MAPPING SPATIAL VARIABILITY OF SOIL FERTILITY STATUS OF DIFFERENT LAND USE AT MUGER SUB-WATERSHED, NORTHERN OROMIA, ETHIOPIA

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Article Info

Received: December,2018

Accepted :June ,2018

Accepted in revised form: June 20,2018

Published: August ,2018:

Abstract

Soil fertility is the ability of a soil to nourish essential nutrients to the plant. In order to implement appropriate soil fertility management in the area where spatial variability of soil prevails, soil fertility status assessment is vital. Hence, this study was conducted in Muger sub-watershed in Ethiopia's Northern Oromia to assess and map the spatial variability of soil fertility status. A total of 25 composite soil samples were collected from cultivated, grazing and forestland of upper, middle and lower slope positions at a depth of 0-20cm for determination of selected soil physical and chemical properties, and their spatial variability was mapped using ordinary kriging techniques of GIS 10 software. The study indicated that there was significant ($p<0.05$) differences in the values of sand, silt, soil organic carbon

(OC),total nitrogen (TN), zinc (Zn), manganese (Mn) and available sulfur (Av.S) among the different land uses of the area. The study also revealed that soils of the area are predominantly sandy clay loam in texture with moderately acidic (5.56-5.93) in reaction. Soil organic carbon (OC) was significantly ($p<0.05$) different across different land uses. The recorded mean values of OC and total nitrogen (TN) were low on cultivated lands but high on grazing and forest lands. Zinc (Zn) content was low on cultivated and grazing lands but high on forest land, indicating that Zn, TN and OC could be the limiting factors for crop growth in the study area. On the contrary, cation exchange capacity (CEC), exchangeable calcium (Ca), Exchangeable potassium (K), and extractable iron (Fe) were high in all land uses. However, copper (Cu), percent base saturation (PBS), extractable manganese (Mn), available phosphorous (Av.P) and available sulfur (Av.S) contents were at medium rate for all land uses. The occurrence of exchangeable bases followed Ca>Mg>K>Na trend in their order of dominance. Soil micronutrients ranged from 57.94-78.42, 6.97-12.37, 2.56-4.45and 0.22-1.31mg kg^{-1} for Fe, Mn, Zn and Cu, respectively. From the findings of this study, it can be concluded that the soils of the cultivated lands were generally low in OC, TN and Zn and medium in Mn and Av. S. Therefore, there is a need for management of soil organic matter and regular application of nitrogen, zinc, phosphorus and sulfur containing mineral fertilizers to the soil in order to replenish the nutrients.

Key words: *Land uses**;** Macronutrients; Micronutrients; Muger sub-watershed; Ordinary Kriging, Soil, Fertility Assessment*

Introduction

The ability of a soil to provide all essential nutrients in adequate quantities, proper balance and its efficiency in transforming nutrients for the growth of plant is referred to as soil fertility. A decline in soil fertility is becoming one of the major challenges for establishing sustainable agriculture in Sub-Saharan African countries (SSA) (Muchena, 2008; Kumar and Babel, 2011) where agriculture accounts the lion's share in their economy. Changes in land use, alteration of the ecosystem and susceptibility of the land to external pressure (Henao and Baanante, 2006; Roy *et al.,* 2003), intensive crop cultivation and complete crop residue removal (Amare *et al.,* 2013) have significantly affected soil physical, chemical, and biological properties. All this ultimately contributed to the deterioration of soil fertility. As a result, it was estimated that close to 85 per cent of tropical soils have some degree of deterioration of soil fertility (Oldeman and van Lynden, 1998).

The total food production in SSA has been growing but at a very slow rate of less than one per cent per year (Depetris *et al.,* 2012; OECD-FAO, 2016). This is rather alarming considering the fact that food production growth rate is not as fast as population growth rate which raises concerns for SSA's ability to self-insure against food insecurity. Hence, to boost agricultural production, soil productivity maintenance remains a major environmental issue in those SSA countries (Oyetunji *et al.,* 2001). The fundamental cause for declining per capital food production in SSA are associated with a negative nutrient balance which ranges from moderate to severe loss of nutrient (Henao and Baanante, 2006). Smaling (1993) estimated that annual net nutrient depletion rates per hectare exceeded 30 and 20kg $ha^{-1}$of N and K, respectively in arable soils of several countries in SSA.

In the case of Ethiopia, the highest rates of nutrient depletion with aggregated national-scale nutrient balances are estimated to be -41kg N, -6kg P and -26kg K ha^{-1} (Stoorvogel and Smaling, 1990). Declining soil fertility has become a major problem to bring about increased and sustainable productivity and to feed the ever-increasing population of the country. In the cultivated fields where farming has been practiced for many decades, depletion of soil organic matter (SOM) due to wide spread use of biomass as fuel, depletion of macro and micronutrients, removal of top soils by erosion, increase of soil salinity with time and inadequate fertilizer application are core soil constraints that stripped the soils of vital nutrients needed to support plant growth (IFPRI, 2010). Also, it is estimated that there is 42 tons ha^{-1} of fertile soils loss every year from croplands compared with 5t ha^{-1} on grass lands (Bojo and Casells, 2005).

Physical fertility of a soil is its ability to allow sufficient entry, movement, and retention of water and air to meet plant needs. Whereas chemically fertile soil contains sufficient amount of the various substances required for plant nutrition in available form (Burt, 2009), an appropriate amount of soil organic matter, and a pH in a suitable range for crop production. Assessing of soil fertility decline is difficult because most soil chemical properties either change very slowly or have large seasonal fluctuations; in both cases, it requires long-term research commitment (Hartemink, 2006). Therefore, the degree of soil productivity is highly important to evaluate soil fertility.

The major contributing factors causing nutrient depletion in Ethiopia emanate from rapid population growth and environmental factors which lead to the conversion of natural forestland and grassland in to cultivated lands (Rahdary *et al.,* 2008; Solomon *et al.,* 2001; Tesfahunegn, 2016). Such land use changes have contributed to soil degradation and soil loss by deteriorating the soil physical and chemical properties (Mishra *et al.,* 2004; Karltun *et al.,* 2013).

Cultivation on steep slopes and fragile soils; declining use of fallowing (Daniel, 2008; Tegenu *et al.,* 2008); limited recycling of dung and crop residue to the soil; application of smaller quantity of plant nutrients from external sources; overgrazing and torrential rainfall patterns (Barry and Ejigu, 2005; Lalisa *et al.,* 2010) are also among the triggering factors for soil degradation.

In order to enhance production and productivity of agricultural sector through the application of different management/conservation options and use the soil resource on the basis of its potentials and limitations, an in- depth knowledge in this regard is imperative. Hence, soil fertility evaluation is an essential means and soil testing is an indispensable tool (Havlin*et al.,* 2005). However, in Ethiopia, limited number of studies have been carried out on soil fertility status except the one conducted by EATA- Ethio SIS at woreda level. Hence, extensive surveys dealing with soil fertility status and its spatial variability at watershed level are scant. Especially in Muger sub-watershed where this research is conducted, the situation is worse and the soil resource has degraded at an alarming rate. Thus, the sustainability of agriculture and the livelihood of the community are under threat. To come up with feasible management practices, investigating the fertility status of the study area is crucial. Hence, the objective of this study was to assess and map the spatial variability of soil fertility status of Muger sub-watershed and to provide basic information for practitioners and resource managers who are responsible to take on mitigation measures on soil depletion in the area.

Materials and Methods

Description of the Study Area

The study area is located at Wuchale district, North Shoa zone of Oromia Regional State, Ethiopia, between 9º34' 2.13" to 9º 35' 44.7"N and 38º 43' 49.02 " to 38º 45' 41.99"E. The sub-watershed is part of Duber watershed in the central highlands of the country. The total area of the sub-watershed is about 931ha. The geology of the study area is characterized by thick flood basalt (trap series) in central Ethiopia, with intermediate and silicic lava and pyroclastic sediments interstratified towards the top of the series. The Arero group of lower complex archean volcanic rock dominantly consists of andesite lava and tuffs, basalt, rhyolites and trachyte (FAO, 1984; BFEDO, 2009) all appeared. Hence, the parent material of the soil is basalt. The highest and lowest elevations are 2672 and 2389 meters above sea level, respectively, and over 95 per cent of the area has an altitude of over 2400meters above sea level (Figure 1.1). The area is largely flat and dissected by seasonal streams and few gentle and steep slopes towards the lowland parts.

The climate of the study area is characterized by dry (October to February Cold-Dry and March to June Hot-Dry) and wet (beginning of June to mid-September) seasons, respectively. A 20-year climate data (1992-2011) indicate that the mean annual rainfall of the area is about 946.1 mm with peak rainy months in mid-July, August and September with a unimodal pattern of rainfall. The rainfall is typically orographic in nature and the distribution is directly correlated to altitude. The mean maximum and minimum annual temperatures of the area are 19.2 and 8.2 ºC, respectively, with mean annual temperature of 14.3 ºC having the warmer and cooler months occurring in May and November, respectively (Figure 1. 2).

The land use systems exercised in the area are both private farming and communal grazing land holdings which can be identified through land use patterns. Cultivated and grazing lands are the major land use types in the area which account 78.3 and 17.6% respectively and the remaining (4.1%) is covered by settlement, miscellaneous and shrub/bush (WANRO, 2014). The vegetation cover of the sub-watershed is very poor, few remnants of indigenous trees such as kosso (HyginiaAbyssnica), Woira (oliva African), Girar (Acacia), etc are seen exceptionally scattered on farmlands and around churches, whereas, eucalyptus trees are seen around homestead. Fuel wood is the major source of energy in the woreda for cooking. As a result, the indigenous trees are being destroyed for firewood and making charcoal as source of energy.

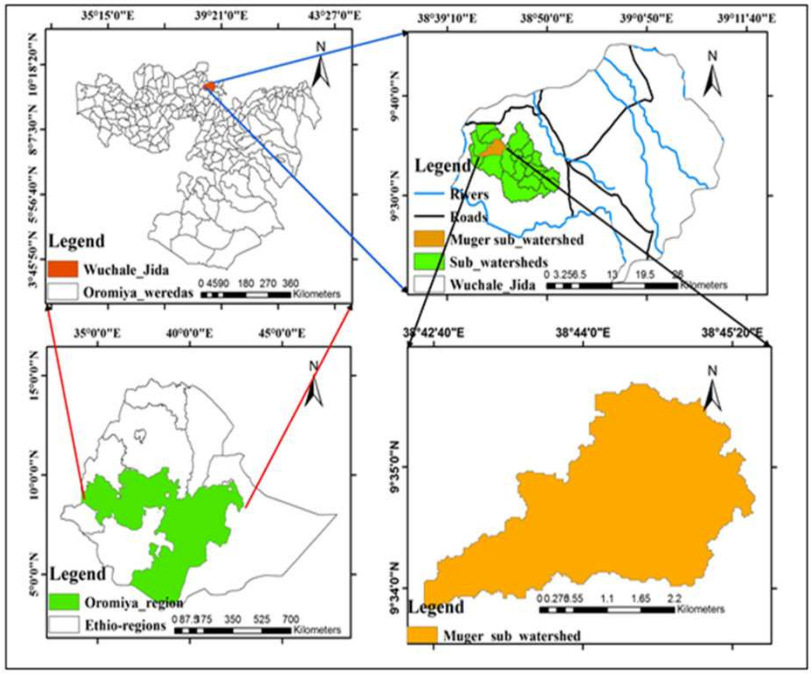

Figure 1.1. Location map of the study area

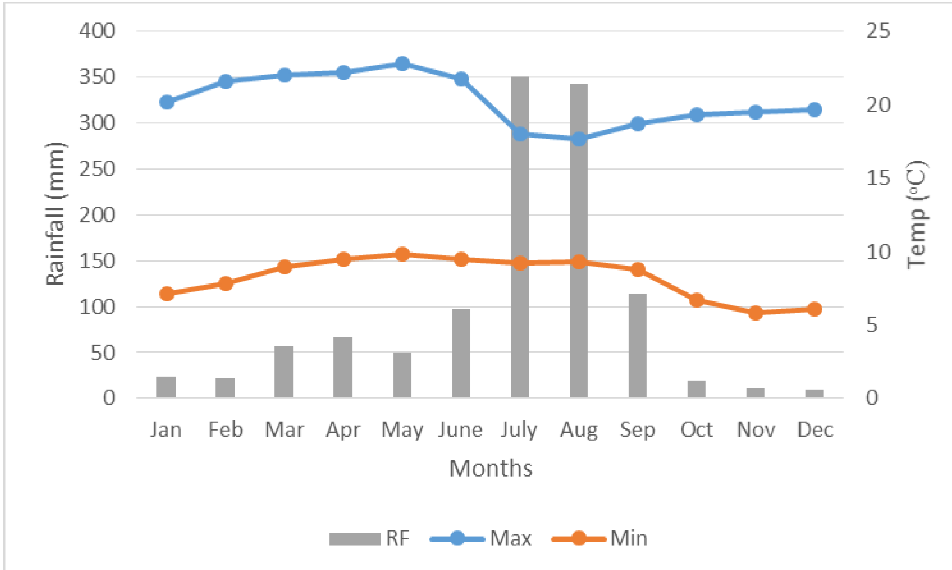

Figure1.2. Mean monthly rainfall, maximum and minimum temperature of the study area

Site Selection and Soil Sampling

Prior to the actual field work, general visual field survey of the study area was carried out to have a general view of the variations in the study area and tentative sampling sites were selected on the topographic map based on topography and land use type of the area. Following site selection, the study area was divided into three slope positions/ categories on the bases of slope gradient. Then, three land use types: forest (around the church yard in the upper position), grazing, and cultivated lands were considered for assessing the fertility status of the soil of the study area. A total of 25 composite soil samples (0-20cm depth) were collected from grazing, cultivated and forestlands of upper, middle and lower slope positions for laboratory analysis. To make one composite sample 7 to 10 sub-samples from each land use types were taken. Since forest land in the study area was found only on the upper slope position, the soil samples collected from this land use were used as a check for comparison purpose.

Soil Preparation

The soil samples collected from the study area were air dried, crushed and passed through 2 mm sieve for physicochemical analysis. For the analysis of organic matter (OM) and total nitrogen (total N), the soil samples were passed through 0.5mm sieve. The collected soil samples were prepared at Fitche soil laboratory center and the analysis was undertaken at the Haramaya University soil chemistry laboratory.

Laboratory Analysis

Determination of particle size distribution was carried out by the Bouyoucos hydrometer method (Bouyoucos, 1962). Particle density was determined by the graduated cylinder method as outlined by (Bashour and Sayegh, 2007). Soil pH was determined in water (pH-H_2O) and 1M KCl (pH-KCl) with 1:2.5 soil to solution ratio using pH meter (Carter and Gregorich, 2008). Organic carbon was determined using the Walkley and Black wet oxidation method (Walkley and Black, 1934). Total N of the soil was determined through digestion, distillation and titration procedures of the Micro-Kjeldahl method (Bremner and Mulvaney, 1982). Available soil phosphorus was determined using the sodium bicarbonate extraction solution (pH 8.5) method and the amount measured by spectrophotometer (Olsen *et al.,* 1954). Exchangeable bases and cation exchange capacity (CEC) of the soils were determined by using the 1M ammonium acetate (pH 7.0) method (Van Reeuwijk, 1993) and available sulfur by turbidimetric method (Kowalenko, 1985). Exchangeable Ca and Mg in the extracts were determined by Atomic Absorption Spectrophotometer (AAS), while flame photometer was used to determine the contents of exchangeable K and Na. Extractable micronutrients (Fe, Mn, Zn and Cu) content of the soils was extracted by diethylene triaminepentaacetic acid (DTPA) method (Houba *et al.,* 1989) and the content in the extract was determined by AAS.

Mapping of Soil Fertility

Mapping of soil nutrients status were carried out by using Arc GIS software version 10.1. Ordinary kriging was used to predict unknown values of soil nutrients concentration for non-sampled areas based on the nearby surveyed data. After kriging was carried out for selective soil parameters, very low, low, medium, high and very high nutrient status classes were defined based on appropriate methods.

Statistical Analysis

Descriptive statistics (mean, range, standard deviation, coefficient of variation) of soil parameters were computed using Statistical Package for Social Science (SPSS) software model to analyze the relationships among and within selected soil physico-chemical properties. The ratings (very low, low, medium, high and very high) of determined values were based on conventional standards to perform the significance differences in soil parameters between different land uses. The coefficient of variation was ranked according to the procedure of (Aweto, 1982) where, CV $\leq$ 25%= low variation, CV>25 $\leq$ 50% = moderate variation, and CV>50% = high variation.

Results and Discussion

The soil fertility status of the study area was evaluated with respect to texture, particle density, bulk density, pH, OC, macronutrients (such as N, P, K, S, and Mg) and micronutrients (such as Fe, Zn, Cu, and Mn), CEC, PBS and the results obtained are presented and discussed below.

Soil Texture and Particle Density

The result in Table 3.1 showed that the soil texture of the study area was predominantly sandy clay loam, while loam is also present. Comparatively the highest mean value of sand and silt fractions (55 and 28.75%, respectively) were observed in the lower grazing and middle cultivated land slope positions, respectively (Table 3.1). Whereas the highest clay fraction (28%) was observed in the upper and lower slope positions of cultivated and grazing lands. Although, the obtained values seem very close, the mean values of sand and silt content were significantly ($P<0.05$) different among the land uses. This might be due to removal of clay particles by erosion from the upper slope of cultivated lands and its subsequent deposition on lower position, while on grazing land the highest clay content observed in the upper slope might be due to grass cover protection of clay particles from erosion.

This result is in agreement with the finding of Alemayehu and Sheleme (2013), who reported relatively higher sand content in grass land soils followed by 'enset' and maize fields, and highest clay on maize plots of the upper 0-15cm depth, at Delbo Atwaro watershed, SNNP Regional state. The correlation analysis result revealed negative and strongly significant (r= -0.581; r=-0.692, p<0.01) relationship between clay with sand and silt (Table 3.5). The calculated coefficient of variation was low (CV<25%) for sand and particle density and low to medium (CV <25 and ≤50%) for silt and clay particle sizes indicating that more variability relative to its mean is observed on sand and particle density than silt and clay. The soil texture of the different land uses were found to be the same except for middle slope cultivated lands, which is loam. This indicates that the different land use types did not have effect on the soil texture of the study area, since texture is an inherent soil property that is not influenced in short period of time. Though soil texture is inherent property, it determines a number of physical and chemical properties of soils. It affects, for instance, the infiltration and retention of water, soil aeration, adsorption of nutrients, microbial activities, tillage and irrigation practices (Gupta, 2004), internal drainage, and root penetration (Hamarashid *et al.,* 2010).

The highest (2.61gm cm^{-3}) and the lowest (2.27gm cm^{-3}) mean values of particle density were recorded on lower slope positions of cultivated and grazing lands, respectively. The highest particle density recorded on cultivated lands than grazing and forest lands might be due to its high sand content and the presence of heavy minerals of Fe. According to the ratings given by Skoop (2002), typical particle density value for mineral soils ranged from 2.5-2.8g cm^{-3}. Accordingly, the mean values of particle density recorded across different positions except the lower slope position of grazing land was found within the given range. Nevertheless, the relatively lower particle density values recorded in the study area are contrary to established facts and could not be explained.

Table 1: Soil physical properties across different LU of Muger Sub-watershed, North Oromia

Parameters	**Descriptive statistics**	**Cultivated land** Upper	Middle	Lower	**Grazing land** Upper	Middle	Lower	**Forest**
Sand (%)	Range	40 -55	50 - 55	44 - 53	50 - 55	49 - 57	51 -57	
	Mean	50.25	51.50	49.00	52.00	53.25	55.00	52.00
	StD.	6.95	2.38	3.92	2.16	3.30	2.71	
	CV (%)	13.82	4.62	7.99	4.15	6.20	4.92	
Silt (%)	Range	15 - 29	27 -30	19 -27	18 - 23	19-23	17-29	
	Mean	24.50	28.75	23.00	20.00	21.50	23.00	19.00
	StD.	6.45	1.26	3.37	2.16	1.73	5.16	
	CV (%)	26.35	4.38	14.64	10.80	8.06	22.45	
Clay	Range	20-31	16-22	22-32	25-30	21-32	14-32	

(%)	Mean	25.25	19.75	28.00	28.00	25.25	22.00	29.00
	StD.	6.08	2.63	4.32	2.45	4.72	7.62	
	CV (%)	24.06	13.32	15.43	8.75	18.68	34.62	
Ps (gm cm^{-3})	Range	2.31-2.61	2.30-2.63	2.60-2.63	2.30-2.63	2.50-2.64	2.00-2.43	
	Mean	2.49	2.54	2.61	2.47	2.59	2.27	2.50
	StD.	0.16	0.16	0.01	0.14	0.06	0.19	
	CV (%)	6.58	6.20	0.57	5.52	2.35	8.18	
BD(gm cm^{-3})	Range	1.11-1.37	1.05-1.37	1.27-1.33	1.19-1.38	1.15-1.33	1.15-1.27	1.19
	Mean	1.26	1.26	1.29	1.27	1.25	1.20	
	StD.	0.11	0.14	0.25	0.09	0.08	0.06	
	CV (%)	8.73	11.11	19.30	7.08	6.40	5.01	
Texture class	SCL	L	SCL	SCL	SCL	SCL	SCL	

LU= Land uses; SCL= Sandy clay loam; L= Loam; CV= Coefficient of variation; Ps= Particle density; StD= Standard deviation.

The bulk density of a soil is a dynamic property that varies with the soil structural conditions. Bulk density is influenced by the amount of organic matter in soils, their texture, constituent minerals and porosity. The knowledge of soil bulk density is essential for soil management, and information about it is important in soil compaction as well as in the planning of modern farming technique. The mean bulk density values under the grazing and cultivated lands were within the range of 1.20g cm^{-3} and 1.29g cm^{-3} as recorded on the lower slope positions of grazing and cultivated lands, respectively. The reason for the highest soil bulk density on the cultivated lands could be due to more percentage of sand but low bulk density observed on grazing and forest land is probably due to high organic matter. These results were in agreement with that of Puget and Lal (2005) and Allen and Pilbeam (2007) who stated that lower bulk density was observed on forest land relative to cultivated and pasture lands. Similarly, Matersha and Mikhabela (2001) reported that virgin forest soil produces lower bulk density than pasture and cultivated lands because of well-developed fine-medium granular structure and high organic matter contents. The ideal bulk density for plant growth is <1.60; <1.40 and <1.10g cm^{-3} for sandy, silty and clayey soils, respectively. Whereas, when a bulk density values >1.80; >1.65 and >1.47g cm^{-3} for sandy, silty and clayey soils, respectively, it restricts root growth (USDA/NRCS, 2014). The acceptable range of bulk density is 1.3 to 1.4 g cm^{-3} for inorganic agricultural soils (Bohn et al., 2001). Based on this ratings, the values of the studied soils were not high as a result the soils in the study area were not too compact to limit root penetration and restrict movement of water and air. This indicates the existence of loose soil conditions in the study area. Thus, the soils of the study area have good structure.

Soil pH, OC, TN, Av.P and Av.S

The highest (5.93) and lowest (5.56) mean values of soil pH in the study area were observed in the lower and upper slope positions of grazing lands, respectively. The lowest pH value under grazing land is also so closer to the value on the forest land. However, the results have shown that soil pH was moderately acidic and showed low variability (CV<25%) within and across different land uses and topographic positions. The finding of this study is much higher as compared with the result reported by Teferi (2008) in nearby district called Kuyu. This could be due to effects of straw management, tillage practice and cropping sequence. This is also confirmed by negative and strong correlation (r= -0.680, p<0.01 and r=-0.450, p< 0.05) between soil pH with available P and Zn, respectively (Table5). According to Gazey and Davies (2009), pH between 5.5 and 7.0 was considered as an ideal for plant growth. Thus, the pH values of soils of the study area are ideal for plant growth and the availability of most of plant nutrients might not be affected with this pH ranges.

Table 2: Descriptive statistics of soil pH, OC, TN, Av.P and Av.S of Muger Sub-watershed

		Cultivated land			Grazing land			
Parameter	Descriptive statistics	Upper	Middle	Lower	Upper	Middle	Lower	Forest
pH	Range	5.56-5.81	5.66-5.99	5.76-5.89	5.52-5.59	5.62-5.78	5.81-6.04	
	Mean	5.66	5.76	5.84	5.56	5.73	5.93	5.57
	StD.	0.11	0.15	0.06	0.03	0.07	0.10	
	CV (%)	1.91	2.67	1.03	0.52	1.29	1.61	
OC (%)	Range	1.23-2.81	1.01-1.68	1.02-1.88	2.81-5.65	2.85-4.56	3.18-4.92	
	Mean	2.12	1.43	1.40	4.79	3.60	3.81	6.06
	StD.	0.77	0.29	0.37	1.33	0.71	0.77	
	CV (%)	36.50	20.29	26.36	27.75	19.74	20.21	
TN (%)	Range	0.12-0.25	0.13-0.17	0.10-0.16	0.29-0.52	0.26-0.39	0.22-0.44	
	Mean	0.19	0.15	0.13	0.43	0.31	0.32	0.59
	StD.	0.06	0.02	0.03	0.10	0.06	0.09	
	CV (%)	32.58	11.20	25.11	23.00	17.79	28.91	
AvP (mg kg-1)	Range	12.18-15.64	6.88-16.75	7.87-16.76	14.52-17.98	7.69-18.41	7.27-11.15	23.41
	Mean	14.69	10.83	12.02	15.96	13.42	8.76	
	StD.	1.68	4.19	4.78	1.52	4.52	1.80	
	CV (%)	11.43	38.69	39.75	9.52	33.68	20.50	
AvS	Range	3.13-	4.84-	4.63-	4.76-	3.97-	3.21-	12.36

(mg		8.16	7.68	8.11	11.04	9.14	10.23
kg^{-1})	Mean	5.91	5.99	6.28	7.42	5.72	6.12
	StD.	2.20	1.33	1.43	2.63	2.35	2.95
	CV (%)	37.15	22.20	22.70	35.43	41.16	48.22

OC= Organic carbon; TN= Total nitrogen, Av.P= Available phosphorus; Av.S= Available sulfur

The mean value of soil organic carbon (OC) across the study area ranged from 1.40 to 4.79% in the lower and upper topographic positions of cultivated and grazing lands, respectively. The amount of OC on cultivated land is by far lower than the amount recorded on forest lands (6.06%) (See table 2). This may reflect differences in organic matter management/ complete removal of crop residue, fast oxidation of OM and limited addition of external organic inputs like compost or manure into cultivated lands. The correlation analysis revealed highly significant and positive ($r = 0.641$, $p < 0.01$) relationship of OC with Zn which implies OC is one source of zinc. The OC content showed low to moderate variability in the investigated soil samples (Table 2). As per the rating of Tekalign (1991), the soil OC of the cultivated land was classified as low, while those of grazing and forest lands were categorized as high.

Based on the rating of Landon (1991), the soil samples of lower and middle slope positions of cultivated lands are categorized as very low (<2%) whereas, soils of upper cultivated lands rated as low (2-4%,) and samples collected from grazing and forest lands were categorized as moderate (4-10%). This finding is in agreement with Malo *et al.* (2005), Eyayu *et al.* (2009), Sheleme, (2011) and Teshome *et al.* (2016), who reported low level of soil OM content in the cultivated lands than grassland. Therefore, incorporation of organic matter is imperative for organic matter improvement of the soil in the study area.

The mean value of total nitrogen (TN) followed the same trend with that of OC on the different land uses and along the various slope positions. The value ranged from 0.13 – 0.43%, the lowest and highest mean values were observed in the lower cultivated and upper grazing land slope positions, respectively. These values recorded on respective land uses might be associated with the content of OM. Although, the highest mean value of TN was recorded on grazing land, it is lower than the value obtained on forest lands. This is in agreement with the finding of Lemma *et al.* (2006) and Alemayehu and Sheleme (2013), who reported that the contribution of OM to total nitrogen is high and soil N content decreased by 64 and 55% in cultivated sites compared to native forest and rangeland, respectively. Total nitrogen measures the total amount of nitrogen present in the soil, much of which is held in organic matter and is not immediately available to plants. Nitrogen is taken by plants in greatest quantity next to carbon, oxygen and hydrogen, but it is one of the most deficient elements for crop production in the tropics (Mesfin, 1998).

As per the rating of Hazelton and Murphy (2007), the recorded total nitrogen values which ranged from 0.13 to 0.43% are categorized as low to high, whereas the value obtained from forest land (0.59%) was very high. Total nitrogen content of the sample soils under study showed low to moderate variability among different land uses and across different topographic positions. The decreasing trend of total nitrogen across slope position is also the same as soil OC implying that OC is one source of TN. This is best described by positive and highly significant (r=0.980, p<0.01) correlation between TN and OC (Table 3.5).

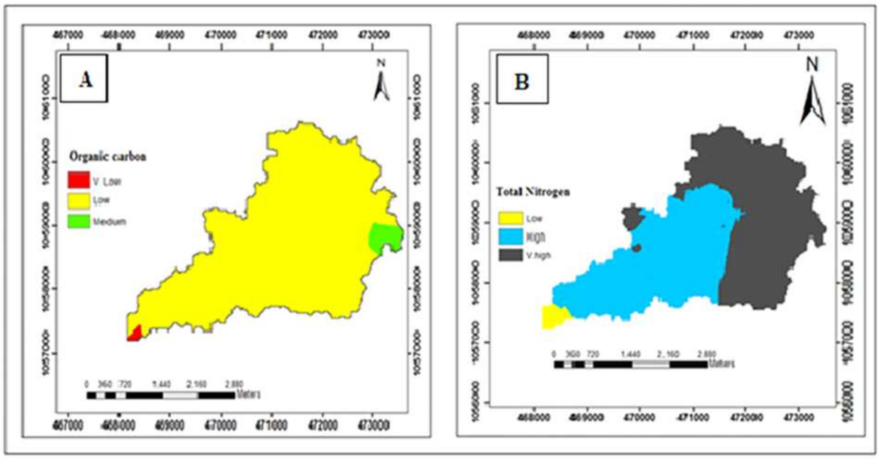

Figure 1: Soil OC (A) and Total Nitrogen (B) status map of Muger Sub-watershed

The mean value of available phosphorus (Olsen P) ranged from 8.76 to 15.96 mg kg^{-1}. The lowest and highest mean values were observed in the lower and upper slope positions of grazing lands (Table 3.2). However, the highest mean available P value of grazing land is comparatively lower than the amount recorded on forest land (23.41 mg kg^{-1}). The mean available P content was not significantly (P<0.05) different among the land use systems.

The variations in available P contents in soils of the study area could be related to differences in management practices, erosion hazard, crop uptake and application of fertilizer. Generally, available phosphorus content of the studied soil varied from low (in upper grazing and cultivated lands) to medium (in middle and lower grazing and cultivated lands). According to Cottenie (1980), available soil P values <5, 5-9, 10-17, 18-25 and >25mg kg^{-1} is rated as very low, low, medium, high and very high, respectively. Based on this rating, the available P of cultivated and upper and middle slope positions of grazing land soils of the study area could be rated as medium. However, soils of the lower slope position of grazing and forest land rated as low and high, respectively. It was also noted that there existed negative and highly significant ($r= -0.680$; $p <0.01$) correlation between available P and soil pH. Moreover, significant and positive correlation ($r= 0.248$; $p <0.05$) was also observed between available P and OC and this implies soil organic matter is one of the pool of P in the soil (Table 5).

The recorded mean value of available sulfur varied from 5.72 to 7.42 mg kg^{-1} in middle and upper slope positions of grazing lands, respectively. The highest mean value which was recorded on grazing land is lower than the value obtained in the forest land (12.36 mg kg^{-1}). Keeping this fact in view, the soil under study may be classified (<2 kg^{-1}), (2-5mg kg^{-1}), (5-20mg kg^{-1}) and (>20mg kg^{-1}) as very low, low, medium and high as per the categorization given by Horneck *et al.* (2011). Accordingly, all land use systems in the study area can be categorized as medium, but the values are to the margin of low category. This finding was supported by Balsa *et al.* (1996) and Arshad *et al.* (2010) who reported intensive cropping resulted in higher sulfur removal and depletion in the soil. Tekalign *et al.* (1991)

and Solomon *et al.* (2001) also reported that the lower content of OM is one of the causes of lower content of S. The correlation analysis, further indicated strongly significant and positive relationship (r= 0.541, r= 0.479, r=0.540; p<0.01) between available S with Zn, OC and TN, respectively (Table 3.5). Similar relationship was reported for soils of the sub-humid areas of Ethiopian highlands (Solomon *et al.,* 2001). This relationship confirmed that soil organic matter is one of the main sources of sulfur. Available sulfur showed moderate variability (CV>25 to <u><</u>50) in the soil samples except in the middle and lower slope positions of cultivated lands (Table 3.2). Sulfur is required for synthesis of S-containing amino acids cysteine, methionine and cysteine, and these are essential components of protein that comprise about 90% of the total S in plants (Havlin *et al.,* 2005).

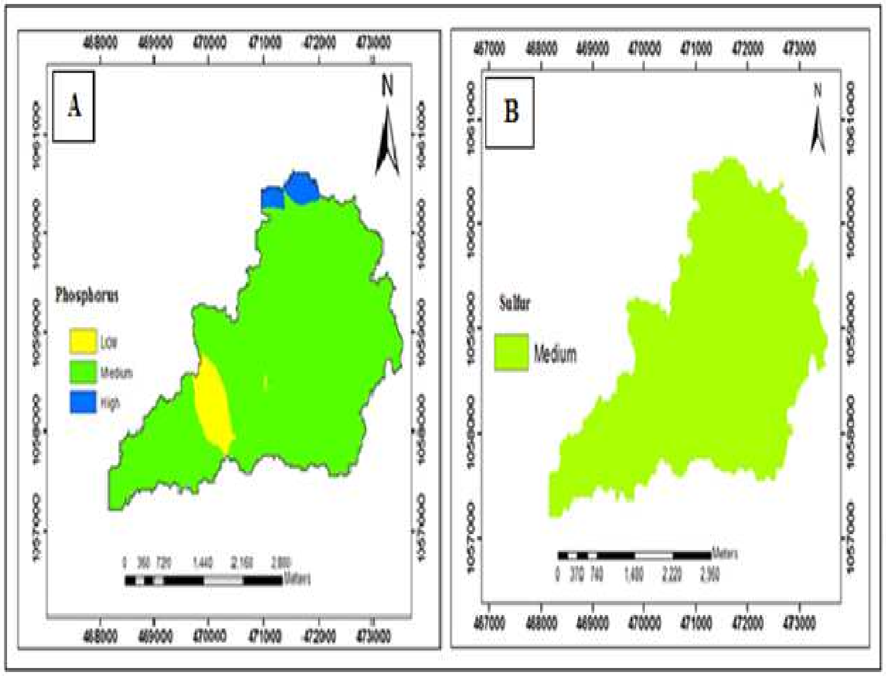

Figure 2: Available P (A) and Available sulfur (B) status map of Muger Sub-watershed

As per the report of Blair *et al.* (1991), the critical level of available S is 6.5mg kg^{-1} for optimum crop production. Also, Arshad *et al.* (2010) reported 10mg kg^{-1} as the critical value for available S in soils. Soils of the tropics generally have low total S contents because of low S containing parent materials or extreme weathering and leaching losses (Acquaye and Kang, 1987). In Ethiopia, low soil sulfur status has become a widespread problem (Mamo and Haque, 1987; Nand *et al.,* 2011; Habtamu *et al.,* 2015). This is because of the close association of organic S with SOC and N in these soils due to the fact that SOM provides the major non-leachable reserve of S and

N in most surface soils. Therefore, regular application of sulfur containing mineral and organic fertilizers to the soil of the study area should be implemented to reduce sulfur mining problem.

From the total area, soils with very low, low and medium organic carbon content cover 5.6 ha (0.60%), 901.4 ha (96.41%) and 27 ha (2.99%), respectively. Very high total N content covers 404 ha (43.25%) of the study area whereas high and low total N content accounts for 516 ha (55.25%) and 14 ha (1.5%), respectively. The extent of available P is 17 ha (1.82%), 896 ha (95.93%) and 21ha (2.25%) for low, medium and high contents in the study area. On the other hand, available sulfur was medium throughout the entire study area.

Cation Exchange Capacity, Exchangeable Bases and Percentage Base Saturation

The soil exchangeable bases, cation exchange capacity and percentage base saturation values of the study area are presented in Table 3.3. The mean CEC values of soils under the cultivated and grazing lands were within the range of 43.53 and 49.51cmol (+) kg^{-1} as recorded on the middle and lower slope positions of the cultivated lands, respectively. The value recorded in forest land (56.10 cmol(+)kg-1) was higher than the values of cultivated and grazing lands. This might be due to relatively high OM content (Yihenew *et al.,* 2015) in forest land and low OM, high leaching of basic cations and clay from cultivated land. The correlation analysis also revealed strongly significant and positive ($r= 0.704$; $p <0.01$) relation between CEC with Ca. The coefficient variation of CEC is low (CV<25) across the different land uses. Low variability of CEC across different land uses could emanate from similarity in land management system and drainage system of the soil. Generally, as per the rating of Hazelton and Murphy (2007), all mean CEC values under the study area are categorized as very high (>40cmol (+) kg-1).

The mean value of exchangeable calcium (Ca) ranged from 9.06 $cmol_{(+)}kg^{-1}$ in the lower grazing land to 13.36 $cmol_{(+)}kg^{-1}$ in the upper grazing lands (Table 3). The highest mean value observed in the upper grazing lands is, however, much lower than the value obtained in the forest land (22.58 $cmol_{(+)}kg^{-1}$). The coefficients of variation is medium (CV >25 ≤50%) in cultivated lands and low (CV <25%) for grazing lands. As indicated in table 3.3, the content of exchangeable Ca decreased with decreasing slope positions, which might be associated with the effect of management and crop uptake as well. This finding is in agreement with Alemayehu and Assefa (2016), who reported highest mean exchangeable Ca^{+2} content in forestland and lowest in cultivated lands. The correlation analysis revealed strongly significant and positive relationship of exchangeable Ca with Mg and PBS (r=0.599, r= 0.788; $p < 0.01$) and significant and positive correlation with clay, available P and iron, respectively (r= 0.420, r= 0.462, r= 0.442; $p<0.05$) (Table 3.5). As per the rating recommended by FAO (2006b), the mean values of exchangeable Ca under the study area rated as high for cultivated and grazing lands but very high for forest land.

Table 3: Descriptive statistics of Ca, Mg, K, Na+CEC, and PBS of Muger Sub-watershed:

Parameter	Descriptive Statistics	Cultivated land			Grazing land			Forest
		Upper	Middle	Lower	Upper	Middle	Lower	
Ca ($cmol_{(+)}kg^{-1}$)	Range	9.76-17.77	6.31-16.41	6.04-12.35	8.78-16.21	10.65-16.07	7.68-10.85	
	Mean	13.33	10.96	9.73	13.36	12.73	9.06	22.58
	StD.	3.82	4.55	2.70	3.21	2.46	1.44	
	CV (%)	28.65	41.47	27.79	24.03	19.35	15.85	
Mg ($cmol_{(+)}kg^{-1}$)	Range	7.85-10.13	6.09-11.94	4.45-8.75	7.47-11.41	9.94-12.40	5.86-7.67	
	Mean	9.08	9.44	7.14	9.53	11.08	6.95	10.82
	StD.	1.02	2.76	2.04	1.97	1.10	0.80	
	CV (%)	11.22	29.29	28.55	20.69	9.95	11.51	
K($cmol_{(+)}kg^{-1}$)	Range	1.32-2.0	0.84-1.98	0.96-1.62	0.64-1.10	0.85-1.23	0.85-1.26	
	Mean	1.67	1.47	1.33	0.94	1.04	0.97	2.12
	StD.	0.29	0.49	0.28	0.21	0.20	0.20	
	CV (%)	17.54	33.22	21.15	22.41	19.30	20.46	
Na ($cmol_{(+)}kg^{1}$)	Range	0.70-1.27	0.66-1.09	0.87-1.23	0.44-1.25	0.87-1.07	1.09-1.31	
	Mean	1.11	0.87	1.06	1.00	1.00	1.15	1.50
	StdDev	0.27	0.18	0.15	0.36	0.09	0.11	
	CV (%)	24.59	20.12	14.35	35.83	9.02	9.61	
CEC($cmol_{(+)}kg^{1}$)	Range	42.43-50.96	36.40-47.22	40.35-55.12	44.10-51.38	39.73-53.25	37.65-49.09	56.10

	Mean	46.28	43.53	49.51	48.10	46.44	44.57	
	StD.	4.29	4.84	6.37	3.37	5.53	4.87	
	CV (%)	9.27	11.12	12.86	7.00	11.91	10.93	
PBS (%)	Range	52.47 - 56.56	38.76-65.53	33.05-42.98	40.99-59.41	49.28-59.13	34.87-45.44	86.22
	Mean	54.41	51.46	38.52	51.34	55.70	40.85	
	StD.	1.88	13.25	4.99	7.85	4.40	4.39	
	CV (%)	3.46	25.74	12.96	15.30	7.90	10.75	

CEC= Cation exchange capacity; PBS= Percent base saturation

The mean value of exchangeable magnesium (Mg) varied from 6.95 to 11.08 $cmol_{(+)}kg^{-1}$ in the lower and middle slope position of grazing lands, respectively. The mean value of exchangeable Mg recorded on the forest land is below the maximum value observed in the grazing land. This finding is contrary with the finding of Habtamu *et al.* (2014), who reported that the highest exchangeable Mg value was observed in the surface layer of forest land and the lowest was on the surface layer of cultivated land. According to the ratings set by Aweto (1982), the coefficient of variation is ranked as low and medium for grazing and cultivated land uses, respectively. According to the ratings suggested by Hazelton and Murphy (2007), the mean value of exchangeable Mg of the study area can be categorized as high to very high. High Mg was recorded in lower cultivated and grazing lands, whereas very high mean values were recorded in the forest as well as upper and middle slope positions of cultivated and grazing lands.

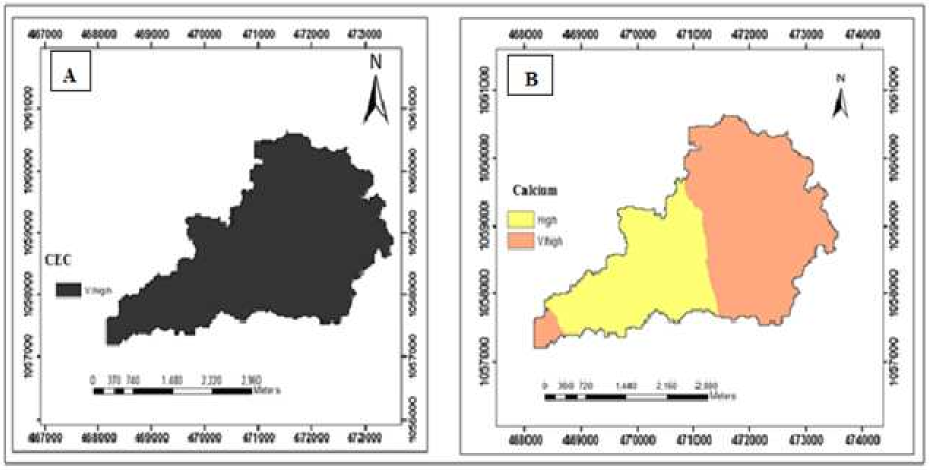

Figure 3: CEC (A) and calcium (B) status map of soils of Muger Sub-watershed.

The mean value of exchangeable potassium in the study areas ranged from 0.94 to 1.67 $cmol_{(+)}kg^{-1}$ in the upper slope positions of grazing and cultivated lands, respectively. However, the relatively highest mean value recorded in the upper cultivated land (1.67 cmol (+) kg^{-1}) was lower than the value obtained in the forest land (2.12 $cmol_{(+)}kg^{-1}$). Although, the obtained values of exchangeable potassium in the study area seem very close to one another, they were significantly ($P<0.05$) different among the land use systems. According to FAO's (2006b) rating, the soil is qualified as high to very high in exchangeable K for all land uses under the study area. Similar finding was reported by Habtamu *et al.* (2014) in which case the highest exchangeable K was recorded on the surface layer of forest land while lowest value in the subsurface layer of grazing land.

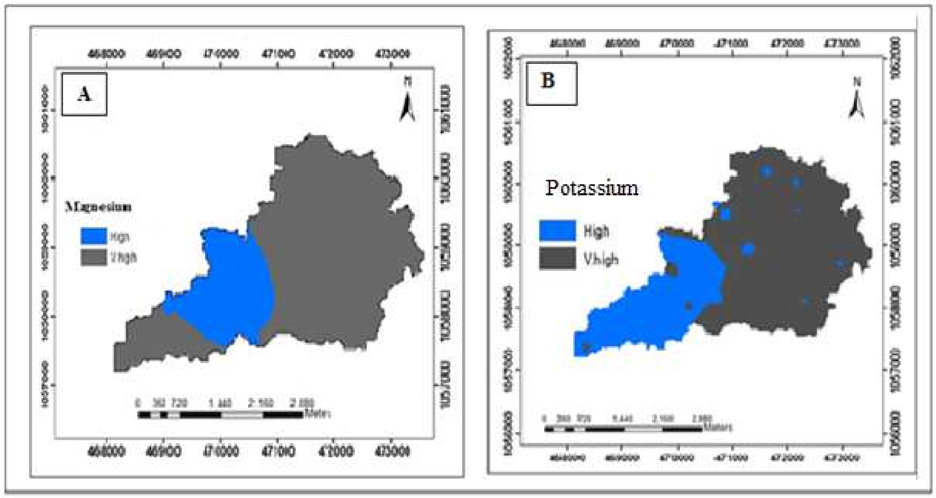

Figure 4: Status map of Exchangeable Magnesium (A) and potassium (B) in soils of Muger Sub-watershed

The highest (1.15 cmol(+)kg^{-1}) mean value of exchangeable Na^+ was observed on lower slope position of grazing lands, whereas the lowest mean value was recorded (0.87 cmol (+)kg^{-1}) on middle slope position of cultivated lands. The highest mean value observed on lower slope position of grazing lands might be due to their high OM content, less amount of soil erosion by water, and high resistance of cations from leaching at foot slopes and areas covered by grass and vegetation (Maja, 2011; Habtamu*et al.,* 2014). However, the highest mean value recorded on grazing lands are lower than the value obtained in the forest lands (1.50 cmol(+) kg^{-1}). Keeping this fact in view, the soil under study may be classified (<0.1 cmol(+) kg^{-1}), (0.1-0.3 cmol(+) kg^{-1}), (0.3- 0.7 cmol(+) kg^{-1}), (0.7-2 cmol(+) kg^{-1}) and (>2 cmol(+)kg^{-1}) as very low, low, medium, high and very high as per the categorization given by FAO (2006b) and Hazalton and Murphy

(2007). Accordingly, the soil of the study area qualified as high for their exchangeable Na^+ content.

The distribution of exchangeable bases in the soils of the study area was dominated by Ca followed by Mg and K in the order of Ca> Mg> K>Na. Generally, the recorded mean values of exchangeable bases could not be the limiting factor for crop growth.

Percent base saturation (PBS) provides an indication of how closely nutrient status approaches potential fertility, which may be affected by variable charge of the clay minerals in the soil. The mean value of PBS under the study area ranged from 38.52 in the lower slope position of the cultivated lands to 55.70% in the middle slope position of grazing lands. However, the value observed on forest land (86.22 %) is much higher than the other land uses. This might be due to relatively high OM contents in forest land as compared to those of the cultivated and grazing lands. According to the ratings of Hazelton and Murphy (2007), the PBS of the study area is moderate for cultivated and grazing lands while it is very high for forest land.

High status of available Ca, Mg and K in the study area cover 320 ha (34.3%), 221 ha (23.6%) and 291 ha (31.2%), respectively. On the other hand, very high levels of exchangeable Ca, Mg and K occur on areas of 614 ha (65.7%), 713 ha (76.4%) and 643 ha (68.8%), respectively. However, the amount of CEC in the study area is categorized as very high and the area coverage is 934 ha (100%).

Extractable Micronutrients

The mean extractable iron content ranged from 57.94 to 78.42 mg kg^{-1} in the lower grazing and upper cultivated slope positions, respectively, and low variability (Aweto, 1982), (CV<25) existed among Fe data. The iron content obtained in forest land was lower than the values recorded in the upper position of cultivated land. Significant and positive (r=0.417, r= 0.480; $p < 0.05$) correlations of Fe were observed with clay and CEC (Table 5). Generally, as per the rating suggested by Jones (2003), the soils under the study were found to be high in extractable Fe. The result of Fe level obtained under the study is similar to previous findings of various researchers (Haque *et al.,* 2000; Eyob, 2015) who reported sufficient level of Fe in the soil samples collected from different parts of Ethiopia. The probable reason for the presence of sufficient level of extractable iron might be associated with the acidic nature of the soil or may be due to the parent material that contains minerals like Feldspar, Magnetite, Hematite and Limonite (Kumar *et al.,* 2013). On the contrary, Teklu (2007) and Yifru and Mesfin (2013) reported Fe deficiency from samples collected from the rift valley regions and central highlands of Ethiopia, respectively. As reported by Diatta and Grzebisz (2006) soil pH is of prime importance in controlling the availability of micronutrients since it directly affects their solubility as well as activity in the soil environment.

Table 4: Descriptive statistics of soil Fe, Mn, Zn and Cu of Muger Sub-watershed, North Oromia

Parameter	Descriptive statistics	Cultivated land			Grazing land			Forest
		Upper	Middle	Lower	Upper	Middle	Lower	
Fe (mg kg^{-1})	Range	60.68-98.74	54.24-71.32	54.01-86.32	53.89-90.46	61.39-98.06	51.47-62.66	
	Mean	78.42	60.06	65.09	67.95	74.39	57.94	69.75
	StD.	18.64	7.76	14.64	15.82	16.22	4.69	
	CV (%)	23.77	12.91	22.49	23.29	21.81	8.10	
Mn (mg kg^{-1})	Range	6.87-13.82	6.87-17.66	6.76-7.30	6.10-18.16	7.19-17.68	6.48-18.02	
	Mean	9.22	10.75	6.97	9.62	12.37	9.76	7.03
	StD.	3.26	5.01	0.25	5.71	5.97	5.53	
	CV (%)	35.30	46.64	3.55	59.42	48.26	56.65	
Zn (mg kg^{-1})	Range	0.05-0.60	0.04-0.40	0.11-0.86	1.04-1.45	0.44-1.13	0.18-0.78	
	Mean	0.30	0.22	0.47	1.31	0.82	0.48	5.63
	StD.	0.24	0.17	0.31	0.18	0.35	0.33	
	CV (%)	77.78	78.24	66.09	14.07	42.62	68.87	
Cu (mg kg^{-1})	Range	2.33-4.54	2.72-7.17	1.70-4.24	2.84-4.29	3.48-5.86	2.08-5.52	
	Mean	3.44	3.96	2.56	3.57	4.45	3.25	5.31
	StD.	0.91	2.15	1.14	0.65	1.06	1.55	
	CV (%)	26.56	54.37	44.74	18.33	23.79	47.75	

The highest (12.37mg kg^{-1}) and the lowest (6.97 mg kg^{-1}) mean values of extractable Mn content were recorded in the middle grazing and lower cultivated land slope positions, respectively. The variation in the extractable manganese of the soil is high with a coefficients of variation (CV >50) in all sample points except lower cultivated slope position. The lower mean value of extractable manganese observed in the lower slope position of cultivated land might be due to parent material from which the soil is formed. Krauskopf (1972) stated that the main source of micronutrient elements in most soils is the parent material. According to Jones *et al.* (2003) ratings, the extractable Mn in the study are is categorized as medium. This could be associated with the pH of the soil. As Chaudari*et al.* (2012) reported, the availability of Mn is very low when the soil pH is above 7.5; this is because of the formation of hydroxides and carbonates. Hence, Mn content of the soil cannot be the limiting factor to successful crop production in the area. Manganese plays an important role in oxidation and reduction processes in plants (Mousavi *et al.,* 2011).

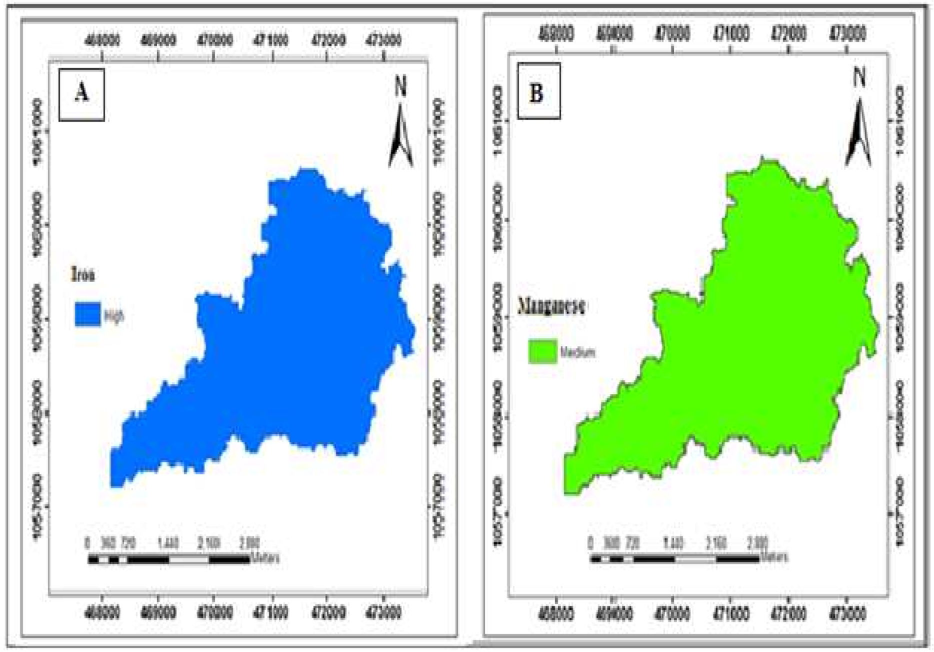

Figure 5: Status map of Extractable Iron (A) and Extractable manganese (B) in soils of Muger Sub-watershed

The highest (1.31mg kg^{-1}) and lowest (0.22mg kg^{-1}) mean value of extractable zinc (Zn) content was observed in the upper grazing and middle slope cultivated lands, respectively. The variation in the extractable Zn of the soil is high (CV>50) among the soil samples in the study area except upper grazing land that showed low variation (CV< 25). The mean values of extractable zinc in cultivated and grazing lands are relatively lower than the value recorded on forest land. Moreover, the mean values of extractable zinc content was significantly ($P<0.05$) different among the land use systems. Generally, as per the ratings suggested by Jones (2003), the extractable Zn in the cultivated land is between very low to low; on the grazing lands it ranges from low to high, whereas on forest land it is very high. This might be due to the presence of more OM in forest land. A significant and positive correlation (r= 0.64, r= 0.707, r=0.562; p> 0.01) is observed between zinc with OC, TN and Av.P and this might indicate that OC is the possible source for extractable zinc in the study area (Table 3.5). In conformity with this observation, Ibrahim *et al.* (2011) also reported a similar finding. Zinc is essential for several biochemical processes in plants such as cytochrome and nucleotide synthesis, chlorophyll production, enzyme activation, and the maintenance of membrane integrity (Havlin *et al.,* 2005).

Mean value of extractable copper (Cu) ranged from 2.56 – 4.45mg kg^{-1} in the lower slope cultivated lands and middle slope position of grazing lands, respectively (Table 4). The mean value recorded in the forest land is higher than the values recorded both in the cultivated and grazing lands. Low coefficient of variation was observed among the soil samples collected from upper and middle slope of grazing lands, whereas medium variability of extractable copper was observed among the soil samples collected across different slopes of cultivated lands. As per the ratings suggested by Jones (2003), the extractable copper values of cultivated and grazing lands are categorized as medium whereas on forest land it is high. The relative abundance of extractable micronutrients in the study area were found in the order of Fe > Mn > Cu >Zn for soils of all land uses. Similar result was reported by Tuma *et al.* (2014), which indicate that the abundance of available micronutrients in Abaya

Chamo lake basin were found to be Fe > Mn > Cu > Zn in almost all surface soils.

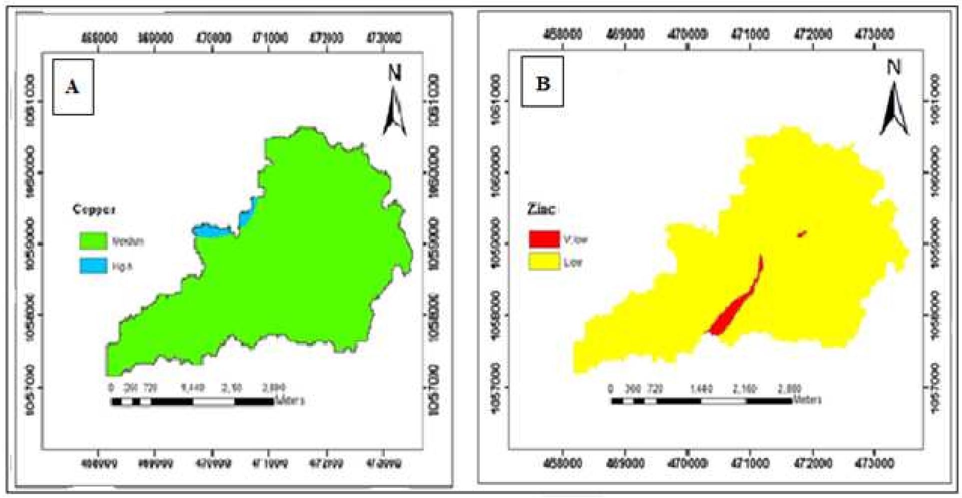

Figure 6: Status map of Extractable copper (A) and Extractable zinc (B) in soils of Muger Sub-watershed

The main sources of micronutrients were to be parent material, farmyard manure, and other soil OM sources. Hence, variation in these source and soil environments ultimately leads in different content of micronutrients. According to Wajahat *et al.* (2006), availability of micronutrient is particularly affected by a change in soil environment. These factors that affect content of micronutrients could be OM, soil pH, and soil texture among few.

The area cover of extractable Zn is 18 ha (2%) and 916 ha (98%) for very low and low status, respectively. Accordingly, medium Cu shared 929 ha (99%) and high Cu shared 5 ha (1%) of the area of the study. With respect to extractable Fe and Mn contents, both of them are in medium status across the study area.

Conclusions

Soil fertility is a dynamic property and it can be changed under the influence of natural and anthropogenic factors. As population number increases, disturbance on soil properties also increases to produce food, fodder, and fiber. So, making soil fertility assessment is essential to make the most of this resource in a sustainable manner and increase productivity. In view of this, assessment of the current soil fertility status and mapping its spatial variability was conducted in Muger sub-watershed, northern Oromia, Ethiopia.

Results from the present study indicated that the soil texture of the study area was predominantly sandy clay loam type. The pH of the soil was found to be moderately acidic (5.56-5.93) and showed low CV across different land uses. On the other hand, organic carbon of the studied soils revealed significantly ($p<0.05$) different value across different land uses; additionally, OC and TN rated as low on cultivated lands and high on grazing and forest land. This could be related with organic matter management and limited addition of external organic inputs. Whereas available sulfur, available P, extractable Mn, extractable Cu and PBS was rated as medium for all land uses except for forest land where Cu, Av.P and PBS ranked as high, The results also indicated that the mean value of extractable Zn was low for both, cultivated and grazing lands but was high for forest land, which indicate deficiency of this nutrient for crops' growth.

Moreover, the value of CEC, Ca, K and Fe in all land uses rated as high.

As a conclusion, the amount of silt, sand, OC, TN, Zn, and K showed significant value difference among land uses. In addition, the mean value of OC, TN, and Zn nutrients are deficient on cultivated lands. This could be related with cultivation of land and related soil disturbances. In order to alleviate this problem and replenish the nutrient status, organic matter, nitrogen, and zinc containing fertilizers should be added to the soil. Additionally, successful integrated soil conservation practice should be implemented to preserve the nutrients and OM from erosion and leaching.

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Table 5: The correlation between properties of the soils in Muger sub-watershed

Sand	Silt	Clay	pH	OC	TN	AvP	AvS	Fe	Mn	Zn	Cu	Ca	Mg	K	CEC	PBS	
Sand	1	-.186	.581**	.279	.253	.230	-.214	.082	-.245	.041	-.021	.047	-.247	.079	-.029	-.377	.037
Silt		1	-.692**	.118	.463*	-.476*	-.200	-.270	-.286	-.025	-.341	-.073	-.288	-.078	.023	-.305	-.125
Clay			1	-.303	.198	.225	.323	.164	.417*	-.010	.297	.026	.420*	.006	.002	.530**	.076
pH				1	-.271	-.320	-.680**	-.156	-.336	-.244	-.450*	-.208	-.496*	-.255	-.104	-.262	-.378
OC					1	.980**	.284	.479*	-.001	.036	.641**	.361	.348	.179	-.266	.068	.317
TN						1	.347	.540**	-.029	-.018	.707**	.398*	.378	.233	-.205	.082	.358
AvP							1	.357	.304	-.046	.562**	.307	.462*	.205	.024	.303	.314
AvS								1	-.306	-.425*	.541**	.268	.195	.077	.051	-.026	.219
Fe									1	.502*	.063	.027	.442*	.056	.152	.480*	.147
Mn										1	-.065	-.019	.182	.059	.046	.220	.055
Zn											1	.304	.586**	.210	.206	.387	.370
Cu												1	.035	-.067	-.117	-.464*	.188
Ca													1	.599**	.396	.704**	.788**
Mg														1	.206	.319	.856**
K															1	.230	.392
CEC																1	.240

PBS	1

**, *Correlation is significant at P< 0.01 and 0.05 levels, respectively