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Soil Fertility Assessment and Mapping of Becheke Sub-Watershed in Haramaya District of East Hararghe Zone of Oromia Region, Ethiopia

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ABSTRACT:
Lack of area-specific information on soil fertility is presenting unprecedented challenge to bring about increased and sustainable productivity in Ethiopia in general and the study area in particular. In view of this, a study was conducted at Becheke Sub Watershed in Haramaya District of East Hararghe Zone of Oromia Region, Ethiopia, to study selected physicochemical properties of soils under different land units and map fertility status of soils of the study area. Based on land use type, soil color, altitude, slope gradient and soil management practices, the study area was divided into7 land units (LUs). A total of 21 composite surface soil samples were collected for laboratory analysis. The results revealed that the dominant textural classes are sandy loam and sandy clay loam with the sand fraction dominating the soil separates' proportion. Bulk density of the soils under different LU varied from 1.32 to1.59 gcm^{-3}, while the total porosity ranged from 40.00 to 50.12%. The lowest bulk density and the highest total porosity were recorded in the virgin land. The pH values varied between slightly acid and neutral with values of 6.04 to 7.17. The soils are generally low in organic matter with values that ranged between 1.02 to 3.92%. Following the low organic matter content, the total N content of the soils was also dominantly low in which values of 0.06 to 0.18 were recorded. The soils were generally better in their available P content (10.67-24.55 mg/kg). The CEC of the soils under the study area ranged from 24.85 to 42.31 and was medium to very high. The soils were also relatively rich in Ca and Mg, whereas K was low in soils of land unit 2. The exchange complex is dominated by Ca^{2+} followed by Mg^{2+}. Generally the extractable micro nutrients were found to be medium to high except Cu which was low to medium. The soil fertility map developed for OM, total N, available P, CEC, Ca, Mg, Fe, and Cu clearly indicates areas of the sub-watershed where these attributes optimum and not optimum. In general, the soils under different land units exhibited difference in the measured soil attributes. The physical parameter studied indicate that the soils are good, while chemical fertility parameters such as OM, total N, K, and Cu are limiting in soils of some land units. Therefore the use of integrated soil fertility management strategy with inclusion and combination of manure, compost, crop rotation, biological and physical soil and water conservation and other practices together with chemical fertilizer and improved crop varieties gives the better production and keeps the soil fertility status to a better level. However, soil analysis by itself cannot go further than the identification of soil nutrients status due to intricate nature of soil. Therefore, the nutrient supplying powers of the soil sand demanding levels of the plants need further correlation and calibration works to come up with site-soil-crop specific fertilizer recommendation.
Keywords: Physicochemical Properties; Soil Fertility; Mapping

1. INTRODUCTION

Soil fertility is a dynamic process comprising physical, chemical and biological properties of the soil. Soil fertility constraints to crop production in Sub-Saharan Africa (SSA) are recognized as the major obstacles to food security in the region (Sanchez *et al*., 2000). Soil fertility shows a downward trend particularly in densely populated and hilly countries of the Rift Valley areas. Ethiopia, Kenya, Rwanda and Malawi had the most negative nutrient balances (Roy *et al*., 2003). According to Bationo *et al*. (2006), the average estimated soil fertility depletion rate of cultivated land in 37 African countries including Ethiopia on 30 years has been 660 kg N ha^{-1},75kg P ha^{-1} and450 kg K ha^{-1}.

Ethiopia is the largest agrarian country in Africa both in terms of area and population. Agriculture is the mainstay of the country's economic activity for the majority of the population and its contribution to the national economy is significant. It accounts for about 43% of the GDP, 90% of exports, and 80% of total employment (CSA, 2013). Despite the achievement, the sector has made poverty and hunger reduction its top priorities and focus of national policy such as Agricultural Development Led Industrialization Plan (ADLIP) to accelerate and sustain agricultural development to end poverty. During the past five years, it has also implemented the Growth and Transformation Plan (GTP) aimed at accelerating growth in all sectors including agriculture. But soil fertility decline has been one of the most challenging and limiting factors for food security in the country (MoARD, 2010). As a result, many people have suffered from food insecurity and associated health problems due to malnutrition (Gete*et al*., 2010*)*.

The primary cause of soil fertility decline include loss of organic matter(OM), macro and micronutrient depletion, soil acidity, topsoil erosion and deterioration of physical soil properties (IFPRI, 2010). In addition, salinity is also a major problem in the country. Low soil fertility is also common for SSA countries (Betiono *et* *al*., 2006; Sommer *et al*., 2013) in which soil fertility is constrained by soil erosion, inherent fertility problem, continuous and long term cultivation and inadequate fertilizer applications.

Hence, soil fertility depletion is considered as the fundamental biophysical cause for declining per capita food production in SSA countries in general and Ethiopia in particular (Sanchez *et al*., 1997). The problems of land degradation and low agricultural productivity in the country, resulting in food insecurity and poverty, are particularly severe in the rural highlands (Nedessa *et al.*, 2005). Studies indicated that in some parts of Ethiopia farmers suffer from lack of what to eat particularly in months starting from June up to September (Abera, 2003). Farmers in most parts of the country actually work hard, in seasons of the year when the rainfall is favorable for their cropping; regardless of their effort they get very little, which does not help them to escape their subsistence way of living. The fault with this agricultural problem is very intricate in nature, the complexity arises from various condition of the country such as the agro-climate, topography of the lands, the soil types and socio-economic status of the farming community and the combination of these; the overall effect of which is finally reflected by soil fertility decline and reduction in yield of crops (Alemayehu *et al*., 2006).

The issue is to solve the problem, systematic application of scientific methods to assess the fertility status of soils through their physical, chemical and biological properties. Research results have shown that the success in soil management to maintain soil quality depends on understanding of the properties of a given soil. This is a requisite for designing appropriate management strategies and thereby solving many challenges that the Ethiopians are facing in the crop and livestock production sectors and in their efforts towards natural resource management for sustainable development (Wakene, 2001). Regional Research Institutes and national and regional soil laboratories, have been progress in terms of resources and output, they are currently carrying out research on various areas of soil and water management, fertilizer recommendations, management of problematic soils, and other relevant areas. However, much of these activities are specific to particular areas selected for study and currently cannot be compiled, compared, or accessed at a national level to enable policymakers and other stakeholders to draw conclusions on the status of soil in Ethiopia as a whole and its implications for food production.

In addition to that soil types and characteristics show great variation within a short distance in the Ethiopian highland (Ahmed, 2002; Mohammed, 2003) and periodic assessment of important soil properties and their responses to changes in land management is necessary in order to improve and maintain the fertility and productivity of soils (Wakene and Heluf, 2003). Current fertilizer recommendations that deal with N and P dosage only, are at least 15 years old, and are largely standardized. It was blanket, which is not site-specific and soil test based but based on out dated very general rate over the whole country. Therefore, differences in soil types must be considered if investments from farmers are to be expected in land improvement and other production enhancing activities in a sustainable way in a country like Ethiopia in general and in the study area in particular. Thus, more research needs to be carried out at a granular, actionable level and sustainable land use management options have to be set and applied. Therefore, the objectives of this study are:

- ➢ To assess and map the fertility status of soils of the study area based on physiographic land units and selected physicochemical properties.

3. MATERIAL AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study was conducted in Becheke sub-watershed in Haramaya district, which is situated in the eastern part of Ethiopia. It lies between $9^0$22' 03"_ 9^0 27' 12" N and 41^0 58' 14" _ 42^0 05' 26" E (Figure 1). Haramaya district is situated between Addis Ababa and Harar city, at a distance of 505 km from Addis Ababa and 20 km north-west of Harar city and the altitude of the studied sub-watershed ranges between 2073 and 2270 m.a.s.l.

3.1.2. Climate

Agro-ecologically the area is classified as semi-arid tropical belt of eastern Ethiopia and is characterized by a sub-humid type of climate. Data recorded from meteorology station located at Haramaya university, indicates that, the mean annual (2005-2014) rainfall of the area is about 839.9 mm. The study area is characterized by a bimodal rainfall distribution pattern. The short rainy season locally, called *Badheessa,* usually starts in March and extends to May, while the main/long rainy season, called *Ganna,* stretches from end of June to September (Kibebew, 2014). The mean monthly, minimum temperature range between 3.2 (in December) and 14.2°C (in January), while maximum range between 22.5 (in December) and 26.2 °C (in May), respectively (Figure 2 and Appendix Tables 3).

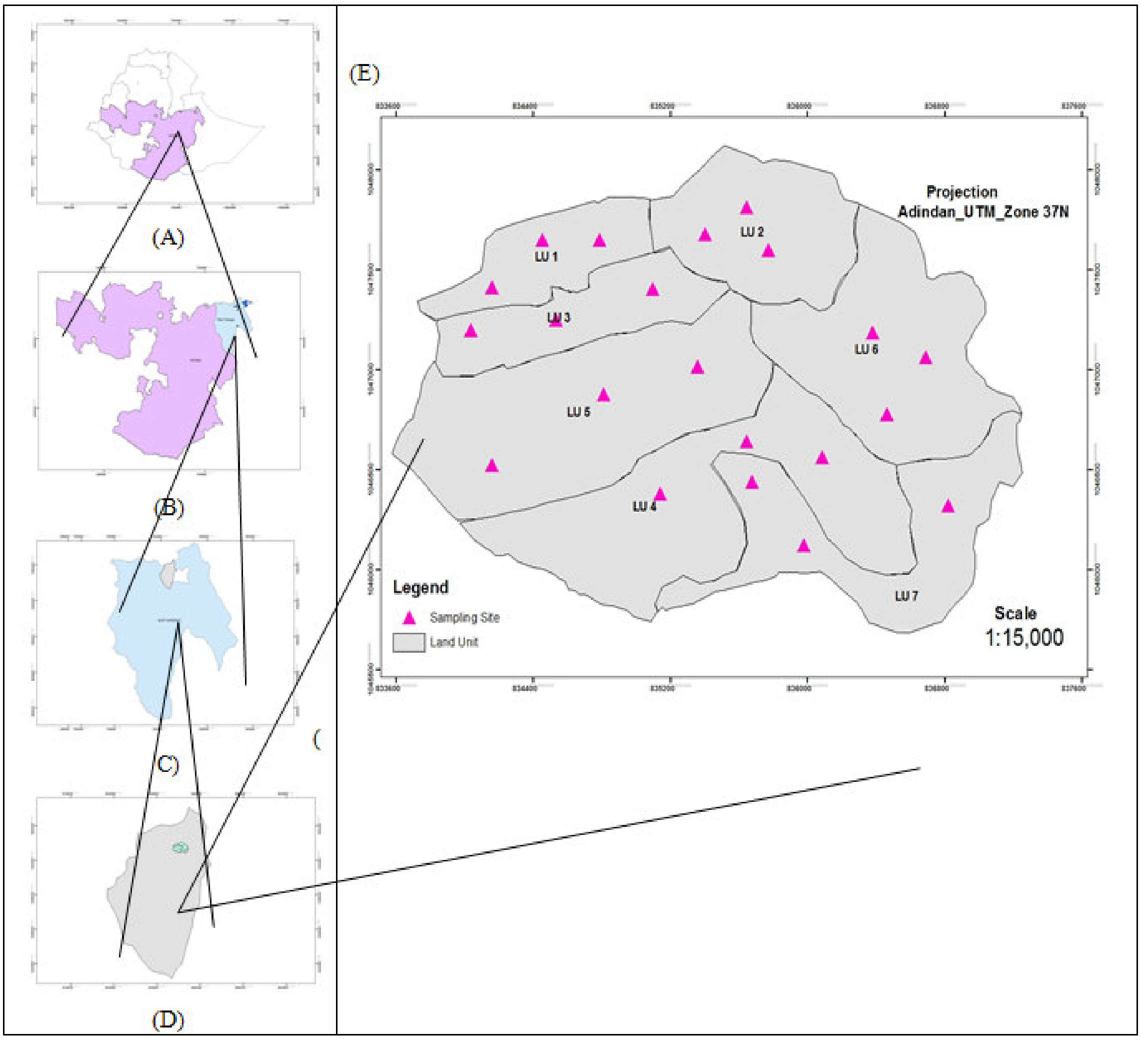


Figure1. Location map of the study area: (A) Oromia Region in Ethiopia, (B) East Hrarghe Zone in Oromia Region, (C) Haramaya District in East Hrarghe Zone, (D) Becheke Sub-Watershed in Haramaya District, and (E) Becheke Sub-Watershed.

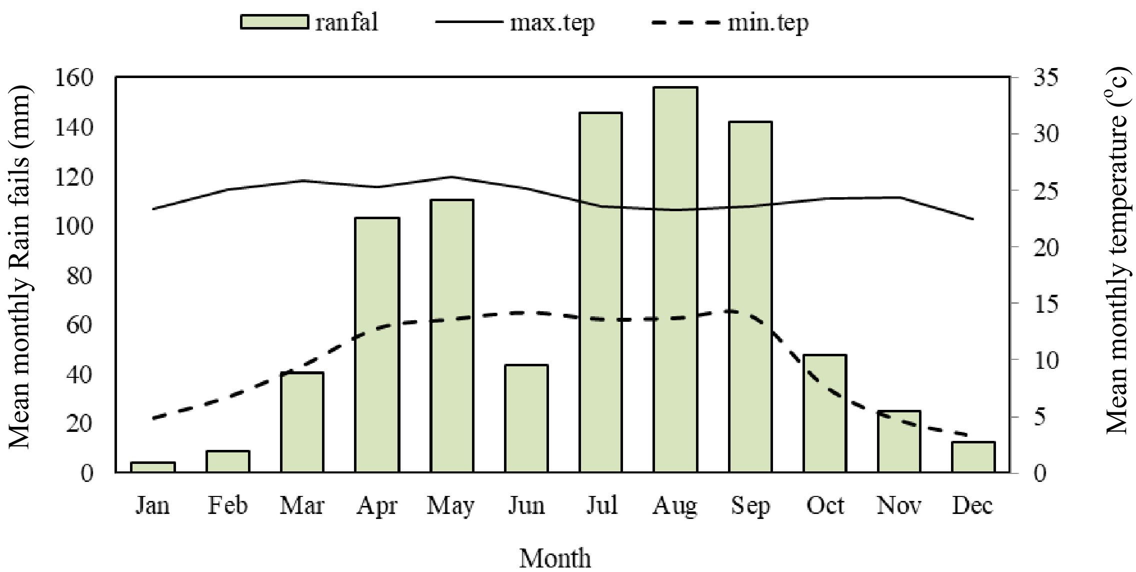


Figure 2. Mean (2005 - 2014) monthly rainfall, monthly maximum and minimum temperatures of the study area based on the records at Haramaya University Meteorological station.

3.1.3. Soils and geology

The Hararghe Zone is generally overlain by limestone and sandstone deposits which began during the Triassic period of the Mesozoic era and during the Jurassic and Cretaceious Period of the same era (Heluf and Yohannes, 1997). According to Solomon (2002) the Highlands, including Lake Haramaya Watershed, lie over the crystalline bedrock of prehistoric Gondwana continent, which became fractured at a much later time. The hard rock's of the Gondwana continent, granite and genesis, formed the Precambrian lay as pen plains below sea level for a longer period resulting in the deposits of very ancient sedimentary rocks in the eastern region. The Precambrian metamorphic rock, granite and to a lesser extent genesis and mica schists, are particularly exposed on the surface throughout Haramaya Watershed area (Tamire, 1986). The steeper slopes have a large rounded boulders of granite rocks exposed on the surface. This is a clear indication of severe erosion that has washed away the surface soil and exposed weathering granite boulders on the land surface. KEC (2005) identified three different types of rocks in the catchment area. These include the unconsolidated sediment which covers 17 km^2 of the watershed, Mesozoic (intrusive and extrusive igneous rocks formed during Mesozoic era) and Precambrian rocks consist the rest 33.3 km^2.

The major soil types identified by Tamire (1986) include Lithosols, Regosols, Cambisols, Vertisols, and Fluvisols. These soils form a typical toposequence in which the Lithosols and Regosols occupy mostly the steeper slopes, while the other soil types occur in the gentle to low-lying landscapes of the watershed.

3.1.4. Land use/cover

Becheke sub-watershed is covered mainly by Bushes of various species, shrubs, Acacia (*Acacia abssinica)*, Junipers and *Olia europaea* and they are scattered in the area, while *Eucalyptus globules* and *Eucalyptus camaldulensis* are found around homesteads. The farming system is mixed crop-livestock production. Nevertheless, due to chronic feed shortage and land for grazing livestock, the population of livestock in the district as a whole and the sub-watershed in particular is very small. The major cereals grown are sorghum (*Sorghum bicolour*) and maize (*Zea mays*) often intercropped with legumes, such as haricot bean (*Phaseolus vulgaris*). Khat (*Catha edulis*) is the main cash crop grown in the study area. Some vegetable crops, such as potato and onion (*Alluim cepa L.*) are grown in the dry season at the lower valley of the watershed where underground water is available for irrigation. The irrigation water source is dominantly traditional hand-dug well developed by the farmers themselves. The main livestock in the area are cattle, donkey, sheep, goat and poultry. Livestock are used as source of food (meet, milk, and milk products), while manure is used for soil fertility maintenance. Through sell of milk and milk products, and live animal, livestock is also a major source of cash for farmers of the study area. On almost all farmlands, terracing and bunding are very common soil and water conservation practices.

3.2. Site Selection, Soil Sampling, and Preparation

Assessment of fertility status of soils of the study area was carried out during 2015/2016 cropping season after crop harvest through examination of selected physical and chemical properties of soils representing different land units. Field data collection and soil sampling were carried out with the help of topographic map of the study area. At the beginning, a preliminary field observation was carried out using the topographic map (scale 1:50000), map sheet numbers of 0942C1, and 0941D2 obtained from the Ethiopian Mapping Agency. Prior to the actual field work, tentative sampling sites (SS) were fixed on the topographic map on the basis of topography of the area.

Based on the field observation, the study area was divided into different land units according to their difference in terms of land use type, surface soil color, altitude, slope gradient , surface land features, and to a lesser extent soil management practices and fertilizer use in previous year. Accordingly, a total of 7 land units were identified and their boundaries demarcated. The peculiar land uses/covers of the identified mapping units is as described below: Land units 1, 2, 3 and 6 were slopping, rain-fed cultivated for production of, mainly, sorghum and maize. Land units 4 and 5 were gently sloping, irrigated lands for which predominantly potato and onion after rain-fed crop harvest are planted, while LU 7 is strongly sloping, virgin land of bushes, shrubs, *Acacia,* and *Junipers and* not cultivate for long years (Table 1).

Table1. Physiographic characteristics of each land units of study area.

LU	Land use	Surface soil color (dry)	Average Altitude(masl)	Average slope (%)	Major crop	Fertilizer used
1	RF.culti.	LB (7.5YR 6/3)	2150	8	Sorghum	DAP, Urea, FYM
2	RF.culti.	LRB (5YR 6/4)	2163	9	Sorghum	DAP, Urea, FYM
3	RF.culti.	RB (5YR 4/3)	2145	6	Sorghum	DAP, Urea, FYM
4	Irrg.culti.	B (7.5YR 4/4)	2132	4	Onion	DAP, Urea, FYM
5	Irrg.culti.	DB (7.5YR 3/2)	2073	3	Potato	DAP, Urea, FYM
6	RF.culti	YR (5YR 4/6)	2147	6	Maize	DAP, Urea, FYM
7	Virgin land	DB (10YR 3/3)	2270	12.5	Shrubs, Bushes Acacia, Junipers	-

Where; RF.culti= rain-fed cultivated, Irrg. culti= Irrigated cultivated, LB= light brown, LRB= light reddish brown, RB= reddish brown, B= brown, DB= dark brown, YR= yellowish red, FYM= Farm yard manure

Top soil color, slope gradient, topography, and altitude difference were specifically considered for delineating the cultivated land units, and the data were recorded and presented in Appendix Tables 1 and 2. Besides these, soil management practices (type of fertilizers used, dominant previous and current crop) in the study area were also recorded by assuming that these can also be source of spatial soil fertility variation. Once the representative LUs were identified on the map and then, during field observation, description of sampling sites (SS) and soil sample collection were carried out for each land units. After delineating the land units, three replications within each land unit were demarcated from which composite surface soil samples at 0-20 cm depth for cultivated land and virgin land units were collected. To make one composite sample, 12 to 25 sub-samples from each replication of each LU were taken in a zigzag pattern based on the complexity of topography and heterogeneity of the soil type.

The total composite samples collected from the 7 land units were 21. During collection of sub-samples, maximum care was taken to address variability of the surroundings in terms of the dominant topography and soil type, so that for those landscapes having uniform topography and homogenous soil type (basically almost similar surface soil color and management practices), a minimum of 12 sub-samples were collected from each replication. Under undulating topography where slope varies in short distance and heterogeneous soil type exist; the numbers of sub-sampling points were extended up to 25.

Elevation, latitude and longitude of the study area were recorded using Garmin GPS 60; while slope gradient was measured using clinometers. Edelman soil auger marked at 20 cm, labeled plastic bag, a permanent marker and buckets were used during sampling. Sampling equipment and buckets used to collect and mix-up soil samples were kept clean. The color of the soils of the study area was recorded in the dry condition using the notations for Hue, Value and Chroma as given in the Mussel Soil Color Charts (KIC, 1994). Hue is the dominant spectral color (red, yellow, green, blue or violet), value is the lightness or darkness of color, and Chroma is the purity or strength of color.

Until soil samples were taken to laboratory, they were air dried by spreading them out in air on a clean plastic sheet. Each sub-sample taken from each sampling point per each land unit was thoroughly mixed in a plastic bucket. After mixing, approximately 1 kg of the composite sample was transported to laboratory for analysis with proper labeling on each sampling bag. Then, each composite sample was air dried, crushed and passed through 2- mm sieve for the determination of most of the soil fertility indicators except for total nitrogen and organic carbon which were passed through 0.5 mm sieve. Following sample preparation, the selected soil physical and chemical properties were analyzed at Haramaya University Soil Science Laboratory.

3.3. Laboratory Analysis of Soil Properties

3.3.1. Analysis of soil physical properties

Soil particle size distribution was analyzed using the Bouyoucos hydrometer method (Bouyoucos, 1962). Soil bulk density, from undisturbed soil samples, was determined using the core method after drying the soil samples in an oven at 105°C to a constant weight (Black, 1965). The core sampled soils were oven dried and the bulk density (BD) was calculated by dividing the mass of the oven dry soil (g) by the respective volume (cm^3) as it exists naturally under field conditions. Total porosity was estimated from the values of BD and particle density (PD), with the latter assumed to have the generally used average value of 2.65gcm^{-3} as:

$$\text{Percent total pore space} = \left[1 - \frac{BD}{PD}\right] \times 100$$

3.3.2. Analysis of soil chemical properties

Soil pH was determined in H_2O using a 1:2.5 soil to water ratio using a digital pH-meter (Van Reeuwijk, 1993). Electrical conductivity was measured from the suspension prepared for pH analysis using electrical conductivity meter. Organic carbon of the soils was determined following the wet digestion method as described by Walkley and Black (1934) while percentage organic matter of the soils was determined by multiplying the percent organic carbon value by 1.724. Total N of the soil was determined by the Micro-Kjeldahl digestion, distillation and titration method (Bremner and Mulvaney, 1982). Available phosphorus was determined using spectrophotometer after extraction of the soil samples with 0.5M sodium bicarbonate ($NaHCO_3$) solution at pH 8.5 following the Olsen extraction method (Olsen *et al.,* 1954).

Exchangeable bases were extracted with 1N ammonium acetate at pH 7. Exchangeable Ca and Mg were measured by atomic absorption spectrophotometer (AAS), while exchangeable Na and K were measured by flame photometer (Rowell, 1994). For the determination of CEC, the soil samples were leached with 1N ammonium acetate solution and washed with ethanol (97%) to remove excess salt followed by leaching with sodium chloride to displace the adsorbed (NH^+_4). The quantity of ammonia was then measured by distillation and taken as CEC of the soil (Chapman, 1965). The percent base saturation of the soils was calculated as the percentage of the sum of the basic exchangeable cations (Ca, Mg, K and Na) to the CEC (Bohn *et al.*, 2001). Extractable micronutrients (Fe, Mn, Zn and Cu) were extracted by DTPA (Di-ethylene Tri-amine Penta-Acetic Acid) extraction method (Lindsay and Norvel, 1978) and all these micronutrients were measured by atomic absorption spectrophotometer.

3.4. Soil Fertility Mapping

Using topographic (1:50000) map and Google Earth/satellite image as a reference, location map of the study area was developed using Arc GIS 10. By recording boundary coordinate points using GPS, delineation of sub-watershed was carried out. After that, the respective coordinate points marked using GPS were fed into the GIS environment; then, polygons for the watershed and for each LU were created by digitizing the recorded boundary points. The area of each LU was estimated from the created polygons using Arc map 10. Based on soil laboratory analyses results, soil fertility indices were generated and ratings were made; and the soils were classified in to different fertility categories, i.e., very low, low, medium, high and very high on the basis of the content of each selected soil parameters. The status of each mapped soil fertility parameters were identified for each LU. For each fertility classes, different symbol colors and patterns were selected from symbol selector of Arc Map 10. Finally, fertility status of each LU in the study area was mapped by using the respective legend symbols. Selected soil fertility parameters which were mapped are soil OM, total N, available P, CEC, exchangeable Ca, exchangeable Mg, and DTPA micronutrients (Fe, Cu).

3.5. Statistical Analysis

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 to critical values for the selected physicochemical properties.

4. RESULTS AND DISCUSSION

4.1. Physiographic Characteristics of the Study Area

Soil color, altitude, slope gradient, topography, land use type and soil management history were considered as the physiographic characteristics of the study site. Land units 1, 2, 3 and 6 were rain-fed cultivated for production of, mainly, sorghum and maize. Land units 4 and 5 were irrigated land for which predominantly potato and onion while LU 7 is virgin land of bushes, shrubs, *Acacia, and Junipers*. Land unit 7 and 5 have average maximum (2270 m.a.s.l) and minimum (2073 m.a.s.l) altitude, respectively.

Soil color of the study area under dry condition varied between reddish brown (5YR 4/3) in LU 3 to dark brown (10YR 3/3) in LUs 7 (Appendix Table 1). In the study area, generally the surface soil color patterns showed variation in relation to position in the landscape, slope, altitude, OM content and other soil chemical composition (especially, Fe content).The reddish brown color in LU 3 might be as a result of oxidation state of Fe. In line with this, Foth (1990) reported that, reddish soil color is due to the presence of iron compounds in various states of oxidation. Dark brown color in LUs 5 and 7 could be attributed to the effect of relatively higher OM content (Appendix Table 1).

Slope is one of the components of physiographic factors that influences drainage, runoff and erosion processes; and through these processes it results in spatial soil fertility difference. The average slope gradient of the LUs in the study area varies from 3 to 12.5%. According to FAO (2006b) slope gradient classification, land units 4 and 5 are gently sloping (2-5 %), while land units 1, 2, 3 and 6 are sloping (5-10%). On the other hand, land unit 7 has strongly sloping (10-15 %) nature. The topographic features, the physical appearance of the natural features of an area of land, of each land unit are presented in Appendix Table 1. Based on these data, the study area is characterized by having flat plain with long smooth slopes of 2 – 3 % (LU 5), undulating with short slope of 1-8% (LUs 1 and 2), gently sloping plain with long smooth slopes of 4 - 8 % (LUs 3,4 and 6) and strongly sloping plain with long smooth slopes > 8 % (LU 7).

4.2. Soil Physical Properties

4.2.1. Soil texture

The data revealed that, According to USDA soil texture classification system, two soil textural classes were observed in the study area. Soil textural classes of all land units of the study area were sandy clay loam except in LUs 1 and 2 which are sandy loam (Table 2). Accordingly, the lowest sand content (47.29%) was recorded on land unit 5, while the highest sand content (71.73%) was observed on land unit 2. On the other hand, the lowest silt (9.72%) and clay (18.55%) content are recorded on land units 2, while the highest silt (18.42%) and clay (34.29%), content are recorded in land unit 5. Generally, sand size fraction followed by clay fraction dominates the study area. The textural classes recorded in soils of almost all the land units imply that, under natural conditions, the soils have good drainage. On the other hand, the high sand proportion may suggest relatively poor water retention capacity, which may make successful rain-fed agriculture difficult particularly under conditions of erratic rainfall.

The slight difference in sand, silt and clay content among the land units could be related to variations in topography, slope, land use and management practices. Similarly, Thangasamy *et al*. (2005) reported that variation in soil texture may be caused by variation in parent material, topography, in situ weathering and translocation of clay. Soils of lower elevation site had higher clay content than higher elevation. In agreement with this, Sitanggang *et al*. (2006) reported that textural variations in Shikohpur watershed area are mainly associated with variation in parent material and topography.

4.2.2. Bulk density and total porosity

The values of bulk density and total porosity for the land units are presented in Table 2. The results of this study revealed variation in soil bulk density among the land units. Relatively the highest (1.59 gcm^{-3}) was observed on LU2 and the lowest (1.32 gcm^{-3}) was observed on LU 7, which are found in rain-fed and virgin land unit, respectively. The variation among the land units could be due to the difference in clay content and organic matter, both of which affect total porosity. This means that land units with high content of clay and organic matter have lower bulk density than those land units with low OM and clay content because of greater pore space associated with high OM and clay contents. The relatively lowest value of bulk density in land unit 7 (1.32 gcm^{-3}) could be due to the high OM, high porosity and less disturbance of the soil by erosion process, as this land unit has vegetation cover. However, the reverse is true for land unit 2 (Table 2).

The bulk density of the studied soils at the depth of upper 20 cm were found to be less than 1.61 g cm^{-3}, which is common and acceptable for sandy loam and sandy clay loam soils (Amusan *et al*., 2001). Therefore, the bulk density is ideal for root activity, water infiltration into soil, and overall growth of crops, and indicates that the soils of the study area are not compacted. Based on the critical level given by Hazelton and Murphy (2007), the soil bulk density of the current study area was moderate (Appendix Table 4).

The total porosity of the soils, in general, varied with bulk density (Table 2). Accordingly, the percent total porosity of all the land units was high (15-40%) to very high (> 40%) according to the FAO (2006b) rating. Total porosity increases as the bulk density decreases while it decreases as bulk density increases. The lowest (40%) and highest (50.19%) total porosity values were observed in the rain-fed land (LU2) and virgin land d(LU7) units, respectively. The higher values of total porosity corresponded to the higher amount of organic matter contents and lower bulk density value. This is in line with report by Mohammed (2003) for soils of Jelo sub-catchment in the Chercher highlands, while Wakene (2001) reported that the low total porosity was the reflection of the low organic matter content around Bako area.

Table2. Selected soil physical properties of different land units in Becheke sub-watershed

Land units	Particle size distribution (%)			Textural class	BD(gcm^{-3})	Total porosity (%)
	Sand	Silt	Clay			
1	69.25	11.64	19.11	Sandy Loam	1.58	40.50
2	71.73	9.72	18.55	Sandy Loam	1.59	40.00
3	64.36	10.85	24.79	Sandy Clay Loam	1.52	42.77
4	51.37	15.34	33.29	Sandy Clay Loam	1.41	46.67
5	47.29	18.42	34.29	Sandy Clay Loam	1.36	48.68
6	61.31	13.18	25.51	Sandy Clay Loam	1.53	42.14
7	61.33	11.59	27.08	Sandy Clay Loam	1.32	50.19

Where; BD= bulk density

4.3. Soil Chemical Properties

4.3.1. Soil reaction (pH) and electrical conductivity

The soil pH values ranged from 6.04 to 7.17 (Table 3). As per the rating established by Tekalign (1991) (Appendix Table 5), the soil reaction can be rated to range from slightly acidic to neutral. The highest and the lowest pH values were recorded in LUs 7 and 2. Accordingly, soils of land units 5 and 7 qualified for the neutral range, while the remaining land units fall under slightly acidic soils range. The highest value of pH in virgin land unit might be associated with limited removal of basic cations by erosion since the land unit was covered by vegetation. The relatively lowest pH value recorded for soils of rain-fed land units, on the other hand, might be attributed to the effects of continuous cultivation, which might have exposed the soils to erosion removal of basic cations as well as their removal from the field via crop harvest. These results are in agreement with those of several others (Gebeyehu, 2007; Papiernik *et al.,* 2007; Habtamu *et al*., 2009; Fantaw and Abdu, 2011) who reported a substantial reduction of pH in surface soils subject to long-term cultivation compared to the uncultivated site.

Regardless of the differences observed in soil pH among the land units, the pH values recorded in the sub-watershed are within the range that are quoted as suitable for production of many crops, for these ranges represents pH values that are ideal for availability of most of the essential nutrient elements and proper functioning of most beneficial soil microorganisms. In agreement with this, Landon (1991) pointed out that most nutrients for field crops are available at pH values of more than 5.5 and less than 7.

Relatively the lowest electrical conductivity (6.3µs/cm) was recorded for soils of land unit 2, whereas the highest value (9.74µs/cm) was recorded on land unit 7. The electrical conductivity of soils of all land units was, however, categorized under low according to Landon (1991). The lowest EC value recorded for soils of land unit 2 could be attributed to the removal of basic cations through erosion with soil and runoff from the relatively sloping land, whereas the highest EC of land unit 7 could be attributed to accumulation of the basic cations because of the vegetation cover as well as low erosion and low disturbance.

Generally, low electrical conductivity recorded in all the land units could be related to the intensive weathering associated with the high rainfall of the area, which removes basic soluble cations by leaching and/or erosion from these soils. This finding is in agreement with the work of Abebe and Endalkachew (2012) who reported that electrical conductivity of soils declined with high amount of rainfall.

4.3.2. Soil organic matter, total nitrogen, and C: N ratio

Similar to the other soil parameters discussed so far, the organic matter content of soils in the sub-watershed showed spatial variation (Table 3). Across the land units, it ranged from 1.02% in LU 2 to 3.92% in LU 7. Following organic matter rating suggested by Tekalign (1991) (Appendix Table 5), the organic matter content of soils in the sub-watershed ranged from low to medium. Accordingly, except LU 7, soils of all the other land units were low in their organic matter content.

The most probable source of variation in OM contents among land units might be variation in altitude, intensity of cultivation, cropping system and soil management practices. The highest OM contents of LU 7(the virgin land) might be due to the contribution of vegetation cover and lower OM decomposition rates. On the other hand, the low levels of OM in the soil of land units of rain fed and irrigated land might be attributed to continuous cultivation with complete removal of crop residue and limited application of farmyard manure**.** This was in line with the findings of several authors (Duff *et al*., 1995; Grace *et al*., 1995). The intensive cultivation is expected to aggravate rapid oxidation of the small amount of organic matter returned to soils of the cultivated lands. Furthermore, total removal of crop residues for other purposes, such as animal feed, fuel, cash, and construction, is a common practice in the study area. In consent with the findings in this study, Wakene and Heluf (2003) and Alemayehu and Sheleme (2013) demonstrated that intensive cultivation results in rapid oxidation of soil organic matter. Furthermore, the total removal of crop residues for animal feed and as source of energy was reported as being among the main reasons for low organic matter content in soils of Ethiopia by Sheleme (2011). Yihenew (2002) also confirmed that most cultivated soils of Ethiopia are generally poor in organic matter content.

On the other hand, regarding with cultivated land units only, relatively higher content of OM was recorded in soils of land units 5 (1.88%) and 4 (1.51%). This might be due to the fact that both land units were irrigated lands with repeated uses of fertilizers for production of vegetables during off season and their relatively level to gentle slope gradient (Appendix Table 1) where the soil moisture storage is better, resulting in better biomass production. Furthermore, the expected impeded drainage related to topography could also slow down the decomposition process. This result is in agreement with the work of Abebe and Endalkachew (2012) in Nitisol of Southwestern Ethiopia.

For relatively coarse textured soils of high sand content, addition of organic matter would help in improving their poor water retention capacity. The findings of this study, unfortunately, imply that the low level of organic matter in these soils is not high enough to improve their major problem, poor water retention, for successful rain-fed crop production. A scenario for improving organic matter level of these soils must be put in place.

Table 3. pH, electrical conductivity, organic matter, total nitrogen, C: N ratio and available phosphorus of soils of different land units.

Land units	pH(H_2O)	EC (µs/cm)	OM (%)	TN (%)	C:N ratio	Av.P (mg/kg
1	6.15	7.72	1.16	0.081	8.29	10.68
2	6.04	6.3	1.02	0.064	9.24	10.67
3	6.31	9.13	1.27	0.098	7.51	11.51
4	6.53	7.43	1.51	0.14	6.27	20.72
5	6.72	6.66	1.88	0.16	6.83	24.55
6	6.52	8.62	1.41	0.11	7.39	14.95
7	7.17	9.74	3.92	0.18	12.54	20.29

Where; EC =electrical conductivity, OM =organic matter, C: N =carbon to nitrogen ratio, Av.P = Available phosphorous

Total N content of the soils in the study area followed similar trend as that of OM (Table 3). It generally increased from land units of rain-fed farmlands through irrigated to virgin land uses, which was the highest. The average total N content ranged from 0.06% in LU 2 to 0.18% in LU 7. On the basis of the rating suggested by Tekalign (1991) (Appendix Table 5), soils of land units 1, 2, 3 and 6(all land units of rain fed agriculture) were found to be low, while land units 4, 5 and 7 (all land units of irrigated and virgin lands) were found to be moderate in average total N content. The comparatively high total N content of soils of land units 7 could be attributed to the relatively high OM content of this land unit, for about 95% of the total nitrogen comes from organic matter (Landon, 1991).

The lower total soil N in most parts of the study area in general could be as a result of cereal based continuous cropping that often returns limited organic source to the soil whereby the continuous cultivation exacerbates the rapid decomposition of this low amount of OM input into the soil system. Lower external N inputs (like plant residues and animal manures) and N (nitrate ions) leaching problem as a result of higher rainfall during summer also contribute to lower total N content in soils of the study area. This finding is in agreement with the research finding of Solomon *et al*. (2002) who reported low level of total N in soils of cultivated land.

Although total nitrogen determination hardly indicates the adequacy of N for successful crop production, soils of the study area are expected to experience nitrogen deficiency. This is so because organic matter, through mineralization, contributes to the available forms of N (NO_3 N and NH_4^+-N). The findings of the study, therefore, clearly indicate that nitrogen-containing fertilizers, mineral or organic sources, should be applied to soils for sustainable crop production.

Carbon to nitrogen ratio(C:N) is an index of nutrient mineralization and immobilization whereby low C:N ratio indicates higher rate of mineralization and higher C:N ratio indicates greater rates of immobilization (Brady and Weil, 2002). The highest C:N ratio was obtained in LU7, while the lowest was recorded in LU4 (Table 3). According to C:N ratio rating suggested by Landon (1991), the C:N ratio ranged from very low (<8) in land units 3, 4,5, and 6, low (8-10) in land units 1 and 2 to medium (10-15) in land unit 7. In effect, the lower the value, the higher is the proportion of N in organic matter (i.e. high quality organic matter) and the more the accumulation of NH_4^+ which stimulates more mineralization. Soils with high values of C:N ratios have organic matter with relatively high lignin and other hard substances that are resistant to decomposition (Olowolafe, 2004).

4.3.3. Available phosphorus

Among the land units, high variability in available P was observed (Table 3). The highest and the lowest concentrations of available P were recorded for land units 5 and 2, respectively. This variability in soil available P content might be the result of different soil management practices, specifically, type and rate of organic fertilizers and rate of inorganic fertilizers utilized in cultivated land units. Besides these factors, variation in parent material, soil texture, degree of P-fixation, soil pH and slope gradient, which can cause downward movement of P with runoff water from top slope and accumulation at the bottom slope, may also contribute for the difference in available P. Moreover, the development agents and farmers of the study area pointed out that DAP application for two seasons a year in irrigated land units were common practice to increase yield. This practice might have contributed to relatively higher available P in soils of irrigated land units.

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. Nevertheless, based on rating suggested by Cottenie (1980) (Appendix Table 5), the available P of the soils of LUs 1, 2, 3 and 6 were medium and the available P of the soils of the other land units (land units of irrigated and virgin lands) was high. Those land units with high available P may not require immediate application of P from external sources. Those that are within the moderate range of available P may require application of P-containing sources of either organic or mineral nature. These highest available P could be due to the application of Di-ammonium Phosphate (DAP) fertilizer twice in a year on the same plot of land in the irrigable lands but once in a year on the land units of rain fed land units and variation in OM content of the soils (Haile and Muktar, 2014)

The lowest P content in land unit 2 could be due to sloping nature of land, which may result in erosion removal of substantial amount of available P from the surface layers. Relatively the sandy nature of this land unit combined with the inherent characteristics of the parent material and relatively lower pH could also be the other causes of lower available P content. The results of this study are in agreement with the findings of Sanchez *et al.* (1997) that P is limiting nutrient in many sandy soils of the semi-arid tropics and in acid, weathered soils of the sub humid and humid tropics.

4.3.4. Cation exchange capacity

The CEC of the soils in the study area ranged from 24.85 to 42.31 (Cmol (+)/kg) (Table 4).As per CEC rating indicated in Hazelton and Murphy (2007) (Appendix Table 6), the CEC of soils under the different land units varied from medium to very high. Very high CEC were recorded in soil of land units 5 and 7; high CEC were recorded in land units 1, 3, 4 and 6, while medium CEC were found in soils of land unit 2.

The variation in CEC values of the studied soils might be the result of observed differences in OM and amount of clay, and soil management practices (intensity of cultivation). The intensive cultivation in the study area, for instance, might have reduced CEC indirectly through its effect on rapid oxidation of the small amount of organic matter in the soil. In line with Alemayehu (2007) and, Fentaw and Yimer (2011) reported that depletion of OM as a result of intensive cultivation contributed to lower CEC of the soils. The lowest CEC in land unit 2 was in line with the relatively low clay content under this land unit (Table 2). This is in agreement with the finding of Teshome *et al.* (2013) in soils of Abobo area, Western Ethiopia, while very high recorded CEC in LUs 5 and 7 were relatively due to high content of clay and OM respectively than other land units. This is also in consent with findings of Yihenew *et al*. (2015) who revealed that high clay and organic matter contents contributed to high CEC. This is expected since clay and organic matter are the two most important components that affect colloidal properties of soils. The CEC values recorded in the study area further indicate that the dominant clay minerals could be those of high activity clays.

Table 4. Cation exchange capacity, exchangeable basic cations and percent base saturation of soils of different land units in Becheke sub-watershed.

Land units	(Cmol(+)/kg soil)					PBS (%)
	CEC	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	
1	26.24	15.38	2.30	0.49	0.30	70.39
2	24.85	13.67	1.83	0.23	0.26	64.37
3	26.52	16.28	2.51	0.51	0.41	74.35
4	34.73	24.63	4.88	0.75	0.45	88.42
5	42.31	32.22	5.18	0.62	0.53	91.14
6	28.65	18.56	2.85	0.52	0.49	78.26
7	42.25	32.63	5.05	0.57	0.45	91.60

Where; CEC = cation exchange capacity; PBS = percent base saturation; Ex. = exchangeable

4.3.5. Exchangeable basic cations and percent base saturation

Like the variations observed in the other soil attributes, exchangeable bases in soils of different land units in the sub-watershed also exhibited spatial variations (Table 4). The exchange complex of the soils is dominantly occupied by Ca^{2+} followed by Mg^{2+}. The monovalent exchangeable basic cations (K^+ and Na^+) were low in proportion.

According to FAO (2006a) rating of exchangeable bases (Appendix Table 6), land units 1, 2, 3 and 6 were high in their exchangeable Ca^{2+}, while all the others were rated as very high in exchangeable Ca^+. Similarly, exchangeable Mg levels in soils of land units 1, 2, 3 and 6 were within the range of medium while land units 4, 5 and 7 were high (FAO, 2006a), The exchangeable K^+, on the other hand, was rated as high for LUs 4 and 5, medium for LUs 1, 3, 6 and 7, and low for LU 2. The exchangeable Na^+ was medium for all land units except land unit 2 which was low.

The variations in exchangeable basic cation content among land units could be due to variation in OM content, amount of clay, parent materials, intensity of cultivation, leaching, erosion, elevation and soil management practices (Appendix Tables 1 and 2). Relatively, the higher exchangeable Mg and K in irrigated land units and Na in land unit 5 could probably be contributed by their relatively higher clay content. While the lowest recorded K in soils of land unit 2 could be low content of OM and clay, since this land unit was slopping which expose the soils to erosion. Exchangeable Ca and Mg appear to increase in the lower elevation sites of the study area. This might be because of removal of these exchangeable basic cations by erosion from higher topography and their subsequent accumulation in the lower elevations.

Generally from soil fertility point of view, exchangeable Ca and Mg fall in the range of medium to very high, this suggests that soils in the study area might not be deficient in these essential mineral nutrients. On the contrary, soils of land unit 2 might be deficient in K and, thus, require application of K-containing external inputs. The availability of basic cations to plants can also be affected by their relative abundance. In the studied soils, the Ca: Mg ratio ranged from 5 to 7. Based on suggestion made by Eckert (1987), the two are present in balanced amount in land unit 4. In the other land units, the ratio shows that Mg could be deficient due to excess exchangeable Ca^{2+}. It means that this excess exchangeable Ca^{2+} can inhibit uptake of Mg by plants from the soil system and, thus, cause Mg deficiency in plant tissue.

In accordance with variations in exchangeable bases and cation exchange capacity, PBS of the soils also varied among the land units in the sub-watershed (Table 4). Accordingly, it varied from 64.37% in LU 2 to 91.60% in LU 7. These values, according to rating indicated in Hazelton and Murphy (2007), were within the ranges of high to very high. It was high in land units 1,2,3 and 6 and very high in the other land units. The high base saturation in the studied soils could be attributed to the high CEC, which retains these basic cations against leaching losses. On the other hand, the relatively low base saturation recorded in soils of the intensively cultivated lands might be ascribed to loss of the basic cations through leaching, erosion removal, and crop harvest. Similar finding was reported by Singh *et al*. (1995), He*et al*. (1999), and Getachew and Heluf, (2007).

4.3.6. Extractable Micronutrients (Fe, Mn, Cu and Zn)

The values of DTPA extractable micronutrients in the soils of the study area ranged from 13.37 to 4.25 mg kg^{-1} for Fe, 20.29 to 8.14 mg kg^{-1} for Mn, 4.78 to 1.22 mg kg^{-1} for Cu, and 2.78 to 0.7 mg kg^{-1} for Zn (Table 5). According to the rating of Jones (2003) (Appendix Table 7), the contents of extractable Fe for all land units was high except LUs 2 and 7 which were medium content. Extractable Mn was medium for all land units except LU 7 which was high. On the other hand, the extractable Cu was within the range of low LUs 1, 2, 3 and, 6, and medium for LUs 4,5, and 7. Similarly, the content of extractable Zn ranged from medium in LUs 1,2 and 3, to high in LUs 4,5,6 and 7.

The variation in extractable micronutrients content might be related to the influences of soil pH, organic matter and CEC content in the soil which was variable along slope gradients. Fisseha (1992) suggested that the solubility and availability of micronutrients is largely influenced by clay content, pH, organic matter and CEC content in the soil and tillage practices. Generally speaking, the selected extractable micronutrients of the study area were medium to high except for Cu which was low in LUs 1, 2, 3 and 6(land units of rain fed agriculture lands). Therefore, Cu containing fertilizers should be applied for improving soils and crop productivity.

Table 5. Selected DTPA extractable micronutrients of soils of different land units in the study area.

Land units	Extractable micronutrients (mg/kg soil)			
	Fe	Mn	Cu	Zn
1	10.17	9.03	1.22	0.76
2	4.25	8.15	2.49	0.70
3	13.37	8.14	2.34	0.86
4	8.47	10.96	3.99	2.78
5	10.04	11.65	4.78	2.71
6	12.61	13.52	2.48	1.86
7	4.46	20.29	3.42	1.73

4.3.7. Simple correlation analysis results

Simple correlation analysis was done to determine the direction and magnitude of relationship among some soil physicochemical properties (Table 6). Accordingly sand was positively and significantly (r = 0.75**) correlated with the bulk density and negatively (r = -0.76**) with the CEC and total porosity (r= -0.75**) of the soils, while clay was positively and significantly (r = 0.78**) correlated with the CEC and total porosity (r = 0.80**) and negatively (r = -0.80**) with the bulk density.

Soil pH was found to be significantly and positively ($P \leq 0.01$) correlated with exchangeable Ca, Mg and Na. However, pH was non-significantly correlated with Fe (r = - 0.30). This is because the solubility and availability of the base forming cations increased as the pH values of the soils increased but not for the Fe. Organic matter was significantly and positively correlated with total N (r = 0.82**). 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. Total N was also significantly and positively (r = 0.79**) correlated with clay content. Available P was significantly and positively correlated with soil pH indicating that available P increased as the soil pH increased from slightly acidic to the neutral range.

Cation exchange capacity was significantly and positively correlated with OM (r = 0.78**) and clay (r= 0.78**). Simple linear correlation analysis also showed that CEC was significantly ($P \leq 0.01$) and positively associated with exchangeable bases (Ca, Mg, K and Na). Similarly, percent base saturation was significantly and positively correlated with soil pH and all the exchangeable bases. Extractable Cu, Mn, and Zn were significantly and positively correlated with soil pH, while extractable Fe did not correlate with soil pH significantly indicating that the pH range recorded in the study area does not affect availability of Fe. On the other hand, only extractable Mn was significantly and positively correlated with soil OM. Extractable Fe was significantly and negatively correlated with soil OM.

Table 6. Correlation coefficients (r) among some physico-chemical properties of soils of the studied area.

	Sand	Clay	BD	TP	pH	EC	OM	TN	Av.P
Sand	1	-0.99**	0.75**	-0.75**	-0.57*	0.11NS	-0.25NS	-0.75**	-0.94**
Clay		1	-0.80**	0.80**	0.62**	-0.01NS	0.32NS	0.79**	0.95**
BD			1	-1**	-0.92**	-0.27NS	-0.80**	-0.98**	-0.90**
TP				1	0.92**	0.27	0.80**	0.98**	0.90**
pH					1	0.53*	0.92**	0.96**	0.76**
EC						1	0.57*	0.36NS	0.01NS
OM							1	0.82**	0.52*
TN								1	0.90**
Av.P									1

Correlation matrix (Continued)

	Ca	Mg	K	Na	CEC	PBS	Fe	Mn	Cu	Zn
Sand	-0.76**	-0.86**	-0.83**	-0.84**	-0.76**	-0.86**	-0.11	-0.27	-0.89**	-0.95**
Clay	0.78**	0.89**	0.85**	0.85**	0.78**	0.89**	0.12	0.33	0.90**	0.94**
BD	-0.98**	-0.96**	-0.68*	-0.70**	-0.97**	-0.96**	0.28	-0.72**	-0.82**	-0.74**
TP	0.98**	0.96**	0.68**	0.70**	0.97**	0.96**	-0.28	0.72**	0.82**	0.74**
pH	0.91**	0.85**	0.58*	0.71**	0.9O**	0.89**	-0.3	0.92**	0.62**	0.60**
EC	0.18	0.12	0.26	0.29	0.14	0.27	-0.09	0.59**	-0.21	-0.12
OM	0.79**	0.67**	0.31	0.39	0.78**	0.69**	-0.50*	0.94**	0.4	0.29
TN	0.97**	0.96**	0.72**	0.77**	0.96**	0.98**	-0.28	0.79**	0.77**	0.76**
Av.P	0.91**	0.98**	0.82**	0.80**	0.90**	0.96**	-0.15	0.53*	0.90**	0.95**
Ca	1	0.96**	0.64**	0.72**	0.99**	0.95**	-0.32	0.73**	0.83**	0.76**
Mg		1	0.79**	0.73**	0.96**	0.98**	-0.28	0.63**	0.87**	0.87**
K			1	0.73**	0.62**	0.83**	-0.13	0.34	0.57*	0.81**
Na				1	0.70**	0.83**	0.27	0.49*	0.70**	0.80**
CEC					1	0.94**	-0.33	0.72**	0.83**	0.75**
PBS						1	-0.21	0.69**	0.82**	0.86**
Fe							1	-0.42	0.1	0.03
Mn								1	0.35	0.38
Cu									1	0.87**
Zn										1

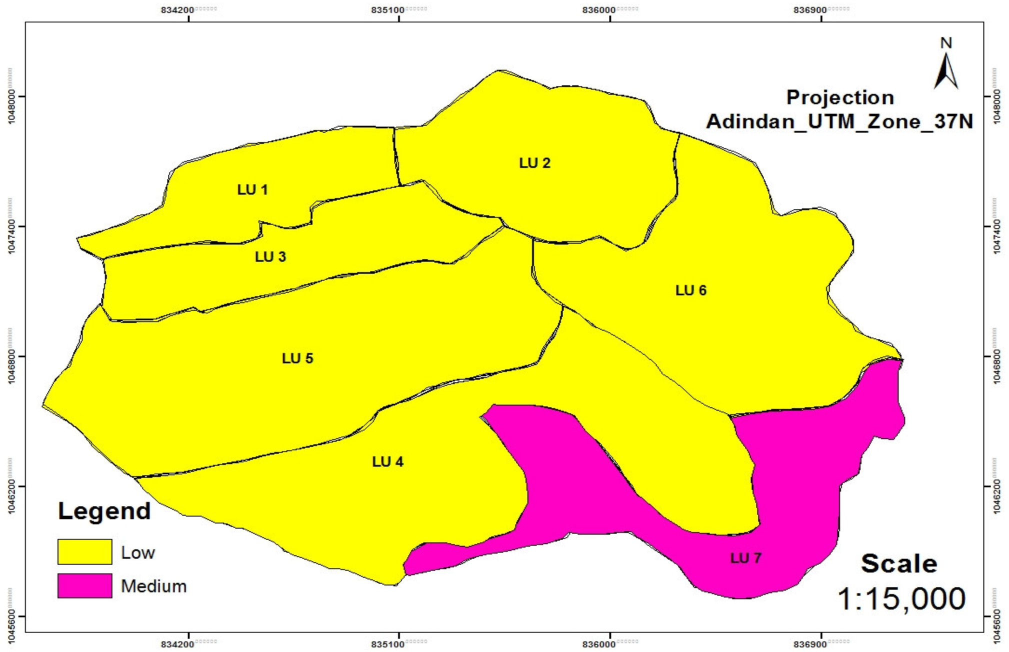
*, ** Significant at 0.05 and 0.01 probabilities, respectively

4.4. Soil Fertility Map of Becheke Sub-Watershed

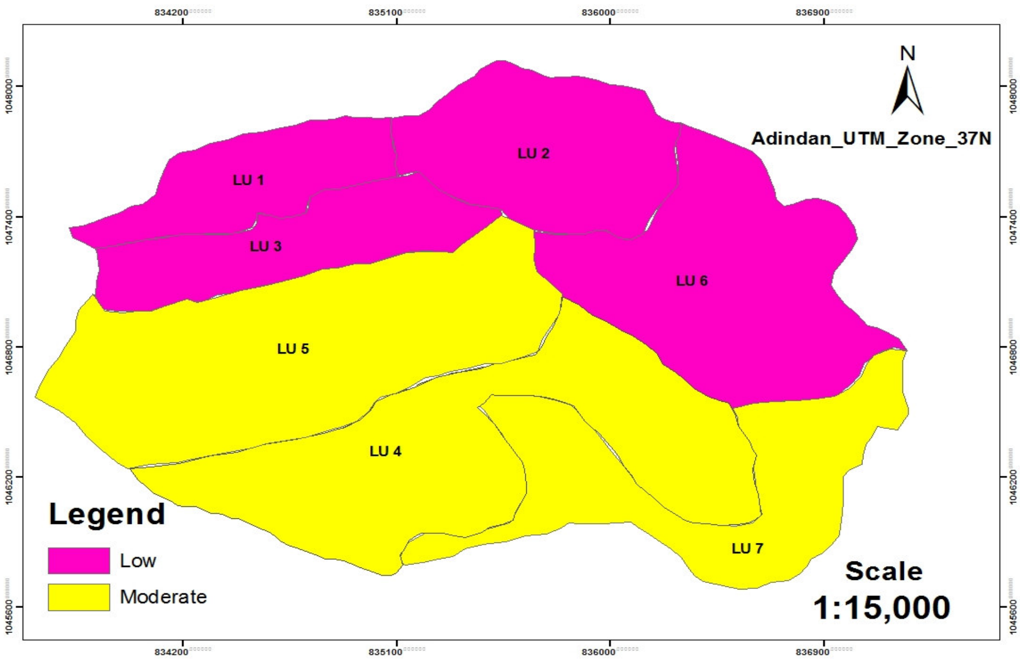
Mapping is important for showing spatial distribution and patterns of selected soil parameters to manage a watershed. Using topographic map (1:50,000) and satellite image as a reference, location map of the study area was drawn. Following study area and land unit demarcation, and soil fertility rating, fertility status of the study area was mapped. The total area covered in the soil fertility mapping is 622.21 ha. From this total area, the area coverage of land units 1, 2, 3, 4, 5, 6, and 7 is 6.74% (41.93 ha), 11.07% (68.85 ha), 8.19% (50.94 ha), 21.29% (132.49 ha), 22.27% (138.56 ha), 17.09% (106.35 ha), and 13.35 % (83.09 ha) (Appendix Table 2), respectively. Selected soil fertility parameters which were mapped include OM, total N, available P, CEC, exchangeable Ca, exchangeable Mg, and extractable micronutrients (Fe and Cu).

Mostly, the maps showed that, low OM content in the study area covers 539.12 ha (86.65%) whereas medium OM content takes 83.09 ha (13.35%). Moderate total N content covers 354.14 ha (56.92%) of the total study area of the land units, whereas low total N content takes 268.07 ha (43.08%) of the study area. The available P content of the studied soils covers 354.14 ha (56.92%) for high, 268.07 ha (43.08%) for medium status of the land units. From the total area, areas with very high, high and low CEC take 221.65 (35.62%), 331.71 ha (53.31%) and 68.85 ha (11.07%) respectively. Exchangeable Ca and Mg of the soils were categorized as high and very high for Ca and medium and high for Mg status among the land units. Accordingly, high and very high exchangeable Ca shared 268.07 ha (43.08%), and 354.14 ha (56.92%), respectively, of the total area of the sub-watershed. On the other hand, medium and high exchangeable Mg covered 268.07 ha (43.08%) and 354.14 ha (56.92%) of the total area of the land units, respectively.

With regard to extractable micronutrients, areas with medium and high extractable Fe content covered 151.94 ha (24.42%) and 470.27 ha (75.58 %), respectively, of the total area. Whereas, 268.07 ha (43.08%) and 354.14 ha (56.92%) of the total area in the sub-watershed was low and medium, respectively, in its extractable Cu content. Figures 3-6 indicate the spatial distribution of status of different soil fertility parameters considered in this study across the 7 land units.

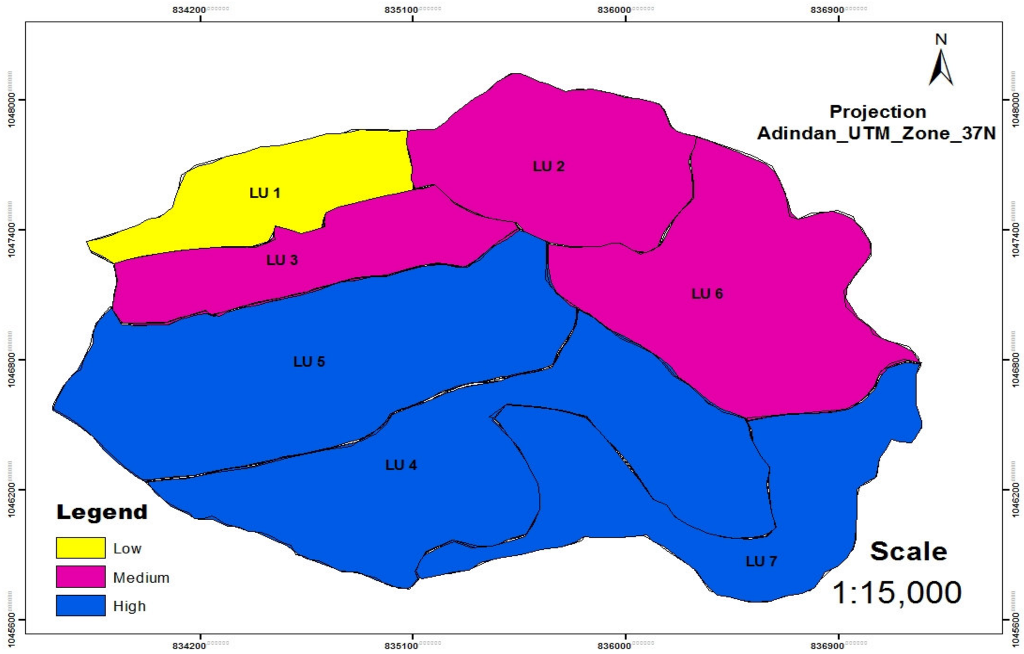


(A)

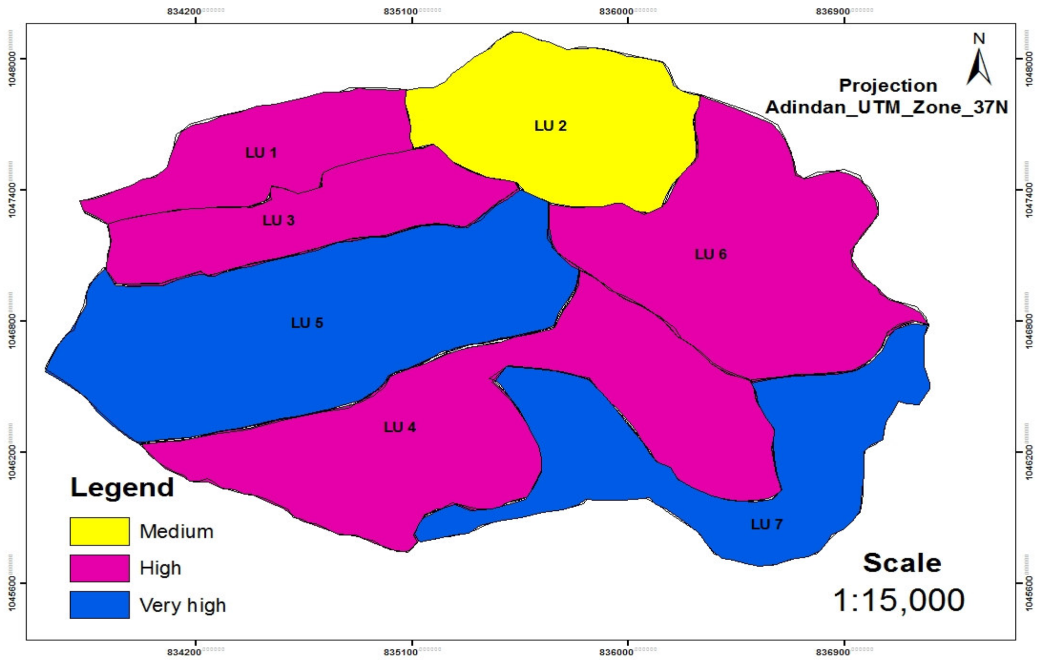


(B)

Figure 3. Spatial distribution of (A) OM (%) and (B) TN (%) in the soils of Becheke sub-watershed.

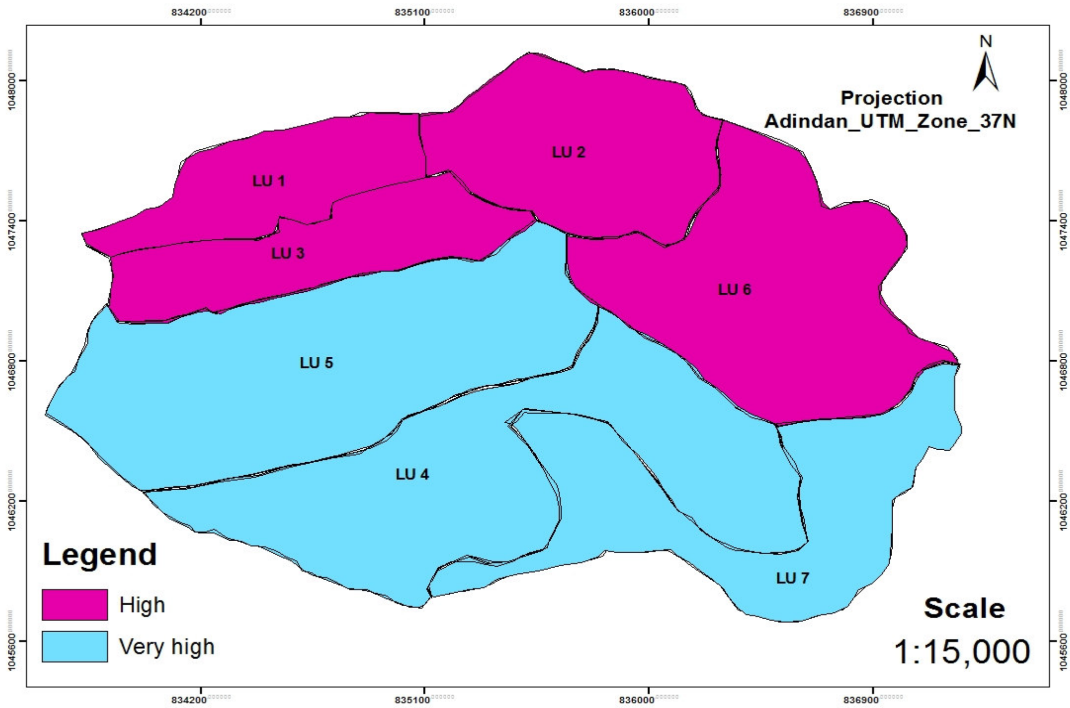


(A)

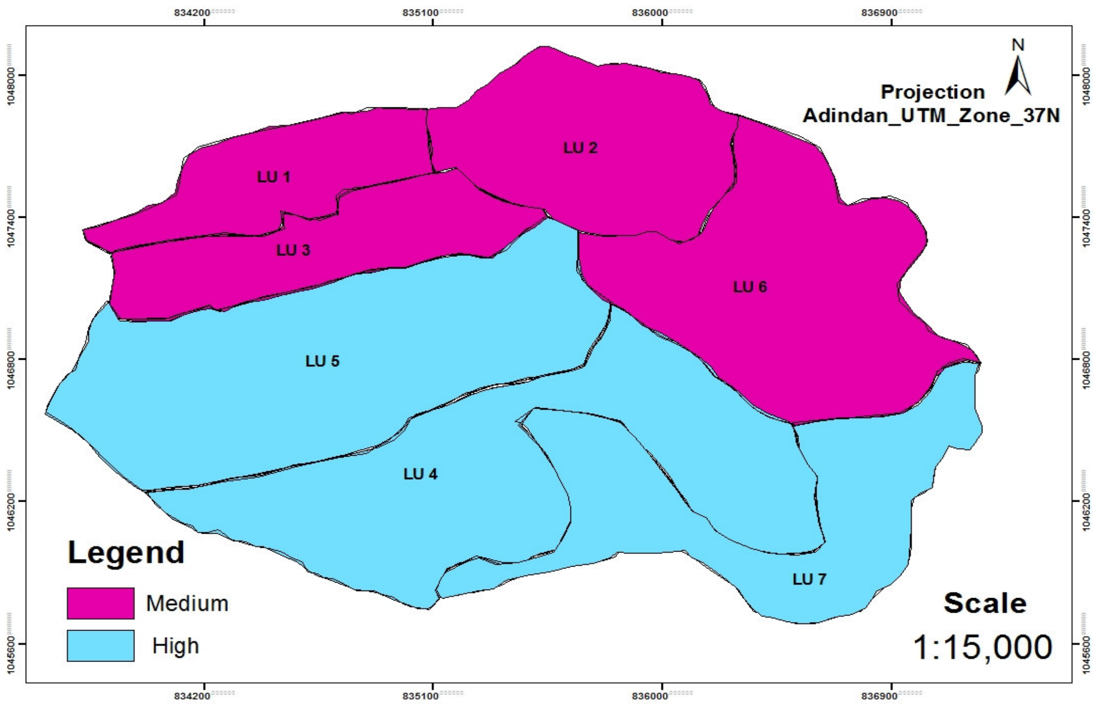


(B)

Figure 4. Spatial distribution of (A), available P (mg/kg) (B), cation exchange capacity (cmol(+)/kg) in the soils of Becheke sub-watershed.

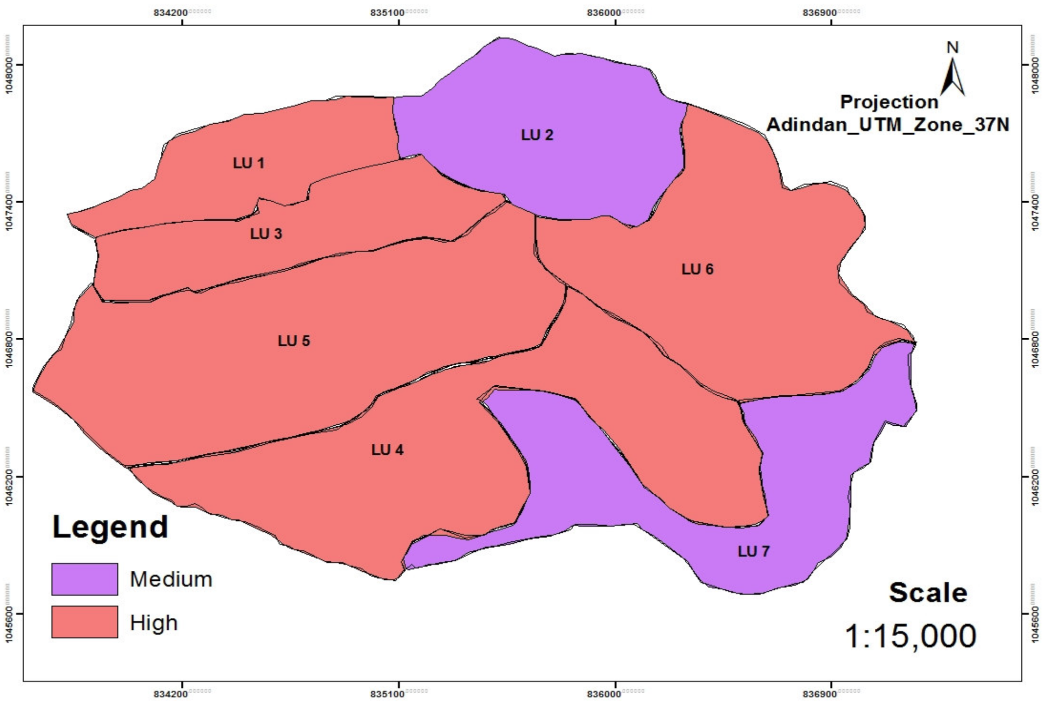


(A)

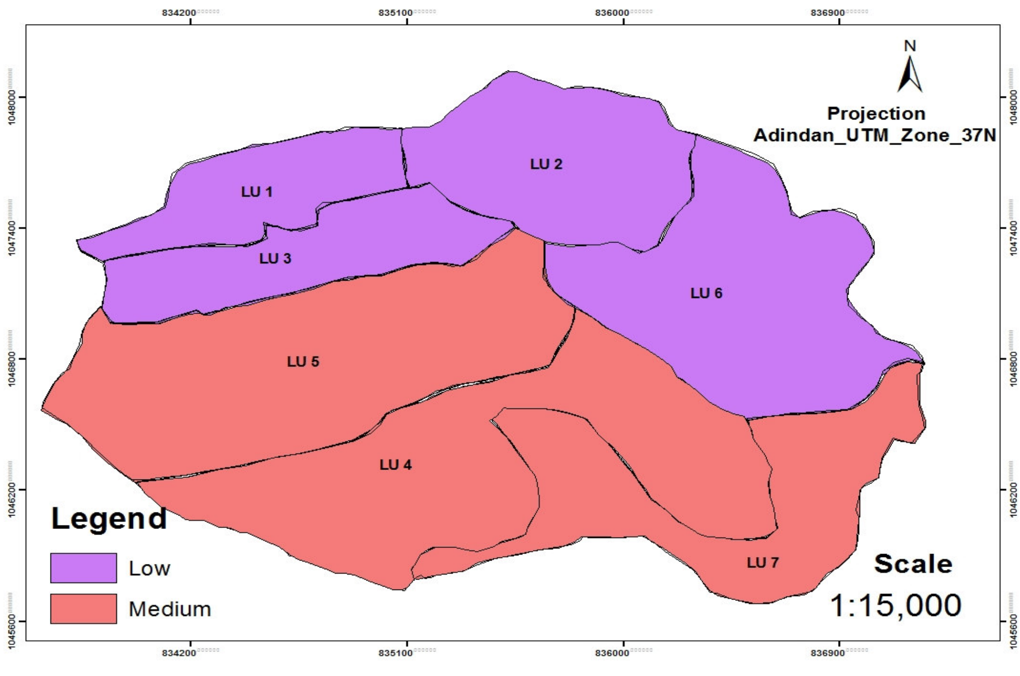


(B)

Figure 5. Spatial distribution of exchangeable bases : (A), Ca and (B), Mg (cmol(+)/kg) in the soils of Becheke sub–watershed.



(A)



(B)

Figure 6. Spatial distribution of extractable micronutrients (A), Fe and (B), Cu (mg/kg) in the soils of Becheke sub-watershed.

5. SUMMARY AND CONCLUSIONS

A study was undertaken to assess soil fertility status of soils of Becheke sub-watershed based on assess and map the fertility status of soils of the study area based on physiographic land units and physicochemical properties. Primarily field observation was undertaken in the study area. Soil color, altitude, slope gradient, topography, land use type and soil management history were used to sub-divide the sub-watershed into 7 land units. Land units 1, 2, 3, and 6 were rain fed, cultivated for production of mainly sorghum and maize. Land units 4 and 5 were irrigated lands for production of predominantly potato and onion, while LU 7 is virgin land of bushes, shrubs, *Acacia* and *Junipers*.

Soils of all land unit of the study area are sandy clay loam except land units 1 and 2 which are sandy loam textural classes. Generally, sand size fraction followed by clay fraction dominated the study area. The bulk density of the studied soils at the depth of upper 20 cm ranged from 1.32 to1.59 gcm^{-3} and was found to be within the range that is acceptable for sandy loam and sandy clay loam soils. Total porosity of the studied soils, on the other hand, varied between 40 and 50.19%, which might also indicate that the soils are porous enough for water movement and good aeration.

Soil reaction (pH) was slightly acidic to neutral in the study area and ranged from 6.04 to 7.17. These values are within the range of soil pH that is considered optimum for production of many crops. The electrical conductivity values recorded in soils under the different land units indicate that the soils are free from salinity problem currently and in the foreseeable future. Organic matter content of the soils ranged from 1.02 to 3.92%, indicating that there is high variability. The values indicate that soils under the different land units are generally poor in their organic matter content and, thus, require an urgent management intervention in order to raise the currently low level of OM. Similar to the OM content, the total nitrogen content of the soils under the different land units was generally in the low category and ranged from 0.06 to 0.18%. The status of available P is better in almost all the land units. It varied from 10.67 to 24.55 mg/kg, which falls in the range of moderate to high.

The CEC of the soils ranged from 24.85 to 42.31 Cmol (+)/kg of soil, which is in the medium to very high CEC category. The soils were generally good in their exchangeable bases except for K in soils of some land units. The exchange complex is dominantly occupied by Ca^{2+}followed by Mg^{2+}.TheDTPA extractable Fe, Mn, and Zn content of soils of 7 land units was medium to high, while that of Cu was low to medium.

The soil fertility map indicates that about 86.65% of the total area in the sub-watershed was low in organic matter content with only 13.35% containing medium level of OM. Similarly, about 43.08 and 56.92 % of the study area was low and moderate, respectively, in total N content. More than 56.92% of the total area was high in available P content. Medium CEC shared 11.07%, high CEC shared 53.31% and very high shared 35.62% of the total area of the land units. The exchangeable Ca contents shared 43.08% and 56.92% for high and very high respectively. Exchangeable Mg also covered 43.08% for medium and 56.92% for high values. Extractable Fe content covered 24.42% and 75.58% for medium and high, respectively, while Cu covered 43.08% for low content and 56.92% for medium portion.

In conclusion, almost all of the studied soil properties varied from LUs to LUs most likely due to variation in slope gradient, elevation, parent material, and soil management practices. The soils of the study area showed potentially desirable physical fertility, exchangeable bases except for K on LUs 2 as well as adequate supply of extractable micronutrients except Cu on LUs of rain-fed agricultural lands. Nevertheless, the soils have problems related to low organic matter, total nitrogen; K in some instances and extractable Cu. In general terms, the virgin land was superior to the cultivated ones in most of the measured soil attributes. Furthermore, fields cultivated under rain-fed conditions were inferior to those cultivated under irrigated management in terms of most of the parameters studied.

On the basis of the limitations identified, it can be recommended that the use of integrated soil fertility management strategy with inclusion and combination of manure, compost, crop rotation, biological and physical soil and water conservation and other practices together with chemical fertilizer and improved crop varieties gives better production and keeps the soil fertility status to a better level. However, soil analysis by itself cannot go further than the identification of soil nutrients status due to intricate nature of soil. Therefore, the nutrient supplying powers of the soils and demanding levels of the plants need further correlation and calibration works to come up with site-soil-crop specific fertilizer recommendation. Therefore, the current study should be complemented with plant tissue analysis that grown on soils of the study area. Nutrient ratings should also be done by considering the local situations of the area.

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7. APPENDICES

Appendix Table 1. Slope gradient classes (FAO, 2006b), dry soil color, site and topography characteristics of each land unit of the study area.

Land units	Slope gradient class: Average slope (%)	Slope gradient class: Description	Topographyic characteristics	Site	Soil color(dry)
1	8	Slopping	US	S	Light brown(7.5YR 6/3)
2	9	Slopping	US	S	Light reddish brown(5YR 6/4)
3	6	Slopping	GS	S	Reddish brown(5YR 4/3)
4	4	Gently slopping	GS	R	Brown (7.5YR 4/4)
5	3	Gently slopping	AF	F	Dark brown(7.5YR3/2)
6	6	slopping	GS	S	Yellowish red(5YR 4/6)
7	12.5	Strongly slopping	SL	S	Dark brown(10YR 3/3)

F= Flat plain, R= Receiving site, S= Shedding site, AF= Almost flat, US= Undulating, GS= Gently sloping, SL= strongly sloping

Appendix Table 2. Area (ha), percent area coverage (%), average altitude, and dominant previous and current crop, type of fertilizer used in different land units of the study area

LU	Area (ha)	Area coverage (%)	Average Altitude (masl)	Dominant previous crop	Dominant current crop	Dominant type of fertilizer used
1	41.93	6.74	2150	Sorghum	Sorghum	DAP,UREA,FYM
2	68.85	11.07	2163	Sorghum	Sorghum	DAP,UREA,FYM
3	50.94	8.19	2145	Sorghum	Sorghum	DAP,UREA,FYM
4	132.49	21.29	2132	Onion	Onion	DAP,UREA,FYM
5	138.56	22.27	2073	Onion	Potato	DAP,UREA,FYM
6	106.35	17.09	2147	Mize	Maize	DAP,UREA,FYM
7	83.09	13.35	2270	Shrubs Junipers tree		

Appendix Table 3. Mean monthly rainfall, monthly minimum and maximum temperatures of the study area for the years 2005 to 2014 (Source: Ethiopian MA, Haramay university Station).

Month	Rainfall(mm)	Maximum Temperature(^{0}C)	Minimum Temperature(^{0}C)
January	4.2	23.3	4.8
February	9.1	25.0	6.7
March	40.6	25.9	9.5
April	103.0	25.3	12.8
May	110.3	26.2	13.6
June	43.6	25.1	14.2
July	145.7	23.6	13.6
August	155.8	23.3	13.7
September	142.3	23.6	13.9
October	47.9	24.3	7.6
November	25	24.4	4.6
December	12.3	22.5	3.2

Appendix Table 4. General scale of bulk density

Bulk density(g/cm3)	Rating
< 1.0	Very low
1.0-1.3	Low
1.3-1.6	Moderate
1.6-1.9	High
>1.9	Very high

Source: Hazelton and Murphy (2007)

Appendix Table 5. Ratings of pH (H_2O), organic matter (OM), total nitrogen (TN), available phosphorus

(Av.P Olsen method) in the soil

pH(1:2.5H_2O)[a]		OM(%)[a]		Total N(%)[a]		Av.P (mg/kg)[b]	
pH	Rating	OM (%)	Rating	TN (%)	Rating	Av.p	Rating
< 4.5	Very SAc	< 0.86	Very low	<0.05	Very Low	<5	Very Low
4.5-5.2	SAc	0.88-2.95	Low	0.05-0.12	Low	5-9	Low
5.3-5.9	MAk	2.95-5.17	Medium	0.12-0.25	Moderate	10-17	Medium
6.0-6.6	Slightly Acid	>5.17	High	>0.25	High	18-25	High
6.7-7.3	Neutral					>25	Very High
7.4-8.0	MAk						
> 8	SAk						

SAc= strongly acid, MAc= moderately acid, MAk= moderately alkaline, SAk= strongly alkaline
Sources: [a]Tekalign (1991), [b]Cottenie (1980).

Appendix Table 6. Ratings of available potassium (Av.K), exchangeable Ca, Mg, K, Na, CEC and PBS in the soil

	Exchangeable Ca,Mg,K,Na and CEC (Cmol(+)/kg)					
Rating	Ca[b]	Mg[b]	K[b]	Na[b]	CEC[c]	PBS (%)
Very Low	<2	<0.3	<0.2	<0.1	<2	0-20
Low	2-5	0.3-1	0.2-0.3	0.1-0.3	6-12	20-40
Medium	5-10	1-3	0.3-0.6	0.3-0.7	12-25	40-60
High	10-20	3-8	0.6-1.2	0.7-2	25-40	60-80
Very High	>20	>8	>1.2	>2	>40	>80

Sources:[b]FAO (2006a), [c]Hazelton and Murphy (2007)

Appendix Table 7. Interpretive Values For DTPA-Extractable Cu,Fe, Mn and Zn (ppm) and Hot Water – Extractable B (ppm)

Test rating	Cu	Fe	Mn	Zn
Very Low	<0.2	0.1-0.6	<0.2	<0.2
Low	0.3-2.5	0.7-2.0	0.3-0.9	0.3-4.0
Medium	2.6-5.0	2.1-5.0	1.0-20	0.5-1.0
High	5.1-10	5.1-250	21-50	1.1-10.0
Very High	>10	>250	>50	>10

Source: Jones, (2003)

Appendix Table 8. Geographical coordinates (grids) of each land unit.

Land Unit 1		Land Unit 2		Land Unit 3		Land Unit 4		LU 4(Continued)	
East	North	East	North	East	North	East	North	East	North
42.04058	9.46072	42.05202	9.46802	42.04068	9.46255	42.05813	9.45982	42.06138	9.45254
42.04302	9.46482	42.05337	9.46817	42.04161	9.46287	42.05784	9.45920	42.06197	9.45210
42.04312	9.46527	42.05384	9.46862	42.04230	9.46304	42.05465	9.45758	42.06236	9.45170
42.04319	9.46569	42.05420	9.4693	42.04250	9.46315	42.04176	9.45357	42.06313	9.45121
42.04331	9.46621	42.05478	9.46933	42.04268	9.46326	42.04252	9.45273	42.06441	9.45091
42.04364	9.46645	42.05565	9.47007	42.04320	9.46316	42.04312	9.45234	42.06567	9.45098
42.04464	9.46693	42.05608	9.47040	42.04403	9.46327	42.04359	9.45204	42.06615	9.45138
42.04909	9.46794	42.05771	9.46985	42.04478	9.46333	42.04394	9.45194	42.06594	9.45206
42.04992	9.46809	42.05809	9.46959	42.04618	9.46317	42.04466	9.45190	42.06575	9.45308
42.05202	9.46802	42.05865	9.46967	42.04686	9.46354	42.04540	9.45156	42.06586	9.45382
42.05223	9.46559	42.05954	9.46965	42.04756	9.46389	42.04695	9.45103	42.06518	9.45502
42.05132	9.46541	42.06061	9.46936	42.04802	9.46407	42.04756	9.45039	42.06471	9.45594
42.05033	9.46520	42.06171	9.46907	42.04880	9.46406	42.04844	9.45010	42.06375	9.45620
42.04942	9.46503	42.06195	9.46882	42.04879	9.46465	42.04931	9.44973	42.06176	9.45812
42.04902	9.46496	42.06214	9.46830	42.04902	9.46496	42.04973	9.44965	42.06089	9.45892
42.04879	9.46465	42.06238	9.46795	42.04942	9.46503	42.05033	9.44951		
42.04880	9.46406	42.06317	9.46768	42.05033	9.46520	42.05098	9.44918		
42.04771	9.46408	42.06160	9.46376	42.05132	9.46541	42.05194	9.44894		
42.04756	9.46389	42.05629	9.46395	42.05223	9.46559	42.05230	9.44932		
42.04686	9.46354	42.05612	9.46428	42.05309	9.46577	42.05220	9.44970		
42.04618	9.46317	42.05309	9.46577	42.05612	9.46428	42.05263	9.45049		
42.04468	9.46340	42.05257	9.46589	42.05629	9.46395	42.05319	9.45072		
42.04403	9.46327	42.05223	9.46559	42.05603	9.46373	42.05364	9.45091		
42.04308	9.46316			42.05546	9.46334	42.05459	9.45065		
42.04320	9.46316			42.05479	9.46263	42.05535	9.45070		
42.0425	9.46315			42.05421	9.46231	42.05586	9.45096		
42.0423	9.46304			42.05389	9.46235	42.05647	9.45116		
42.04161	9.46287			42.05317	9.46248	42.05710	9.45234		
42.04068	9.46255			42.05235	9.46240	42.05697	9.45332		
				42.05121	9.46196	42.05666	9.45397		
				42.05073	9.46199	42.05594	9.45511		
				42.04936	9.46172	42.05499	9.45605		
				42.04781	9.46130	42.05572	9.45652		
				42.04552	9.46070	42.05729	9.45640		
				42.04441	9.46039	42.05885	9.45606		
				42.04097	9.46007	42.05929	9.45536		
				42.04058	9.46072	42.05982	9.45480		
				42.04075	9.46184	42.06067	9.45366		

Appendix Table 8 Continued

Land Unit 5		Land Unit 6		Land Unit 7		LU 7(Continued)	
East	North	East	North	East	North	East	North
42.05629	9.46395	42.06317	9.46768	42.05230	9.44932	42.07119	9.45482
42.05603	9.46373	42.06416	9.46733	42.05220	9.44970	42.07048	9.45508
42.05546	9.46334	42.06534	9.46686	42.05263	9.45049	42.07010	9.45417
42.05479	9.46263	42.06609	9.46643	42.05319	9.45072	42.06992	9.45348
42.05421	9.46231	42.06634	9.46597	42.05364	9.45091	42.06931	9.45296
42.05389	9.46235	42.06659	9.46522	42.05459	9.45065	42.06920	9.45257
42.05317	9.46248	42.06668	9.46439	42.05535	9.45070	42.06907	9.45206
42.05235	9.46240	42.06705	9.46423	42.05586	9.45096	42.06917	9.45087
42.05121	9.46196	42.06762	9.46446	42.05647	9.45116	42.06905	9.45043
42.05073	9.46199	42.06820	9.46453	42.05710	9.45234	42.06777	9.44916
42.04936	9.46172	42.06857	9.46454	42.05697	9.45332	42.06710	9.44865
42.04781	9.46130	42.06919	9.46431	42.05666	9.45397	42.06647	9.44850
42.04552	9.46070	42.06952	9.46381	42.05594	9.45511	42.06571	9.44825
42.04441	9.46039	42.06971	9.46346	42.05499	9.45605	42.06502	9.44827
42.04097	9.46007	42.06986	9.46319	42.05572	9.45652	42.06427	9.44847
42.04058	9.46072	42.06983	9.46265	42.05729	9.45640	42.06301	9.44941
42.03943	9.45825	42.06924	9.46184	42.05885	9.45606	42.06258	9.44990
42.03911	9.45800	42.06910	9.46153	42.05929	9.45536	42.06185	9.45046
42.03877	9.45750	42.06879	9.46128	42.05982	9.45480	42.06063	9.45125
42.03835	9.45677	42.06889	9.46060	42.06067	9.45366	42.06017	9.45101
42.03840	9.45652	42.06931	9.46009	42.06138	9.45254	42.05883	9.45111
42.03903	9.45613	42.06977	9.45973	42.06197	9.45210	42.05752	9.45064
42.03961	9.45564	42.06991	9.45936	42.06236	9.45170	42.05541	9.45020
42.04052	9.45462	42.07040	9.45916	42.06313	9.45121	42.05384	9.44968
42.04155	9.45390	42.07126	9.45892	42.06441	9.45091	42.05296	9.44943
42.04176	9.45357	42.07164	9.45851	42.06567	9.45098		
42.05426	9.45774	42.07172	9.45812	42.06615	9.45138		
42.05784	9.45920	42.06655	9.45619	42.06594	9.45206		
42.05813	9.45982	42.06589	9.45608	42.06575	9.45308		
		42.06557	9.45611	42.06586	9.45382		
		42.06471	9.45594	42.06518	9.45502		
		42.06375	9.45620	42.06471	9.45594		
		42.06176	9.45812	42.06589	9.45608		
		42.06145	9.45830	42.0668	9.45608		
		42.06089	9.45892	42.07172	9.45812		
		42.06160	9.46376	42.07151	9.45636		
				42.07177	9.45547		