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RESEARCH PAPER

Soil Fertility Evaluation and Mapping in Sdeyni Watershed, Habru District, Northeastern Ethiopia

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Abstract

Soil nutrient mining, poor use of external inputs, soil erosion, are the major soil constraints affecting sustainable crop production in Ethiopia. In the study area, the soils were not characterized to provide location specific information for crop producers. Thus, this study was initiated with the objective of evaluation and mapping of soil fertility in Sdeyni Watershed. Cultivated lands in the watershed were selected and divided into eight land units (LUs). Three replicated composite soil samples were collected from the depths of 0-20 cm from each land unit comprising a total of 24 composite soil samples. Data analysis was done following one way ANOVA using R software, and mapping was performed using GIS software. The result showed that most soil properties were significantly different in the land units. Clay texture, slightly acidic soils (6.02-6.74), medium organic matter (OM) content (2.96-4.59%), low to medium total nitrogen (0.10-0.24%), medium to high available phosphorus (6.40-12.44 mg kg-1), and medium to high cation exchange capacity (11.90-27.00 cmol (+) kg-1), and moderate to high percent base saturation (41.40- 67.23%) were the observed soil fertility parameters. Soil fertility management through addition of organic and inorganic fertilizer sources should get immediate attention to maintain optimum crop production sustainably.

Keywords: GIS, Habru District, Land units, Soil fertility

Introduction

Ethiopia's economy is dependent on agriculture, which accounts for 40% of the GDP, 80% of exports, and an estimated 75% percent of the country's workforce (USAID, 2021). However, high level of nutrient mining, poor use of external inputs, soil erosion, old farm management practices, and limited capacity to respond to environmental shocks (Amante et al., 2014; Agegnehu et al., 2016) are major characteristics of this economic activity. Replenishment of soil nutrient stock from organic and inorganic sources is very low as compared with the need of the soil and the crop. Average productivity of cereals is revolving around 2.1t ha-1 as compared to that of the estimated average potential (3.2 t ha-1) in the country for the studied crops (Daniel and Rozina, 2022).

In order to foster agricultural development in Ethiopia, the soil resource information available is not sufficient to decide the nutrient requirement of each crop across regions with complex land form and diverse climate. Most areas in the country continue to use blanket fertilizer recommendation though some attempts were done to cluster based on nutrient limitations as explained by soil fertility maps prepared through EthioSIS (2014).

Based on the result of the national soil fertility survey, it was reported that Ethiopian soils are characterized by either acidity or alkalinity and are poor in macro-and micronutrients (e.g. S, Zn, B, Cu, and Fe) in addition to N and P (Tamene et al., 2017). Soil properties are subjected to changes due to erosion, leaching, fixation, and volatilization. These necessitate periodic assessment of soils nutrient stock to maintain the fertility and productivity of soils. Soil fertility management as part of the improved farming practices need local assessment to quantify the status of essential nutrients, rating, and mapping (Kedir et al., 2016). Such evaluation and mapping are helpful to planning and applying fertilizer resources in a sustainable agroecosystem.

The chemical and physical properties of soils are effects of soil forming factors which have spatial variations at a specific mapping scale. These soil properties were used for interpretation of soil fertility without reference to area class map until the introduction of Global Positioning Systems (GPS) and Geographic Information Systems (GIS) technologies (Khadka et al., 2019). The application of these tools has simplified geographic data collection, map synthesis, and generation of soil attribute data for users. Researchers worldwide have used GIS for soil fertility mapping, soil type mapping, and suitability of soils for various crop productions (Prabhavati et al., 2015; Fekadu et al., 2018; Fekadu and Negese, 2020). The most powerful geostatistical tool which is used to interpolate spatial variation of soil fertility is ordinary kriging because it provides a higher level of prediction accuracy (Song et al., 2013).The soil fertility mapping can be used for delineating soil fertility status, studying soil fertility changing due to land use dynamics and determining nutrient requirement for the deficient areas.

Soil testing is one of the techniques to evaluate the nutrient content of a soil, the reaction of a soil (acid or alkaline), nutrient dynamics, and helps to recommend how much nutrient is to be added to meet crop requirement. However, the soils in the study area were not systematically analyzed and documented to provide information for crop producers. Farmers in the study area still continue application of blanket recommendation of fertilizers without sufficient research based information on the types and levels of soil nutrients. Therefore, this study was initiated with the objective of evaluating soil fertility status and mapping in Sdeyni watershed, Habru District, Northeastern, Ethiopia.

Materials and methods

Description of Study Area

The study was conducted at Sdeyni Watershed, which is located in Habru District of Northeastern, Ethiopia (Figure 1). The center of the district is Mersa, which is located at 491 km North of Addis Ababa on the main road to Woldia. Geographically, the study area lies between 11˚45’13” to 11˚27’35’’ North latitude and 39˚38’17” to 39˚49’22’’East longitude, and at an altitude ranging from 500 to 2400 meters above sea level (m.a.s.l.). The area coverage of the watershed is about 10461ha.

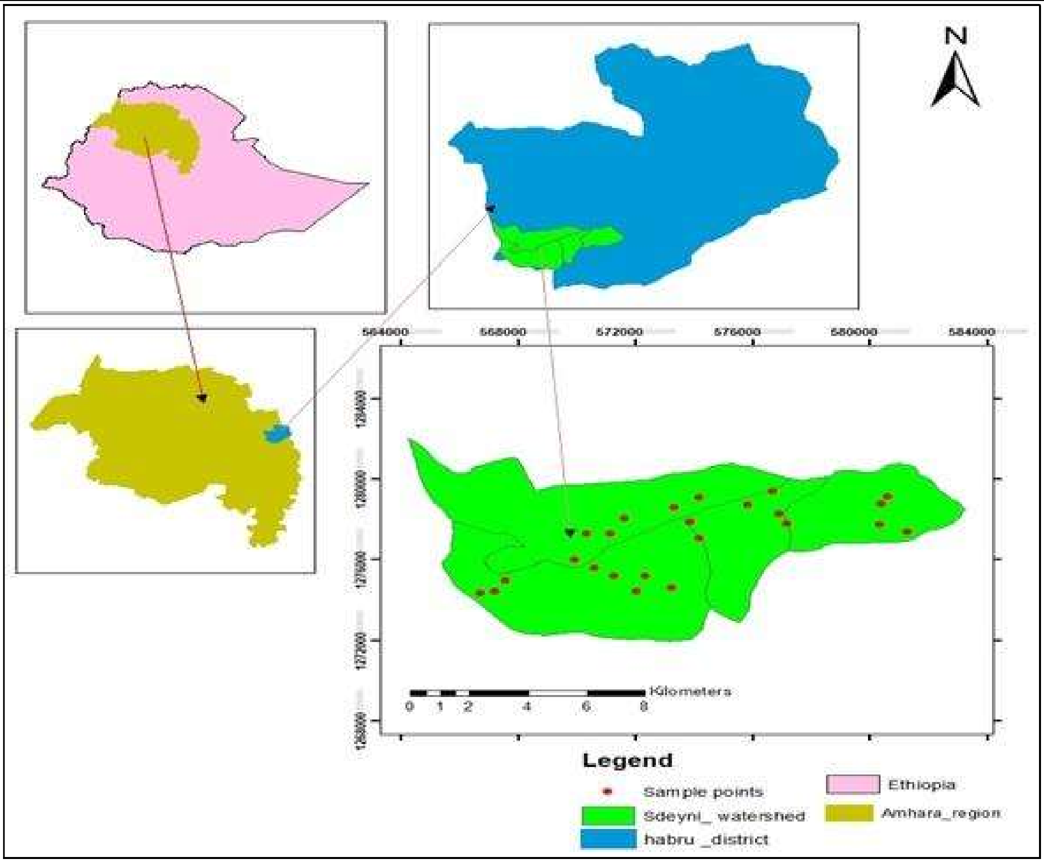

Figure1 Map of Sdeyni Watershed

The topography of the study area is mostly characterized by 35% mountains, 40% flat, 22% valleys and 3% others (Habru District Office of Agriculture, 2021). The major land use patterns of the study area comprise of cultivated land (44%), grazing land (20%), forest/shrub land (23%), infrastructure and settlement (10%), and unproductive land (3%). The agro-ecological situation of the district is divided into three elevation and temperature zones, namely: lowland (kolla) (64.7%), midland (woina-dega) (32.3%), highland and (dega) (3%). The annual mean temperature ranges from 15oC to 28oC. The coldest month is October while the warmest month is May. The area receives a mean annual rainfall of 700 to 1000 mm with erratic distribution.

Most of the people in the study area mixed crop-livestock agriculture system. Crop production is dependent on both rain-fed and irrigation system. The most common annual crops in the study area are Teff, Sorghum, and Maize which are grown in rainfed system while different vegetables such as Cabbage, Pepper, Tomato, Onion, and fruits like, Orange, Mango, and Lemon are grown through irrigation.

Field Survey, Sampling Site Selection, and Soil Sample Collection

A preliminary survey and field observation was carried out in December 2021 in the watershed to have general information about the land use and land cover types, topography, and farming system, and to decide the representative land units for soil sampling.

Field data collection and soil sampling was carried out with the help of atopographic map of the study area, and satellite image of April 2020. Prior to the actual field work, tentative sampling sites were fixed on the satellite image on the basis of topography and land unit of the area.

From the study area soil fertility assessment on cultivated land was done by dividing the land in to different land units (LUs) according to their differences in terms of surface soil color, altitude, slope gradient and aspect, surface land features, and to a lesser extent soil management practices such as type of fertilizers used, and current crop. Accordingly, a total of eight land units were identified and demarcated (Table 1). Delineation was done using GPS to collect geographic data in each boundary, and the map was produced using GIS software. Once the representative LUs were identified, description of sampling site and soil sampling was carried out for each land unit. Three replicated composite soil samples were collected from the depths of 0-20 cm for each land unit. The samples were collected following a zigzag pattern based on the complexity of topography and heterogeneity of the soil type. A total of 24 composite soil samples were collected from 8 LUs. Depending on the size of the replications and their variability, 10 to 15 auger points were taken to make one composite sample.

The soil samples collected from representative fields' were air-dried, mixing and passing through a 2 mm sieve for the analysis of selected soil physical and chemical properties parameters except for total nitrogen and organic carbon which were passed through 0.5 mm sieve. After mixing, approximately 0.5 kg of the composite soil samples was transported to laboratory for analysis with proper labeling on each sampling bag. Undisturbed soil samples were collected from the same soil depth, and eight land units to determine soil bulk density values. Cylindrical metal core with a volume of 100 cm3 was pressed into the soil until it is filled. The soil was trimmed at both ends with a knife and covered with a cap, labeled, and packed in a box. whereas the disturbed soil samples were taken by using an auger to measure the rest selected soil physical and chemical properties. Following sample preparation, the selected soil physical and chemical properties were analyzed at Srinka Agricultural Research Center soil laboratory, following the standard procedures.

Table 1. Summary of characteristics of land units in Sdeyni watershed (Authors' survey)

Land unit	Area (ha)	Altitude (m a.s.l)	Slope (%)	Aspect	Soil type	Land use type	Current crop	Residue Mgt.	Fertilizers used
1	1267.6	1865	5	Southeast	EutricLeptosols	Crop land	Teff	cleared	NPS
2	1255.5	1678	2	Northeast	Lithic Leptosols	Crop land	Sorghum	cleared	NPS
3	2281.6	1624	5	Northeast	Lithic Leptosols	Crop land	Teff	Well-managed	NPS
4	1418.0	1710	5	Southeast	Lithic Leptosols	Crop land	Sorghum	cleared	NPS
5	86.8	1558	4	Southeast	Lithic Leptosols	Crop land	Teff	cleared	Urea
6	1595.0	1443	4	Northeast	EutricVertisols	Crop land	Sorghum	cleared	Urea
7	23.0	1415	5	Southeast	EutricVertisols	Cropland	Sorghum	cleared	Urea
8	1134.2	1396	2	Southeast	EutricVertisols	Crop land	Sorghum	cleared	Urea

Sample Preparation and Laboratory Analysis

For determination of particle size distribution, hydrometer method was used (Day, 1965). Then after, soil textural class names was assigned based on the relative contents of the percent sand, silt, and clay using the soil textural triangle of the USDA. Bulk density (BD) of soils was determined from undisturbed soil samples collected from each land use type using a core sampler and weighed at field moisture content and then dried in an oven at 105°C for 24 hours.

The soil pH was measured using soil to water suspension (1:2.5) by pH meter, whereas electrical conductivity was measured by conductivity meter(Van Reeuwijk, 1992) using the suspension prepared for pH analysis. The determination of organic carbon, the Walkley and Black (1934) method was used in which the carbon will oxidized under standard conditions with potassium dichromate (K2Cr2O7) in sulfuric acid solution. Finally, the organic matter content of the soil was calculated by multiplying the organic carbon percentage by 1.724 following the assumptions that OM is composed of 58% carbon. The total nitrogen content in soils was determined using the Kjeldahl digestion, distillation and titration method by oxidizing the OM in concentrated sulfuric acid solution (0.1N H2SO4) as described by Black (1965).

Exchangeable bases (Na+, K+, Mg2+ and Ca2+) were determined after extracting the soil samples by ammonium acetate (1N NH4OAc) at pH 7.0. Exchangeable Na+ and K+ were analyzed by flame photometer while Ca and Mg in the extracts were analyzed using atomic absorption spectrophotometer (AAS) as described by Rowell (1994). Cation exchange capacity were determined titrimetrically by distillation of ammonium that could be displaced by sodium from NaCl solution (Chapman, 1965). Percent base saturation was calculated by dividing the sum of the charge equivalents of the base forming cations (Na+, K+, Mg2+ and Ca2+) by the CEC of the soil and multiplying by 100.

Statistical Analysis

One-way analysis of variance (ANOVA) was applied using R software to analyze the selected soil physicochemical properties it indicates soil fertility assessment. Moreover, the least significant difference (LSD) test ($P < 0.05$) was used to compare the mean values of the selected soil physicochemical properties of the land units.

Soil Fertility Mapping

Using topographic (1:50,000) map and satellite image as a reference, location map of the study area was developed using Arc GIS 10.3. This watershed was then divided into 8 land units. After that, the respective coordinate points marked using GPS were fed into the GIS environment; then, polygons for the watershed and for each land unit were created by digitizing the recorded boundary points. Ordinary kriging was used to predict unknown values of soil nutrients concentration for non–sampled areas based on the nearby surveyed data. Point data of selective soil attributes were interpolated across the study area using the geo–statistical model and their spatial prediction were evaluated. For every soil property the experimental variogram was calculated. Mapping of predicted soil nutrients were carried out by using Arc GIS software version 10.3.

Based on the results of the laboratory analysis, soil fertility indices were generated and ratings made. Accordingly, the soils were classified into different fertility categories, i.e., very low, low, medium, high and very high on the basis of the content of each selected soil parameters. For each fertility class, different symbol, colors, and patterns were selected from symbol selector of Arc Map 10.3. Finally, the fertility status of the land units was mapped by using the respective legend symbols. Selected soil fertility parameters mapped were soil pH, organic matter (OM), total N, available P, CEC, exchangeable Na+, K+, Ca2+, and Mg2+.

Results and discussions

Physical Properties of Soils under Different Land Units

Significant differences (P ≤ 0.05) were perceived among the three soil separates (Table 2) in different land units (LUs). The highest mean values of clay (65.41%), silt (27.91%), and sand (22.08%) fractions were recorded for LUs 3, 2 and 5, respectively, whereas the lowest clay (52.91%), silt (19.58%), and sand (15.00%) fractions were observed in LUs 2, 3 and 3, respectively. The textural classes in all land units fall in clay, as confirmed from the result, the clay content in all land units were above 50%. The most probable reasons for the minor variations in each soil separate may be due to differences in topography, slope gradient, erosion and deposition. Consistent with this suggestion, Fekadu et al. (2018) reported that variation in soil texture may be caused by variation in parent material, topography, in situ weathering and translocation of clay. From this study, it was found that soils of lower elevation sites have higher clay content than higher elevation sites. In agreement with this finding, Teshome et al. (2016) reported that textural variations are mainly associated with variation in parent material and topography.

Table 2. Selected soil physical properties under different land units

Land unit	Bulk density	Clay (%)	Silt (%)	Sand (%)	Textural class
LU1	0.85^{b}(0.13)	57.91^{a}(2.88)	23.75^{a}(5.44)	18.33^{a}(8.32)	Clay
LU2	0.84^{b}(0.10)	52.91^{a}(1.44)	27.91^{a}(5.05)	19.16^{a}(3.60)	Clay
LU3	0.87^{b}(0.09)	65.41a(11.81)	19.58^{a}(9.54)	15.00^{a}(5.72)	Clay
LU4	0.95^{b}(0.02)	56.25^{a}(2.50)	25.00^{a}(2.50)	18.75^{a}(2.50)	Clay
LU5	0.92^{b}(0.06)	54.25^{a}(3.81)	23.33^{a}(3.81)	22.08^{a}(1.44)	Clay
LU6	1.02^{b}(0.01)	56.25^{a}(5.00)	23.33^{a}(1.44)	20.41^{a}(5.20)	Clay
LU7	1.37^{a}(0.07)	55.41^{a}(3.81)	25.00^{a}(2.50)	19.58^{a}(3.81)	Clay
LU8	1.41^{a}(0.08)	57.08^{a}(3.81)	26.25^{a}(2.16)	16.66^{a}(2.60)	Clay

Note: Values followed by the same letter within a column are not significantly different at p ≤ 0.05

Bulk density

Statistically significant differences (P ≤ 0.05) were observed among average soil bulk density values of the land units (Table 2). The highest (1.41 g cm-3) and the lowest (0.84 g cm-3) mean bulk density values were recorded for LUs 8 and 2, respectively. The variation in bulk density could be attributed to variation in soil OM content, and intensity of cultivation (Sharma. and Anil, 2003). Accordingly, the highest bulk density for LU 8 could be due to lower soil OM content and higher degree of soil compaction due to intensive cultivation since this LU has been cultivated for a long period of time. In contrast, the lower bulk density in LU 2 could be attributed to relatively higher soil OM content owing to trees litter fall and dieback of fine roots, higher total porosity and less frequent disturbance of the land, and the contribution of trees in loosening the soil structure through their roots. According to Hazelton and Murphy (2016), the limiting value of bulk density at which crop roots are likely to be restricted is 1.4 g cm-3 for clay soils. Most of the soil bulk density values of the different land units of the area were suitable for crop production.

Chemical Properties of Soils under Different Land Units

Soil reaction (pH)

Statistically significant differences ($P \leq 0.05$) were observed among soil pH values of the land units (Table 3). The lowest (6.02) and highest (6.74) pH values were recorded for LU 1, and 8, respectively. As per the ratings established by Jones (2012), soils having a pH value of 6 to 7 are classified as slightly acidic in their reaction (Figure 2). 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 limited within the observed pH range.

Organic matter, total N, and available P

Significant differences ($p \leq 0.05$) were observed among soil OM values of the land units (Table 3). The mean organic matter content of the soils in the area ranges from 2.96% (LU 8) to 4.59% (LU 3). According to the rating suggested by Tekalign (1991), the soil OM content of all LUs in the study area can be categorized in the range of medium soil OM content (Figure 2). Although the OM content of the soils in all land units falls in the same rating, there is statistical difference in the land units. The most probable source of variation in soil OM contents among the land units might be variation in altitude, intensity of cultivation, cropping system and soil management practices. The highest OM content of LU 3 could be due to the relatively better residue deposition of the previous crop, and the addition of litter from scattered trees around the crop land. On the other hand, the lower OM content in other land units might be due to higher rate of OM decomposition aggravated by intensive cultivation, and also perhaps because of low rate of return of organic materials as crop residues due to a number of competing ends such as animal feed, fuel, construction, etc. Similarly, Alemayehu and Sheleme (2013) reported that lower OM was recorded in cultivated field than other land uses; and this was because of the effect of continuous cultivation and OM oxidation. The medium content of OM in land units indicates good structural condition, high structural stability, pH buffering capacity, soil nutrient levels (especially N), water-holding capacity Hazelton and Murphy (2016).

Table 3. Soil pH, EC, OM, Total N, and available P under different land units

Land unit	PH (H_2O)	EC (dS/m)	OM (%)	Total N (%)	Available P (mg kg^{-1})
LU1	6.02^{d}(0.01)	0.17^{b}(0.03)	3.99^{b}(0.19)	0.21a(0.01)	12.44^{a}(1.00)
LU2	6.04^{d}(0.01)	0.19^{b}(0.07)	3.78^{b}(0.15)	0.21a(0.01)	11.76^{ab}(0.37)
LU3	6.20^{c}(0.10)	0.17^{b}(0.07)	4.59^{a}(0.45)	0.24^{a}(0.03)	11.98^{a}(0.75)
LU4	6.02^{d}(0.01)	0.27^{b}(0.14)	3.13^{c}(0.16)	0.15^{b}(0.01)	11.38^{ab}(0.92)
LU5	6.41^{b}(0.01)	0.19^{b}(0.09)	3.04^{c}(0.11)	0.12^{bc}(0.01)	9.91b^{c}(0.67)
LU6	6.64^{a}(0.04)	0.34^{b}(0.16)	3.06^{c}(0.18)	0.12^{bc}(0.01)	8.63^{cd}(0.38)
LU7	6.73^{a}(0.03)	0.49^{ab}(0.36)	3.02^{c}(0.09)	0.10^{c}(0.00)	7.33^{de}(0.87)
LU8	6.74^{a}(0.01)	0.79^{a}(0.04)	2.96^{c}(0.05)	0.11^{c}(0.00)	6.40^{e}(0.33)

Note: Values followed by the same letter within a column are not significantly different at $p \leq 0$; EC=Electrical conductivity; OM=Organic matter

The total N was significantly ($p \leq 0.05$) affected by differences in land units (Table 3). The average percent total N content of the soils in the study area ranged from 0.10% (LU7) to 0.24% (LU3). According to the rating suggested by Tekalign (1991), soils of LUs 1, 2, 3 and 4 were medium while the soils of LUs 5, 6, 7 and 8 were found to be low in total N content. The contents of total N of soils in the area showed a similar trend with the contents of OM. These facts indicate that the major source of total N and its ultimate source of variation is OM content. Consequently, the lower total N content in LU 7 could be due to its lower OM content as a result of faster rate of degradation and consequent removal of the OM, coupled with limited application of mineral N and organic fertilizers. Land units 1, 2, 3, and 4 had moderate contents of total N as compared to the remaining cultivated land units. These land units are found with dispersed trees on farm lands, near settlements and they have better chances for receiving organic N sources due to anthropogenic activities. These lands in general need optimum N application for increased productivity and sustainable yield of agricultural crops.

The average contents of available P in the soils of the area ranged from 6.40 mg kg^{-1} (LU 8) to 12.44 mg kg^{-1} (LU 1) of soils (Table 3). Based on the rating suggested by Olsen (1954), the available P contents of LUs 1, 2, 3, and 4 were found in high ranges, whereas, the LUs of 5, 6, 7 and 8 are rated in medium ranges (Figure 2). The variability in available P contents of soils might be due to different soil management practices, specifically, type and rate of organic fertilizers and inorganic fertilizer applied to the cultivated land units.

The higher P content in all cultivated land units could be due to the application of NPS fertilizer (residual P), suitable soil pH for P availability, and the consequence of long-term manure and house refuse applications and the associated increase in microbial activity as they are found near to settlement areas.

Table 4. Cation exchange capacity, exchangeable bases, and percent base saturation of soils under different land units of the crop land

Land unit	CEC (cmol(+)/kg)	Ca^{2+} (cmol(+)/kg)	Mg^{2+} (cmol(+)/kg)	K^{+} (cmol(+)/kg)	Na^{+} (cmol(+)/kg)	PBS (%)
LU1	27.00^{a}(1.58)	7.08^{a}(0.40)	3.93^{a}(0.65)	0.67^{a}(0.07)	0.63^{a}(0.09)	45.59^{c}
LU2	22.40^{bc}(0.91)	6.22^{ab}(0.08)	3.03^{abcd}(0.03)	0.65^{ab}(0.04)	0.61^{a}(0.09)	46.92^{c}
LU3	20.23^{ab}(1.60)	6.35^{ab}(0.11)	3.36^{ab}(0.34)	0.58^{abc}(0.01)	0.57^{ab}(0.03)	41.40^{d}
LU4	2.4b^{c}(0.91)	6.67^{a}(1.21)	3.25^{abc}(0.40)	0.58^{abc}(0.03)	0.62^{a}(0.01)	49.64^{bc}
LU5	19.46^{cd}(1.20)	5.58^{ab}(0.57)	2.34^{cd}(0.29)	0.55^{bcd}(0.02)	0.51^{ab}(0.01)	46.15^{c}
LU6	15.86d^{e}(1.70)	5.91^{ab}(0.36)	2.57^{bcd}(0.44)	0.52^{cde}(0.03)	0.45^{b}(0.03)	59.58^{b}
LU7	2.66^{e}(1.61)	5.02^{b}(0.68)	2.30^{cd}(0.08)	0.45^{de}(0.02)	0.45^{b}(0.02)	64.93^{ab}
LU8	1.90^{e}(0.78)	4.93^{b}(0.35)	2.21d(0.07)	0.43^{e}(0.01)	0.43^{b}(0.02)	67.23^{a}

Note: Values followed by the same letter within a column are not significantly different at $P \leq 0.05$; CEC=Cation exchange capacity; PBS=Percent base saturation

Cation exchange capacity, exchangeable cations, and PBS

Analysis of variance showed that the CEC of the soils in the study area varied significantly ($p \leq 0.05$) among the land units (Table 4). The highest (27.00 cmol$_{(+)}$ kg^{-1}) and the lowest (11.90 cmol$_{(+)}$ kg^{-1}) mean values of CEC were recorded in LUs 1 and 8, respectively. Based on the rating suggested by Hazelton and Murphy (2016), soils of LUs 1 and 3 were categorized to high range, whereas the CEC value of the remaining land unit were medium (Figure 3).

The variation in CEC values of the studied soils may be because of variation in OM content, type and amount of clay, and intensity of cultivation. The relatively higher CEC value of soils of LUs 1 and 3 could be mainly due to relatively higher clay content and probably the predominance of 2:1 clay mineral like semectites. The highest CEC value of land unit 1 may be due to its relatively higher OM content. Consistent with this suggestion, Solly *et al.* (2020) reported that OM is responsible for about 35-50% of the total CEC of surface mineral soils. Therefore, soil CEC is expected to increase through improvement in soil OM content. Although there is variability in CEC values of the studied soils, the medium to high CEC values indicate that the soils can retain high amounts of cations such as K^+, Ca^{2+} and Mg^{2+} to support plant growth. Fekadu *et al.* (2018) reported that high CEC offers high buffering capacity to the soil. Furthermore, high CEC values have been implicated in high yields obtained from most agricultural soils.

Exchangeable basic cations varied significantly ($P \leq 0.05$), for exchangeable Ca2+, Mg2+, K+ and Na+ ($P < 0.05$) for the land units (Table 4). The highest (7.08 cmol(+) kg-1) and the lowest (4.93 cmol(+) kg-1) mean values of exchangeable Ca2+ were recorded for LUs 1 and 8, respectively. Soils of LUs 1 and 8 had the highest (3.93 cmol(+) kg-1) and lowest (2.21 cmol(+) kg-1) exchangeable Mg2+. The highest exchangeable K+ (0.67 cmol(+) kg-1) the lowest exchangeable K+ (0.43 cmol(+) kg-1) were recorded in LUs, 1 and 8. The lowest (0.43 cmol(+) kg-1) exchangeable Na+ was recorded in LU 8 while the highest exchangeable Na+ (0.63 cmol(+) kg-1) was recorded in LU 1 (Table 4). The order of exchangeable basic cations in the studied land units is Ca2+ > Mg2+ > K+ > Na+. Based on the rating of exchangeable basic cations set by FAO (2006), the mean values of exchangeable Ca2+ in all LUs except LUs 8 are medium ranges and the only LUs 8 are low range. The mean value of exchangeable Mg in LUs 1, 2, 3, 4, were high whereas it was medium in LUs 5, 6, 7, 8. The mean value of exchangeable K+ in LUs, 1 and 2 were high but medium in LUs, 3, 4, 5, 6,7,8 (Figure 3). On the other hand, the soils of all LUs exchangeable Na were medium.

The variation in exchangeable basic cation content among land units could be due to variation in OM content, amount of clay, cultivation intensity, elevation, and soil management practices. Exchangeable Ca2+ and Mg2+ appeared to decrease in the lower elevation sites of the study area. This might be attributed to removal of these exchangeable basic cations by leaching from higher topography and their subsequent accumulation in the lower elevations. From soil fertility point of view, exchangeable Ca2+, Mg2+, and K+ in most of the land units were in the range of medium. This implies that soils of the study area are not deficient in exchangeable basic cations. However, supplementing the soils with regular addition of organic and inorganic fertilizers materials are required to meet its maintenance requirement and sustaining productivity. Corroborating this result, Tuma (2007) also reported the same order of abundance of basic cations on the exchangeable complex of fluvial soils in Gamo Gofa zone, Ethiopia, and pointed out that such an order is favorable for crop production.

The highest (67.23%) and the lowest (41.40%) mean values of PBS were recorded for LUs 8 and 3, respectively (Table 13). Based on the rating suggested by Hazelton and Murphy (2016), soils of LUs 1-6 are in a moderate range in status while LU 7 and 8 fall in a high rating. The trends in a high PBS followed the trend of the LUs with lower CEC values. Thus, variability in PBS could also be due to variation in pH, OM content, soil texture, and soil management practices.

Mapping of Soil Fertility status

The topographic map of the study area (1: 50000) was used as a reference to undertake field survey and thereby to demarcate the initial sampling sites using GPS. The easting and northing coordinates (grids) of each sampling sites were thoroughly recorded. The size of each sampling site was large enough to represent each of the respective 8 land units for mapping the spatial variability of the soil fertility in the study area. Accordingly, the total area of the land units was 10461 ha with the minimum and maximum areas of 686.8 and 2281.6 ha for land units 5 and 3, respectively.

The selected soil fertility parameters mapped are pH, OM, Total N, available P, K+, Ca2+, Mg2+, and CEC (Figure 2 and 3). Area of each selected soil fertility parameters with respective soil fertility status is presented in Appendix Table 14. Medium total N content covers 9327.5 ha (89.2%) of the total area of the land units whereas high total N content takes greater portion (10.8%) of the land units. The available P contents of the soils covers 6222.7 ha (59.5%) for high, 4239 ha (40.5%) for medium status of the land units.

The area coverage of available K+ is 1267.6 ha (12.1%) and 9194.1ha (87.9%) for the low and medium status of land units respectively. High CEC shared 1267.6 ha (12.2%) and low CEC shared 9194.1 ha (87.9%) of the total area of the land units. The total area of the watershed contained moderate soil OM (Figure 2).

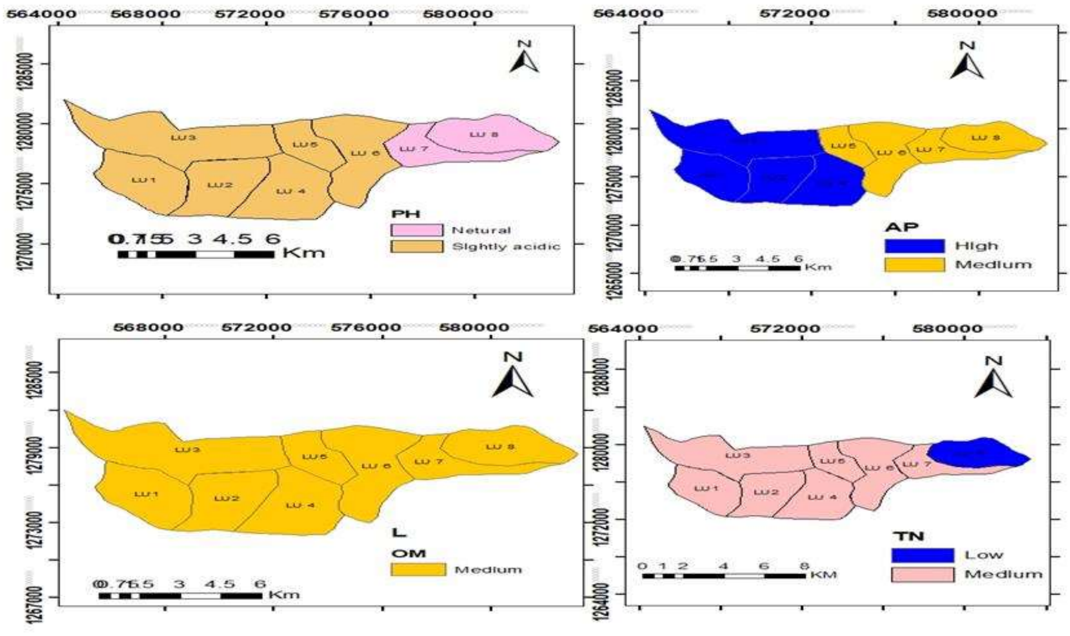

Figure 2. Spatial distribution of pH, OM, total N, Available P

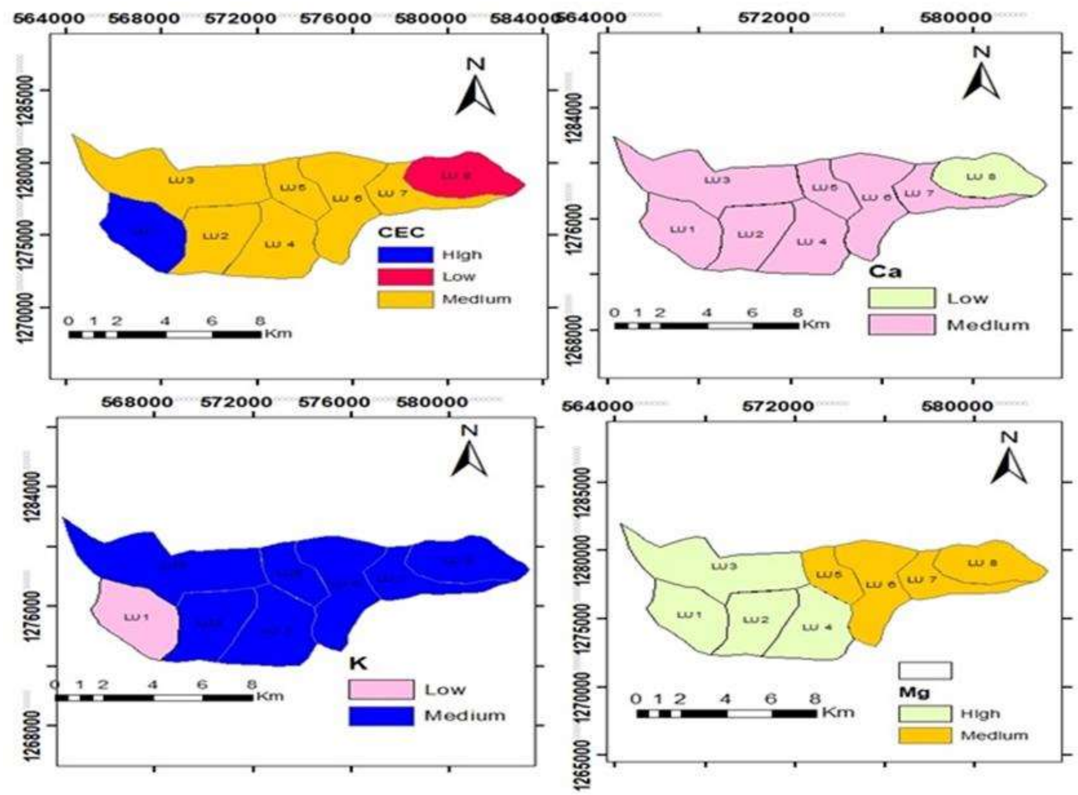

Figure 3. Spatial distribution of exchangeable Ca2+, K+ Mg2+ and CEC

Conclusions

Twenty four soil samples from eight land units were collected, analyzed and the maps were generated using GIS software. Generally, the soil textural class was clay in all land units. The bulk density value varied significantly among the sampled land units. However, these bulk density values were under unsuitable range for crop production. Soil pH was slightly acidic in all land units and preferred by most agricultural crops. Soils of half of the sampled land units had medium total N content, while the remaining had low. The available P contents of the sampled land units were rated between high to medium range. Similarly, the soils from two of the land units were categorized to high CEC range, whereas the CEC value of the remaining land unit was medium. The overall result showed immediate soil fertility management intervention should be applied. Organic and inorganic fertilizers sources should be applied depending on the limitation of the identified nutrient in each land unit to maintain the fertility of the land for sustainable production of agricultural crops.

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