: Barnett, V. Payne, R. and Steiner, R. (Eds). *Agricultural Sustainability: Economic, Environmental and Statistical Considerations*. pp. 85-109. New York, USA: John Wiley and Sons**,** Inc.

EMA (Ethiopian Mapping Authority). 1975. National Atlas of Ethiopia, Addis Ababa, Ethiopia.

Eyasu, E. 2002. Farmers Perception of Soil Fertility Changes and Management. Institute for Sustainable Development, Addis Ababa, Ethiopia.

FAO (Food and Agricultural Organization), 2006. Scaling soil nutrient balances. *Fertilizer and plant nutrition bulletin*. No15. FAO, Rome, Italy.

FAO (Food and Agriculture Organization). 2006a. Plant Nutrition for Food Security: A guide for integrated nutrient management. FAO, Rome.

FAO (Food and Agriculture Organization). 2006b. Guidelines for soil description. FAO, Rome.

FAO (Food and Agricultural Organization). 2006c. Guidelines for soil profile description. Soil Resources, Management and Conservation Service, Land and Water Development Division, FAO, Rome.

Fisseha, I. 1992. Macro- and micronutrients distribution in Ethiopian Vertisols landscapes. (Published doctoral dissertation) Doctoral thesis**.** Institute fur Bondenkunde und Standortslehre, University of Hohenheim, Germany, p. 201.

Foth, H. D. 1990. *Fundamentals of Soil Science 8th Edition*. New York,USA: John Wiley and Sons, Inc.

Foth, H. D. and Ellis, B. G. 1997. *Soil Fertility*. Canada: John Wiley & Sons, Inc.

Grace, P. R., J. M. Oades, H. Keith and T. W. Hancock, 1995. Trends in wheat yields and soil organic carbon in the permanent rotation trial at the Waite Agricultural Research Institute, South Australia. *Australian Journal of Experimental Agriculture*. 35: 857-864.

Havlin J. L., Beaton J. D., Tisdale S. L., Nelson W. L. 1999. *Soil Fertility and Fertilizers*. New Jersely, USA: Prentice Hall. Inc pp. 345-355.

Hazelton, P. and B. Murphy, 2007. *Interpreting soil test results: What do all the numbers mean? (2nd Edition)*. CSIRO Publishing. 152p.

He, Z. L. Alva, A. K. Calvert, D. V. Li, Y. C. and Banks, D.J. 1999. Effects of nitrogen fertilization of grape fruit trees on soil acidification and nutrient availability in a Riviera Fine Sand. *Journal of Plantand Soil* 206: 11-19.

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 Journal of Natural Resources*. 8 (2): 177-197.

Jackson, M. L. 1973. *Soil Chemical Analysis*. New Delhi: Prentice Hall of Indian Pvt. Ltd. P 498.

Jones, J. Benton. 2003. Agronomic Hand Book: Management of crops, soils and their fertility. Washington, USA: CRC Press.

Juo, A. S. R., K. Franzlucbbers, A. Dabiri and B. Ikhile, 1996. Soil properties and crop performance on a kaolinitic Alfisol after 15 years of fallow and continuous cultivation. *Journal of Plant and Soil* 180: 209-217.

Khalifa, E. M., M. A. El-Desoky, M. A. Gameh and M. E. Faragallah, 1996. Status of some micronutrients and their relations to mineral composition of the Nile valley desert interference zone soils, East of Assiut city. *Assiut Journal of Agricultural Sciences* 27(3): 107-127.

King, R. B. and Birchall, C. J. 1975. Land systems and soils of the Southern Rift Valley, Ethiopia. Land Resource Report. Ministry of Overseas Development, Land Resources Division.

Lindsay, W. L. and Norvell, W.A. 1978. Development of DPTA soil test for zinc, copper, iron and manganese. *Journal of American Soil Science Society*. 42: 421-428.

Makin, M. J., Kingham, T. J., Waddams, A. E., Birchall, C. J., and Teffera, T. 1975. Development prospects in the southern Rift Valley, Ethiopia. Ministry of Overseas Development, Land Resource Study, 21, LRD, Surbiton.

Mebit, K. 2006. Physico-Chemical Properties and Classification of Soils along the Toposequence at Woreta Agricultural Technical Vocational Education and Training College Research Farm, Ethiopia (Published MSc. thesis). Alemaya University, Alemaya, Ethiopia.

Mesfin, A. 1996. The Challenges and Future prospects of Soil Chemistry in Ethiopia. Proceedings of the third conference of the Ethiopian Society of Soil Science. February 28-29, 1996 Addis Ababa, Ethiopia: Ethiopian Society of Soil Science.

Mesfin, A. 1998. *Nature and Management of Ethiopian Soils*. Alemaya University of Agriculture, Ethiopia.

Mohammed, A. 2003. Land suitability evaluation in the Jelo Catchment, Chercher Highlands, Ethiopia (Published doctoral dissertation) Doctoral thesis. University of Free State, Bloemfontein, South Africa.

Olsen, S. R., Cole, C. V., Watanabe, F. S. and Dean, L. A. 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. USDA circular 939. 1-19p.

Paulos, D. 1996. Availability of phosphorus in the coffee soils of southwest Ethiopia. In: Tekalign Mamo and Mitiku Haile (Eds.). pp. 119-129. Soil: The Resource Base for Survival. Proceeding of the second Conference of the Ethiopian Society of Soil Science (ESSS), 23-24 September 1993, Addis Ababa, Ethiopia.

Ponnamperuma, F. N. 1972. The chemistry of submerged soils. *Journal of Advance Agronomy*. 24:29-40.

Regis V. 1998. *Micronutrients*. Department of Agronomy, Iowa State University Ames, IA 50011, p. 69.

Richards, J. E., T. E. Bates and S. C. Steepard, 1995. Change in the forms and distribution of soil phosphorous due to long- term corn production. *Canada Journal of Soil Science* 72: 311-317.

Rowell, D. L. 1994. *Soil science: Method and applications*. England: Addison Wesley Longman Limited.

Saggar, S., K. R. Tate, C.W. Feltham, C. W. Childs and A. Parshotam, 1994. Carbon turnover in a range of allophonic soils amended with 14C-labelled glucose. *Journal of Soil Biology and Biochemistry* 26: 1263-1271.

Saggar, S., A. Parshotam, G. P. Sparling, C. W. Feltham and P.B.S. Hart, 1996. 14C-labelled ryegrass turnover and residence times in soils varying in clay content and mineralogy. *Journal of Soil Biology and Biochemistry* 28: 1677-1686.

Saikh, H., Varadachari, C. and Ghosh, K. 1998b. Effects of deforestation and cultivation on soil CEC and contents of exchangeable bases. A case study in Simplipal National Park, India. *Indian journal of Soil science*.204: 67-75.

Singh, M and G. S. Sekhon, 1993. DPTA extractible micronutrient cations in some bench mark soil series of India. *Indian Journal of Soil Science* 41:566-568.

Singh, H., Sharma, K. N. and Aroa, B. S. 1995. Influence of continuous fertilization to a maize system on the changes in soil fertility. *Journal of Fert. Res.* 40: 7-19.

Taye, K., Mesfin, A. and Paulos, D. 2003. Contribution of organic amendment to physico-chemical conditions of coffee nursery media. Proceedings of the 6th conference of Ethiopian Society of Soil Science. February 28- March 1, 2002. Addis Ababa, Ethiopia: Ethiopian Society of Soil Science.

Tekalign, M. and I. Haque, 1991. Phosphorus status of some Ethiopian soils, II. Forms and distribution of inorganic phosphates and their relation to available phosphorus. *Journal of Tropical Agriculture.* 68: 1: 2-8.

Tekalign Tadesse. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Documnt NO 13. International Livestock Research Center for Africa (ILCA), Addis Ababa.

Uehara, G. and Gilman, G. 1981. The mineralogy, chemistry and physics of tropical soils with variable charge clays. Westview Tropical Agricultural Series, Boulder, Colorado, 4: 170.

UNDP and FAO, 1984. Geomorphology and soils of Ethiopia. Assistance to land use planning. FAO, Rome. 248p.

Wakene, N. 2001. Assessment of important physicochemical properties of Dystric Udalf (Dystric Nitosols) under different management systems in Bakoarea, Western Ethiopia (Published MSc thesis). Alemaya University, Alemaya, Ethiopia.

Wakene, N. and Heluf, G. 2003. Forms of phosphorus and status of available micronutrients under different land-use systems of Alfisols in Bako area of Ethiopia. *Ethiopian Journal of Natural Resources*. 5(1): 17-37.

Walkley, A. and I. A. Black, 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Journal of Soil Science* 37: 29-38.

Werner M. R. 1997. Soil Quality characteristics during conversion to organic orchard management. *Journal of Soil Ecology* 5:151-167.

Wondimagegne, C. and Abere, M. 2012. Selected Physical and Chemical Characteristics of Soils of the Middle Awash Irrigated Farm Lands, Ethiopia. *Ethiopian Journal of Agricultural Science.* 22:127-142.

Yadav, B. K. 2011. Micronutrient status of soils under legume crops in arid region of western Rajasthan, India. *Journal of Plant Science.* 4 (3): 94-97.