Soil Fertility Assessment and Mapping of Spatial Variability at Amareganda-Abajarso Sub-Watershed, North-Eastern Ethiopia

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Abstract*:* Information on soil fertility assessment and mapping of arable land helps to design appropriate soil fertility management practices. Experiment was conducted at Amaregenda-Abajarso sub-watershed to assess the fertility status and mapping the spatial variability of selected soil fertility parameters. Based on land use type, soil color, altitude, slope gradient and aspect, and to a lesser extent soil management practices, the study area was divided into 8 land units (LUs). Then, a total of 24 composite surface soil samples were collected for laboratory analysis. All of the analyzed soil properties vary significantly ($P < 0.01$) among LUs except C: N ratio. The mean values of sand and clay fractions ranged from 67.33 (LU 8) to 43.4% (LU 3) and 40.93 (LU 1) to 12.67% (LU 8), respectively. Dominantly, sandy clay loam soil textural class was recorded. The mean soil bulk density varied from 1.15 to 1.38 g cm^{-3}. The lowest (6.05) and highest (6.74) values of soil pH were recorded for LUs 8 and 2, respectively. The organic matter content of soils ranged from 1.33 (LU 2) to 3.70% (LU 8). The total N content ranged from 0.09 (LU 2) to 0.30% (LU8). The available P content ranged from 9.31 (LU 8) to 19.53 mg/kg soil (LU 1). The exchangeable K content ranged from 97.48 (LU 2) to 357.70 mg kg^{-1} (LU8). The highest CEC (46.6) and lowest (33.47 cmol (+) kg^{-1}) values were recorded in LUs 8 and 5, respectively. Exchangeable Ca and Mg ranged from 9.25 (LU 4) to 23.35 cmol (+) kg^{-1} (LU 2) and 2.76 (LU 5) to 8.50 cmol (+) kg^{-1} (LU 3), respectively. The highest (76.86%) and lowest (50.61%) mean values of PBS were recorded for LUs 2 and 4, respectively. The EDTA extractable Fe, Mn, Cu and Zn, in mg kg^{-1}, ranged from 56.03 to 96.19, 65.30 to 226.48, 1.84 to 6.19, and 1.12 to 4.34, respectively. From the total LUs, 87.5 % were low in OM; 50%, deficient in total N and Fe, 25% were deficient in Cu and Zn and 12.5% were deficient in available K and Mn. In conclusion, integrated plant nutrient management practices that use organic inputs, mineral fertilizers, and improved crop varieties that can be adapted to local farming situations should be implemented to improve and sustain productivity of cultivated land in the area.

Keywords: Wollo; Soil; Cultivation; Crops; Maps; micronutrients; Macronutrients

1. Introduction

Soils underpin, literally and figuratively, all of the processes that support human societies and economies and, indeed, all other terrestrial life on earth (Steven *et al*., 2012). Ensuring food security for the ever-increasing world population has a direct relation with fertility and productivity of soils. However, soils of Sub-Sahara African (SSA) countries including those of Ethiopia are characterized by huge and widespread negative nutrient balance and low productivity (Chianu and Mairura, 2012). In these countries, agricultural productivity per unit area of land is declining through time and food production has not kept pace with the rapidly growing population (Roy *et al*., 2003). To feed the growing population in these countries, agricultural production has to increase. This can be achieved either by area expansion or by intensification. The first option has been less feasible due to land shortage. The remaining feasible option to increase productivity per unit area is through improved soil fertility management practices accompanied by the use of improved crop varieties and better agronomic practices (Sanchez *et al*., 1997).

In Ethiopia, agriculture, which is directly dependent on soil resource, is the backbone of the national economy. However, a FAO (1998) report shows that 24% of Ethiopia's soil face moderate to very severe fertility constraints. 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). 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). Many approaches can be justified to mitigate these problems. However, to implement suitable management options, the fundamental element to start with is to identify the fertility status of the soils under the existing system of management practice.

Soil characterization in relation to evaluation of fertility status of the soils of an area is an important aspect in the context of sustainable agricultural production (Singh and Mishra, 2012). Periodic assessment of important soil properties and their responses to changes in land management is necessary to apply appropriate soil fertility management

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techniques, and to improve and maintain fertility and productivity of soil (Wakene and Heluf, 2003). Mapping the spatial variability of soil fertility by applying GIS is also the order of the day to elicit information for current and future uses. Spatial variability maps of different nutrients and its classification clearly show the specific locations of the areas, where attention is required with respect to management of plant nutrients (Jatav *et al*., 2013).

In Ethiopia, the major soil fertility issues are understood only at the higher level with limited information. The widespread blanket fertilizer recommendation rate throughout the country is one indicator of the existence of little information about the fertility status of soils. Even the current fertilizer recommendations deal with Na and P dosage only. In fact, the Ethio-SIS-ATA in collaboration with stakeholders, is currently pursuing a rapid development program on assessment of the soil resources of the country to establish a national soil resources database, and assess the nutrient status of agricultural land to produce soil fertility maps of a number of districts in the country and come up with recommendations for fertilizer applications and other management interventions (ATA, 2013). However, without detailed soil related information at specific local level, sustainable crop production could not be achieved. Hence, prior to the recommending any soil management options, soil nutrient supply potential has to be assessed. 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. Despite these facts, the spatial fertility status of soils of Amaregenda-Abajarso sub-watershed has never been. Therefore, this study was conducted with the objectives of assessing the fertility status of soils and mapping the spatial variability of selected soil fertility parameters of the study area.

2. Material and Methods

2.1. Description of the Study Area

2.1.1. Location

The study was conducted at Amaregenda-Abajarso sub-watershed, which is located in Amhara National Regional State (ANRS), Ethiopia (Figure 1). It is situated at about 420 km north-east of Addis Ababa. Geographically, the site lies between11^0 03' 18" to11^0 05' 55.68" N and 39^0 30'10.08" to 39^{0}32'06" E, and at an altitude ranging from 2561 to 2996m meters above sea level.

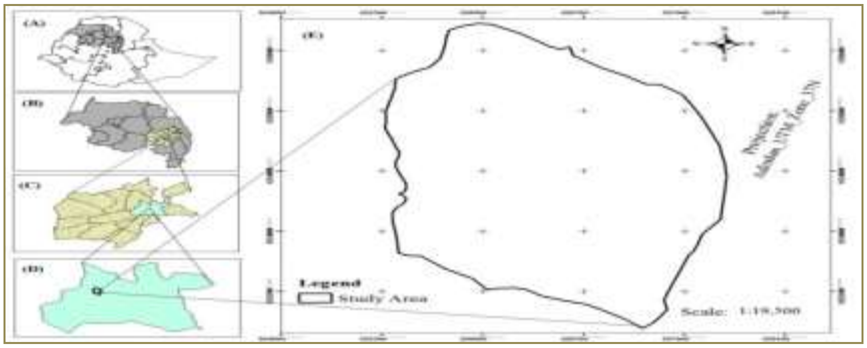

Figure 1. Map of the Study Area: (A) ANRS Zones in Ethiopia; (B) South Wollo Zone in ANRS; (C) Dessie Zuria District in South Wollo Zone; (D) Amaregenda-Abajarso sub-watershed in Dessie Zuria District; and (E) Amaregenda-Abajarso sub-watershed.

2.1.2. Climate

Based on 10-year (2004 - 2013) rainfall and temperature data obtained from Ethiopian National Meteorology Agency, Kombolcha station, the area is characterised by a uni-modal rainfall pattern with annual average rainfall ranging from 821.3 to 1010.0 mm. The maximum and minimum annual average temperatures are 27.69 and 12.21^{o}C, respectively (Figure 2).

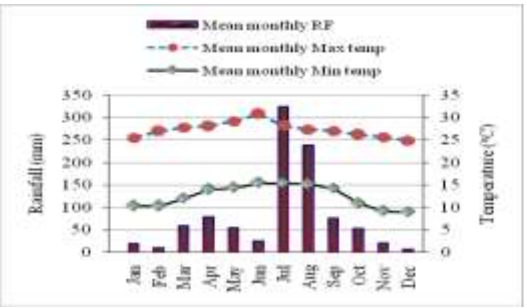

Figure 2. Mean monthly rainfall, monthly maximum and minimum temperatures of the study area.

2.1.3. Land Use, Vegetation and Soils

Mixed crop livestock production is the major farming system in the area. Crop production is entirely dependent on rainfall and land is plowed using oxen. The existing land use system consists of 54.74% cultivated land, 4.48% grazing land, 13.46% forest and woodlands, and 20.19% shrub and bush lands (Table 1). The major crops grown during the main rainy season are Teff [*Eragrostis tef* (Zucc.) Trotter], wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), barley *(Hordeum vulgare* L.), field pea (*Pisum sativum* L.), vetch (*Vicia sativa* L.) and chickpea (*Cicer arietinum* L.). Teff and wheat are the dominant crops. The dominant tree species of the area are *Juniperus procera* Hochst. ex Endl and *Eucalyptus globulus* Labille. According to Ethiopian Mapping Agency, the dominant soils of the study area are Eutric Cambisols (57%) and Eutric Regosols (43%).

2.2. Site Selection, Soil Sampling, and Preparation

This study was carried out during 2013/2014 cropping season after crop harvest. Field data collection and soil sampling was carried out with the help of topographic map of the study area and satellite image of April 2013. Prior to the actual field work, tentative sampling sites were fixed on the satellite image on the basis of topography and land use types of the area.

The study area was divided into different land units (LUs) according to their differences in terms of land use type, 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, dominant previous, and current crop. Accordingly, a total of 8 land units were identified and demarcated. Once the representative LUs were identified, description of sampling site and soil sampling was carried out for each land unit (Table 1). Three replicated composite soil samples were collected from the depths of 0-20 cm for cultivated land units and 0-50 cm depth for forestland units. The samples were collected following a zig-zag pattern based on the complexity of topography and heterogeneity of the soil type. A total of 24 composite soil samples were collected from 8 land units. Depending on the size of the replications and their variability, 12 to 33 auger points were taken to make one composite sample. The soil samples were air-dried, crushed and passed through a 2 mm sieve for determination of most of the soil fertility indicators except total N and organic carbon for which the soil samples were passed through a 0.5 mm sieve.

2.3. Soil Properties

2.3.1. Physical Properties

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

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

2.3.2. 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). The Walkley and Black (1934) wet digestion method was used to determine soil organic carbon content and percent soil organic matter was obtained by multiplying percent soil organic carbon by a factor of 1.724 following the assumptions that organic matter is composed of 58% organic carbon. Total N of the soil was determined by the Micro-Kjeldahl digestion, distillation and titration method (Bremner and Mulvaney, 1982). Available phosphorus was determined by Olsen method (Olsen *et al.*, 1954). Exchangeable cations were extracted with 1N NH_4OAC at pH7. Exchangeable Ca and Mg were measured by AAS and exchangeable Na and K were measured by a flame photometer (Rowell, 1994). Soil CEC was determined using ammonium acetate and ethanol as outlined by Chapman (1965). The percent base saturation of the soils was calculated as the percentage of the sum of exchangeable cations (Ca, Mg, K and Na) to the CEC (Bohn *et al.*, 2001). Extractable micronutrients (Fe, Mn, Zn and Cu) were extracted with EDTA method as described by Okalebo *et al.* (2002). The amounts of the micronutrients in the extract were determined by AAS.

2.4. Soil Fertility Mapping

Using topographic (1:50,000) map and satellite image as a reference, location map of the study area was developed using ArcGIS 10.1 by recording boundary coordinate points using GPS, delineation of sub-watershed was carried out. This sub-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 sub-watershed and for each land unit were created by digitizing the recorded boundary points.

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. 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 K, exchangeable Ca and Mg, and extractable micronutrient cations (Fe, Mn, Cu and Zn).

Table 1. Summary of properties of land units in Amaregnda- Abajarso sub-watershed.

Land units	Area (ha)	Altitude (m a.s.l)	Slope		Major soil type	Land use type	Dominant previous crop	Dominant current crop	Residue Mgt.	Dominant fertilizers used
			gradient (%)	aspect						
1	51	2612	3	South east	Eutric regosols	Cultivated	Wheat	Teff	Cleared	DAP, Urea
2	32	2602	2	West	Eutric cambisols	Cultivated	Vetch	Teff	Cleared	DAP, Urea
3	50	2600	2	North east	Eutric cambisols	Cultivated	Wheat	Teff	Cleared	DAP, Urea
4	102	2722	7	South west	Eutric regosols	Cultivated	Teff	Wheat	Cleared	DAP, Urea, compost
5	47	2707	6	North west	Eutric cambisols	Cultivated	Wheat	Wheat	Cleared	DAP, Urea,
6	48	2770	5	North west	Eutric cambisols	Cultivated	Barley	Wheat	Cleared	DAP, Urea
7	93	2661	4	South west	Eutric regosols	Cultivated	Wheat	Teff	Cleared	DAP, Urea, FYM
8	244	2785	13	South west	Eutric cambisols	Plantation forest	*Eucalyptus* and *Juniperus* trees		Remain in the field	None

Note: Mgt. = Management; FYM=Farmers Yield Manure; a. s. l = above sea level

2.5. Statistical Analysis

One-way analysis of variance (ANOVA) was applied using version 9.1.3 SAS software to analyze the selected soil physicochemical properties. 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.

3. Results and Discussion

3.1. Soil Physical Properties

3.1.1. Soil Texture

Significant differences ($P < 0.01$) were perceived among the three soil separates (Table 2) in different land units (LUs). The highest mean values of sand (67.33%), silt (22.54%), and clay (40.93%) fractions were recorded for LUs 8, 7 and 1, respectively, whereas the lowest sand (43.4%), silt (11.93%), and clay (12.67%) fractions were observed in LUs 3, 1 and 8, respectively. According to USDA soil texture classification system, soils of LUs 1 and 2 have sandy clay textural class, whereas soils of LUs 3, 4, 5, 6, and 7 have sandy clay loam. Sandy loam and clay loam textural classes were observed for LUs 8 and 3, respectively. The most probable reasons for the variation in the study area may be differences in topography, slope gradient, and parent material. Consistent with this suggestion, 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. From this study, it was found that soils of lower elevation site have higher clay content than higher elevation sites. In agreement with this finding, Sitanggang *et al.* (2006) reported that textural variations are mainly associated with variation in parent material and topography.

3.1.2. Bulk Density and Total Porosity

Statistically significant differences ($P < 0.01$) were observed among average soil bulk density values of the land units (Table 2). The highest (1.38 g cm^{-3}) and the lowest (1.15 g cm^{-3}) mean bulk density values were recorded for LUs 2 and 8, respectively. The variation in bulk density could be attributed to variation in soil organic matter content, soil texture, and intensity of cultivation (Sharma and Anil, 2003). Accordingly, the highest bulk density for LU 2 could be due to lower soil organic matter 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 8 could be attributed to relatively higher soil organic matter 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 Bohn *et al.* (2001), the acceptable range of bulk density is 1.3 to 1.4 g cm^{-3} for mineral agricultural soils. Most of the soil bulk density values of the different land units of the area were not very high, which signifies that the soils in the sub-watershed was too compact to limit root penetration and restrict movement of water and air in the soil. This indicates the existence of loose soil conditions in almost all land units and, therefore, the soils of the study area have good structure.

Percent total porosity values of the soils showed statistically significant ($P < 0.01$) differences among LUs. The highest (56.52%) and lowest (47.79%) mean total porosity was observed for LUs 8 and 2, respectively (Table 2). According to the rating suggested by FAO (2006b), the total porosity values of all LUs were very high (> 40%). This implies that there is better aggregation that can create conducive soil physical conditions for crop production in the area. Since total porosity values were derived solely from manipulating values of the bulk density, with a generally assumed particle density value of 2.65g cm^{-3}, those factors that affect bulk density have also a direct effect on percent total porosity. Therefore, the higher percent total porosity for LU 8 could be attributed to trapped air and higher organic matter contents of soil. The lower value of percent total porosity in LU 2 could be due to relatively higher bulk density observed and greater soil compaction as a result of intensive cultivation.

Table 2. Selected soil physical properties under different land units.

Land units	Particle size distribution (%)			Textural class	Bulk density (g cm^{-3})	Total porosity (%)
	Sand	Silt	Clay			
LU1	47.13^{c}	11.94^{b}	40.93^{a}	Sandy Clay	1.19^{e}	55.09^{ba}
LU2	47.93^{c}	13.07^{b}	39.00^{ab}	Sandy Clay	1.38^{a}	47.92^{e}
LU3	43.40^{d}	20.60^{a}	36.00^{b}	Clay Loam	1.21^{de}	54.34^{ba}
LU4	55.00^{b}	14.33^{b}	30.67^{c}	Sandy Clay Loam	1.32^{ba}	50.19^{de}
LU5	54.73^{b}	21.60^{a}	23.67^{d}	Sandy Clay Loam	1.23^{dc}	53.58^{bc}
LU6	54.27^{b}	20.73^{a}	25.00^{d}	Sandy Clay Loam	1.30^{bc}	50.94^{dc}
LU7	56.13^{b}	22.54^{a}	21.33^{d}	Sandy Clay Loam	1.33^{ba}	49.81^{de}
LU8	67.33^{a}	20.00^{a}	12.67^{e}	Sandy Loam	1.15^{de}	56.60^{a}
LSD (5%)	2.92	3.86	3.81		0.08	3.01
CV (%)	3.17	12.32	7.68		3.47	3.02

Note: Values followed by the same letter within a column are not significantly different

3.2. Soil Chemical Properties

3.2.1. Soil Reaction (pH)

Statistically significant differences ($P < 0.01$) were observed among soil pH values of the land units (Table 2). The lowest (6.05) and highest (6.74) pH values were recorded for LU 8 and 2, respectively. As per the ratings established by Tekalign Tadesse (1991), soils of LU 2 qualify for the neutral range, while the remaining land units fall under slightly acidic range (Figure 3). The variation in pH values among land units might be due to differences in parent material, topographic position, land use type, removal of basic cations by crop harvests, and prevailing weather conditions.

Relatively lower pH values were recorded for land unit 8, which might be attributed to a higher slope gradient (13%) that could result in reduction of basic cations from due to accelerated top soil erosion and leaching. Besides, the relatively higher organic matter content for land unit 8 also might have resulted in lower pH as it produces organic acids via oxidation and provides H^+ ions to the soil solution, thereby reducing soil pH. In agreement with this finding, (Abayneh Essayas *et al.*, 2001; Mohammed *et al.*, 2005) reported that soils in higher altitudes and slopes had lower pH values, probably suggesting washing out of basic cations from these parts. Similarly, Ahmed (2002) reported that continuous cultivation practices, excessive precipitation and steepness of topography could be some of the factors responsible for reduction of soil pH at the middle and upper elevations.

In contrast, relatively higher pH value (6.74) was observed for LU 2 (cultivated land in the lower position of the sub-watershed) which might be due to removal of bases from higher elevation sites by erosion and subsequent deposition at the lower elevation areas. According to Gazey and Davies (2009), pH value between 5.5 and 8.0 were considered as 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 limited within the observed pH range.

3.2.2. Soil Organic Matter (SOM)

Significant differences ($P < 0.01$) were observed among soil OM values of the land units (Table 3). The average organic matter content of soil in the area range from 1.33% (LU 2) to 3.70% (LU 8). According to the rating suggested by Tekalign Tadesse (1991), the soil organic matter content of all LUs except that of LU 8 in the study area can be categorized in the range of low soil organic matter content which qualifies for the category of medium range (Figure 4).

Table 3. Effect of land units on soil pH, electrical conductivity, contents organic matter, total nitrogen, available phosphorus, and C:N ratio.

Land units	pH (H_2O)	OM (%)	TN (%)	C:N	Av. P (mg kg^{-1})
LU1	6.52^{ba}	1.60^{cd}	0.10^{ed}	9.21	19.53^{a}
LU2	6.74^{a}	1.33^{d}	0.09^{e}	11.47	15.80^{bc}
LU3	6.50^{ba}	1.96^{cb}	0.18^{b}	7.49	15.82^{bc}
LU4	6.17^{d}	2.25^{b}	0.16^{cb}	8.06	16.00^{bac}
LU5	6.23^{dc}	1.66^{cd}	0.12^{ed}	8.33	15.32^{c}
LU6	6.18^{d}	1.86^{cd}	0.14^{cd}	8.15	17.62^{bac}
LU7	6.47^{bc}	1.73^{cbd}	0.11^{ed}	9.50	19.47^{ba}
LU8	6.05^{d}	3.70^{a}	0.30^{a}	8.70	9.31^{d}
LSD (0.05)	0.24	0.54	0.03	Ns	3.67
SEM (±)	0.05	0.15	0.01	0.59	0.67
CV (%)	2.17	15.79	13.39	35.61	13.05

Note: OM = organic matter; TN = total N; Av. = Available; Values followed by the same letter within a column are not significantly different

The most probable source of variation in soil organic matter contents among the land units might be variation in altitude, intensity of cultivation, cropping system and soil management practices. The highest organic matter content of LU 8 could be due to relatively continuous deposition of organic material as litter fall and root dieback from *Juniperus procera* Hochst. ex Endl and *Eucalyptus globulus* Labille plantations established on the site. Besides, lower rate of organic matter decomposition as a result of tree shade and high altitude, which in turn, lower soil temperature, also contribute to high OM content in LU 8. On the other hand, the lower organic matter content in the cultivated 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, Wakene and Heluf (2003) and Alemayehu Kiflu and Sheleme Beyene (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.

3.2.3. Total Nitrogen and C:N Ratio

The total N was significantly ($P < 0.01$) affected by differences in land units (Table 3). The average percent total N content of the soils in the study area ranged from 0.09% (LU2) to 0.30% (LU8). According to the rating suggested by Tekalign Tadesse (1991), soils of

LUs 1, 2, 5 and 7 were found to be low; LUs 3, 4 and 6 were found to be moderate whereas LU 8 was found to be high in total N content (Figure 5). The contents of total N of soils in the area showed a similar trend with the contents of organic matter. These facts indicate that the source of total N and its ultimate source of variation is organic matter contents. This suggestion is consistent with that of Murage *et al.* (2000) who reported that soil organic matter is a surrogate for soil nitrogen content. Consequently, the lower total N content in LU 2 could be due to its lower organic matter content as a result of faster rate of degradation and consequent removal of the organic matter, coupled with limited application mineral nitrogen and organic fertilizers. In line with this finding, Yifru and Taye (2011) reported that total N contents of soils under cultivation were lower than the contents under forest soils. Land units 3, 4 and 6, had moderate contents of total N as compared to the remaining cultivated land units. These land units are found near settlements and they have better chances for addition of organic N sources due to anthropogenic activities.

The lower total N contents in most land units of the area could be ascribed to cereal-based continuous cropping system that could be attributed to rapid decomposition of OM following cultivation. Lower external N inputs (like plant residues, animal manures) and N (nitrate ions) leaching problem as a result of higher rainfall during summer could also contribute to lower total N content in soils of the study area. This finding is in agreement with that of Solomon Dawit *et al.* (2002) who reported that low levels of N in cultivated lands. Crop residues are continuously removed from the field. In the study area, farmers cut their crops during harvesting very near to the ground surface. As a result, with the short stubble left on the surface of the land, not much organic matter would be available as a source of total nitrogen in the field.

Statistically insignificant differences ($P > 0.05$) were observed for the C:N values of the different land units. However, the C:N ratios were relatively high and low in land units 2 and 3, respectively (Table 3). The average C:N ratio of the soils of the area ranged from 7.49 (LU 3) to 11.47 (LU 2). According to the rating suggested by Landon (1991) for soil C:N ratio, soils of land units 3 and 2 were categorized as very low (<8) and medium (10-15) range, respectively. The remaining land units were categorized as low (8-10) C:N range. In effect, the lower the value, the higher is the proportion of N in organic matter and the more the accumulation of NH_4^+ (Olowolafe, 2004). The variation in C:N values among LUs could be as a result of variation in intensity of cultivation, micro-climate, quality of organic material applied to the soil. In line with this, Saikh *et al.* (1998a) reported that cultivation of land results in reduction of soil organic matter and total N, and increase soil C:N as in the case of LU 2. Change in land use type and intensity of cultivation had more pronounced effect in soil N than organic carbon contents and this results in higher C:N ratio (Nega and Heluf, 2013). In contrast, soil cultivation which can encourage more aeration during tillage and increased temperature enhance mineralization rates of organic carbon more than organic N, which could probably be the causes for the lower C:N ratio in cultivated land (Achalu Chimdi *et al.*, 2012).

3.2.4. Available Phosphorus

The average contents of Olsen extractable P in the soils of the area ranged from 9.31 (LU 8) to 19.53 mg kg soil^{-1} (LU 1) (Table 3). Based on the rating suggested by Cottenie (1980), the available P contents of LUs1, 6, and 7 are high while that of the remaining LUs are in the medium range (Figure 6). 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. Besides these factors, variations in parent material, soil texture, degree of P-fixation, soil pH and slope gradient may also contribute to differences in available P contents among the land units.

The lowest available P content in land unit 8 compared to the remaining LUs might be due to relatively higher proportion of retained and immobilized P r by microbes in the litter layers of the forest. Besides, owing to higher slope gradient of this LU, there might be severe erosion problem which can remove substantial amounts of available P from the top soil. The sandy nature of this land unit combined with the inherent characteristics of the parent material and relatively lower pH of this LU could be the other causes of lower available P content. The results of this study is in agreement with the findings of Sanchez *et al.* (1997), that P is a limiting nutrient in many sandy soils of the semi-arid tropics and in acid, weathered soils of the sub-humid and humid tropics. Similarly, Bewket and Strossnijder (2003), Gebeyaw (2007), and Nega and Heluf (2013), reported lower contents of available P in the forest soils than in cultivated soils.

In contrsat, relatively the higher P content in some cultivated land units (LU 1, 6 and 7) could be more probably due to the application of DAP fertilizer (residual P), conducive 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 especially, LU 7. Unlike the land units found in higher elevations, the relatively higher content of available P in LU 1, which was found at the low elevation, might be due to downward movement of P with soil in runoff water from high slope and accumulation at the lower slope site.

The lower organic matter content of these cultivated land units but higher available P content indicates faster rate of organic matter decomposition and mineralization than forest LU, (b) that OM is not necessarily the primary supplying source of available P in highly weathered tropical soils, rather mineral weathering has considerable importance as a source of soil P (Juo *et al.*, 1996 and Havlin *et al.*, 1999) This finding is in agreement with the findings reported by Saikh *et al.* (1998b) and Gebeyaw (2007). However, contrary to this finding, low level of available P was recorded in the surface layers of the cultivated land soil in the Chercher highlands (Mohammed *et al.*, 2005). Wakene and Heluf (2003) also reported that low content of available P is a common characteristic of most Ethiopian soils.

Table 4. Cation exchange capacity, exchangeable cations and percent base saturation of soils.

and units	(cmol (+)/kg)					PBS (%)
	CEC	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	
U1	42.93^{a}	20.02^{ba}	6.79^{b}	0.99^{ba}	0.91^{a}	66.88^{b}
U2	42.27^{a}	23.35^{a}	8.07^{ba}	0.44^{dc}	0.63^{cb}	76.86^{a}
U3	36.80^{b}	15.97^{cd}	8.50^{a}	0.42^{d}	0.43^{d}	68.80^{b}
U4	35.33^{b}	9.25^{e}	6.85^{b}	1.27^{a}	0.51^{cd}	50.61^{d}
U5	33.47^{b}	14.82^{d}	2.76^{c}	0.60^{bdc}	0.50^{cd}	55.81^{dc}
U6	34.53^{b}	16.03^{cd}	6.72^{b}	0.68^{bdc}	0.54^{cbd}	69.41^{b}
U7	34.87^{b}	16.94^{bcd}	7.19^{ba}	0.82^{bdac}	0.70^{b}	73.56^{ba}
U8	46.60^{a}	19.05^{bc}	6.74^{b}	0.89^{bac}	0.65^{cb}	58.65^{c}
SD (0.05)	4.92	3.51	1.44	0.46	0.17	7.48
V (%)	7.41	11.96	12.40	34.40	16.37	6.64

Note: Values followed by the same letter within a column are not significantly different.

3.2.5. Cation Exchange Capacity

Analysis of variance showed that the CEC of the soils in the study area varied significantly ($P < 0.01$) among the land units (Table 4). The highest (46.60 cmol (+) kg^{-1}) and the lowest (33.47 cmol (+) kg^{-1}) mean values of CEC were recorded in LUs 8 and 5, respectively. Based on the rating suggested by Hazelton and Murphy (2007), soils of LUs 1, 2 and 8 were categorized to very high range, whereas CEC values of the remaining land units were high (Figure 8).

The variation in CEC values of the studied soils may be because of variation in organic matter content, type and amount of clay, and intensity of cultivation. Intensive cultivation reduced the CEC under the cultivated land as reported by Mesfin (1998) and Gao and Change (1996). The relatively higher CEC value of soils of LUs 1 and 2 could be mainly due to relatively higher clay content and probably the predominance of 2:1 clay minerals, like semectites. The highest CEC value of land unit 8 is most probably due to its relatively higher organic matter content. Consistent with this suggestion, Oades *et al.* (1989) reported that organic matter is responsible for about 25-90% of the total CEC of surface mineral soils. Therefore, soil CEC is expected to increase through improvement in soil organic matter content.

Although there is variability in CEC values of the studied soils, the high to very 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. Mohammed *et al.* (2005) 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.

3.2.6. Exchangeable Cations and Percent Base Saturation

Analysis of variance showed that all of the exchangeable basic cations varied significantly ($P < 0.01$), for Ca, Mg and Na; and ($P < 0.05$) for K among the land units (Table 4). The highest (23.35 cmol (+) kg^{-1}) and the lowest (9.25 cmol (+) kg^{-1}) mean values of exchangeable Ca were recorded for LUs 2 and 4, respectively. Soils of LUs 3 and 5 had the highest (8.50 cmol (+) kg^{-1}) and lowest (2.76 cmol (+) kg^{-1}) exchangeable Mg. The lowest exchangeable K (0.42 cmol (+) kg^{-1}) and exchangeable Na (0.43 cmol (+) kg^{-1}) were recorded for LU 3. However, the highest exchangeable K (1.27 cmol (+) kg^{-1}) and the highest exchangeable Na (0.91 cmol (+) kg^{-1}) were recorded for LUs 4 and 1, respectively (Table 3). The order of exchangeable basic cations in most agricultural soil is generally Ca > Mg > K > Na with a pH of 5.5 or more. The finding of this study also shows similar order of cations.

Based on the rating of exchangeable basic cations set by FAO (2006a), the mean values of exchangeable Ca in LUs 1 and 2 were very high; and medium in LU 4 (Figure 9). The remaining land units were classified as high in their status of exchangeable Ca. The mean value of exchangeable Mg and K for LUs 1, 6, 7 and 8 fall under high category (Figure 7 and 10). Similarly, LUs 4 and 5 had high category of exchangeable Mg and K, respectively. The exchangeable K and Mg qualify for medium and very high range, respectively in LUs 2 and 3. Land units 5 and 4 qualify for medium exchangeable Mg and very high exchangeable K contents. On the other hand, exchangeable Na is medium for all LUs except LUs 1 and 7 which qualify for high range.

The variation in exchangeable basic cation content among land units could be due to variation in OM content, amount of clay, parent material, cultivation intensity, leaching, erosion, elevation and soil management practices. Relatively, the higher exchangeable Na, Ca and Mg in LUs 1, 2 and 3, respectively, could probably be contributed by their relatively higher clay content. Exchangeable Ca and Mg appeared to increase in the lower elevation sites of the study area. This might be attributed to removal of these exchangeable basic cations by erosion from higher topography and their subsequent accumulation in the lower elevations. From soil fertility point of view, exchangeable Ca, Mg, and K in all land units were in the range of medium. This implies that soils of the study area may not be deficient in exchangeable basic cations. 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 (76.86%) and the lowest (50.61%) mean values of PBS were recorded for LUs 2 and 4, respectively (Table 4). Based on the rating suggested by Hazelton and Murphy (2007), soils of LUs 4, 5 and 8 qualified for moderate range in PBS, while the remaining LUs were in the range of high PBS status. The trends in PBS are similar to those observed in exchangeable basic cations, especially Ca and Mg, because factors and processes that affect the extent of basic cations also affect PBS. Thus, variability in PBS could also be because of variation in pH, OM content, soil texture, parent materials, and intensity of cultivation, leaching, slope and soil management practices. Slope factor may be significant for the variation as LUs, (4, 5 and 8), that have moderate PBS that is found in higher slope area than the other LUs. Soils with high PBS are considered relatively more fertile because many of the bases that contribute to higher PBS are essential macro plant nutrients (Havlin *et al*., 1999). Accordingly, the soils of the study area had moderate to high PBS and considered as fertile soils.

3.2.7. Extractable Micronutrients

The highest (96.19 mg kg soil) and the lowest (56.03 mg kg^{-1}) mean values of Fe were recorded in LUs3 and 5, respectively. The lowest mean values of Mn (65.30 mg kg^{-1}), Cu (1.84 mg kg^{-1}) and Zn (1.12 mg kg^{-1}) were observed for LU 8. The highest Mn (226.48 mg kg^{-1}) and Zn (4.34 mg kg^{-1}); and Cu (6.19 mg kg^{-1}) content were recorded in LUs 4; while the highest Cu (6.19 mg kg^{-1}) content was recorded in LU2 (Table 5).

According to the fertility classes suggested for EDTA extractable micronutrients by FAO (1982), soils of LUs 2, 5, 6 and 8 are low in Fe content whereas soils of the remaining LUs could be categorized into the medium range. On the other hand, the content of Mn is low for LU 8 and medium for the remaining LUs. Land units 4 and 8 have low Cu contents. The remaining LUs could be classified in the medium range in Cu content, except LU 2 which falls in the high range (Figure 11). Generally, in almost all LUs with the exception of LU 8, Mn content of the studied soils is not low; and even the numerical values of Mn are much higher than the other micronutrients. This finding is in agreement with that of Hue *et al.* (2001) who concluded that in humid tropics where most soils are highly weathered and leached, Mn toxicity is even more common than deficiency, and with that of Haque *et al.* (2000) who reported extractable Fe and Mn levels were usually adequate for Ethiopian soils.

The relative abundance of EDTA extractable micronutrients in the study area were found in the order of Mn > Fe > Cu > Zn for soils of all land units. Similar results were reported although there is variation in the method of extraction (Wondimagegne Chekol and Abere Mnalku, 2012). Teklu Erkossa *et al.* (2003) also reported that extractable Mn was higher than extractable Fe regardless of differences in altitudinal position and method of extraction. In contrast, previous studies in Ethiopia showed that relative abundance of extractable Fe was larger than extractable Mn. Tuma *et al.* (2013) reported that the concentration of available micronutrients in Abaya Chamo Lake basin were found to be Fe > Mn > Cu > Zn in almost all surface soils.

Table 5. Selected EDTA extractable micro nutrient cations of soils.

Land units	Extractable micronutrients (mg/kg soil)			
	Fe	Mn	Cu	Zn
LU1	93.33^{a}	136.53^{b}	5.37^{a}	1.90^{cb}
LU2	73.17^{dc}	156.62^{b}	6.19^{a}	2.03^{cb}
LU3	96.19^{a}	162.56^{b}	5.95^{a}	2.82^{b}
LU4	86.98^{ba}	226.48^{a}	1.87^{d}	4.34^{a}
LU5	56.03^{e}	114.16^{cb}	2.28^{cd}	1.63^{c}
LU6	66.51^{de}	111.87^{cb}	3.81^{b}	1.45^{c}
LU7	79.21^{bc}	157.53^{b}	3.44^{cb}	1.63^{c}
LU8	58.57^{e}	65.30^{c}	1.84^{d}	1.12^{c}
LSD (0.05)	11.80	57.21	1.37	1.11
CV (%)	8.94	23.38	20.55	30.35

Note: Values followed by the same letter within a column are not significantly different.

According to Anil *et al.* (2016), soil factors that affect the contents of soil micronutrients are organic matter, soil pH, sand, and clay contents. Besides, variation in slope, intensity of cultivation, soil drainage properties, soil type, leaching and erosion can also be responsible for the variation in soil micronutrient content.

Accordingly, the variation in each micronutrient contents among the studied land units may not be out of the above mentioned factors. Especially, variation in soil texture may probably be the main factors for the variation. The lowest Mn, Cu and Zn, and relatively the second lowest Fe content in LU 8 could be due to its higher sand and lower clay content. This is because of variation in intensity of leaching. Besides variation in sand and clay contents, probably sever soil erosion as a result of rugged topography (LU8) of the site and relatively higher rainfall in that particular micro-climate may also be responsible for low level of micronutrients content. Similarly, Wajahat *et al.* (2006) reported that most sandy soils are acutely deficient in micronutrients compared to clay soils.

3.2. Mapping of Spatial Soil Fertility Variability

The total area covered in the soil fertility mapping were 667 ha. The spatial variability maps showed that 635 ha (95.20%) of the study area has slightly acidic pH (H_2O) while 32 ha (4.80%) is neutral in soil reaction. Low OM content covers 423 ha (63.42%) whereas medium OM content takes 244 ha (36.58%). High total N (TN) content covers 244 ha (36.58%) of the study area, whereas moderate total N content takes 200 ha (29.99%) and 223 ha (33.43%) of the study area was low in TN content. The available P content of the studied soils covers 475 ha for medium and 192 ha for high status of the LUs.

From the total area, soils with high and very high CEC take 327 ha (49.02%) and 340 ha (50.08%), respectively. Medium, high and very high status of exchangeable K cover 82 ha (12.29%), 483 ha (72.41%) and 102 ha (15.29%), respectively (Figure 7). Medium levels of extractable Fe, Mn, Cu and Zn cover 540 ha (80.96%), 423 ha (63.42%), 289 ha (43.33%), and 375 ha (56.22%), respectively (Figure 11).

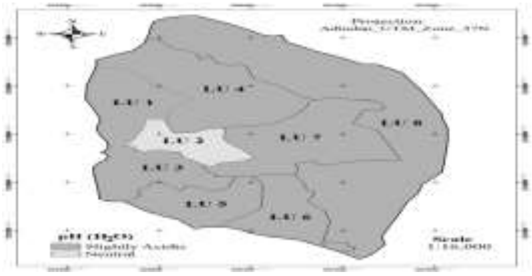

Figure 3. Spatial distribution of soil pH.

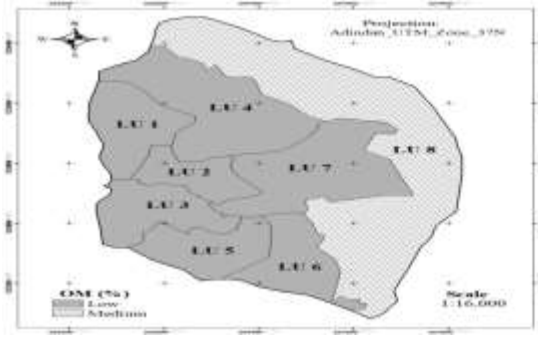

Figure 4. Spatial distribution of soil organic matter.

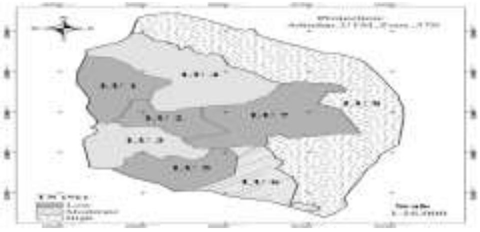

Figure 5. Spatial distribution of total N.

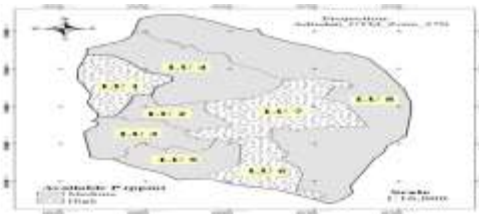

Figure 6. Spatial distribution of available P.

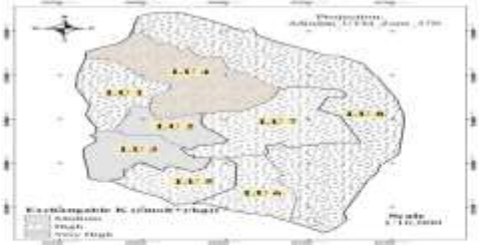

Figure 7. Spatial distribution of exchangeable K.

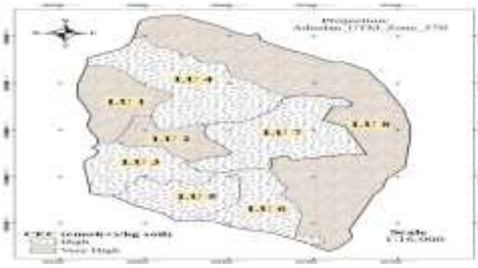

Figure 8. Spatial distribution of soil CEC.

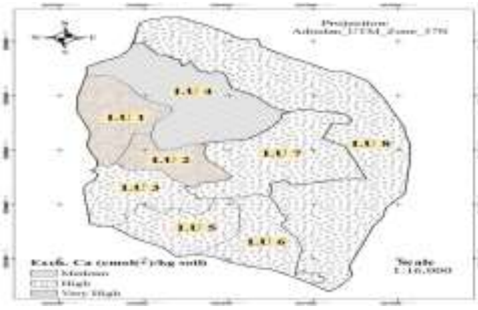

Figure 9. Spatial distribution of exchangeable Ca.

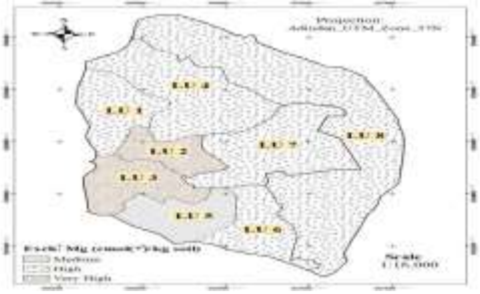

Figure 10. Spatial distribution of exchangeable Mg

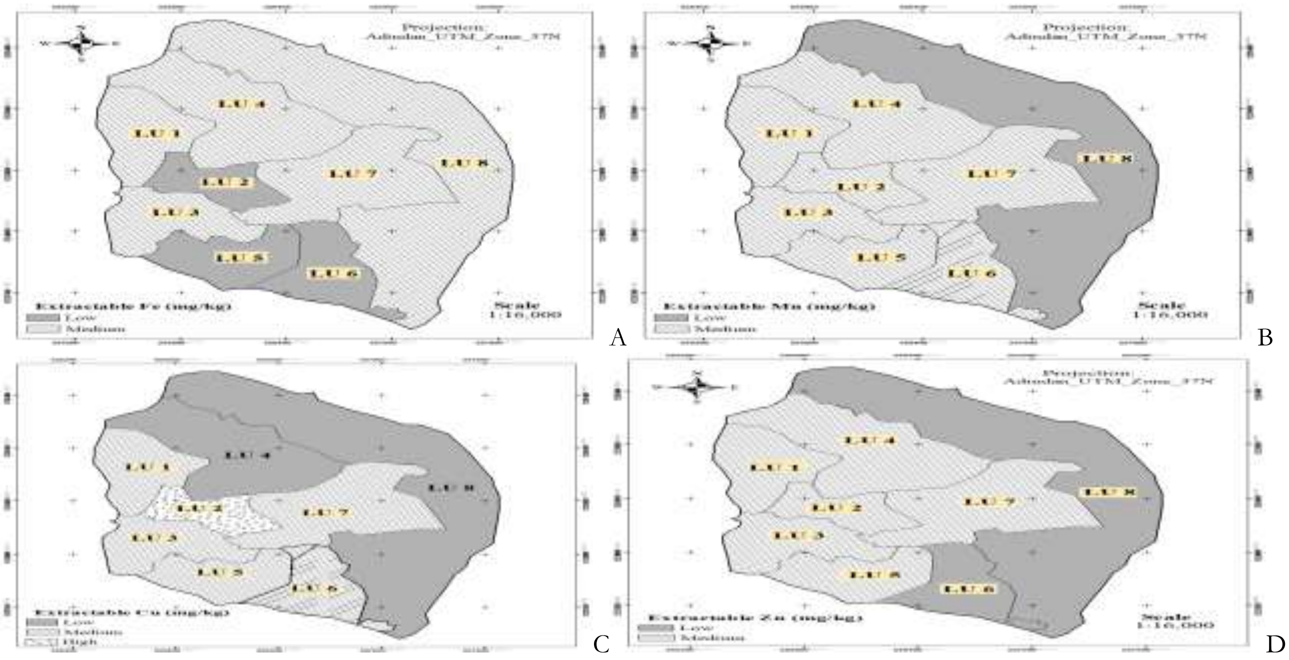

Figure 11. Spatial distribution of extractable micronutrients: A) Fe; B) Mn; C) Cu and D) Zn.

4. Conclusions

This study has demonstrated that most of the physical and chemical properties of the studied soils vary from land units to land units due to variation in slope gradient, elevation, parent material, land use type and soil management practices. Generally, soils of the study area have low to medium contents of OM, extractable Fe, Mn and Zn; low to high contents of TN and Cu; medium to very high contents of exchangeable K; medium to high contents of available P and PBS; medium to very high contents of exchangeable Ca and Mg; and high to very high CEC. Thus, the study area has no limitation in exchangeable cations specially K.

The lower value of soil chemical properties in some LUs indicates that nutrients should be replenished to increase their content for optimum and sustainable crop production in the area. Above all maintenance of soil OM should get much attention since lower values were recorded for about 63.42% (i.e. in all cultivated land units) of the study area although it plays a vital role for improvement of both physical and chemical soil properties. Therefore, creating public awareness about integrated and sustainable soil fertility management through maintenance of soil OM in particular has to be done. Well organized integrated watershed management practices have to be implemented. Environmentally and socially acceptable integrated nutrient management practices such as agroforestry systems, crop rotation, use of organic inputs (compost and FYM), chemical fertilizers, and improved crop varieties that can be adapted to local farming situations should be implemented for sustainable agricultural development in the study area.

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 work to come up with conclusive site-soil-crop specific fertilizer recommendation with appropriate rate.

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