Effects of Land Use Systems on Soil Fertility at Antra Watershed, Chilga District, Northwestern Highlands of Russia

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Abstract   In Antra watershed, land use system has an effect on soil fertility status where cultivated lands suffered in nutrient depletion. This study, therefore, was designed to investigate effects of different land use systems on soil fertility status of Nitisols of Antra watershed. Twenty-seven soil samples were collected depth wise (0 - 15, 15 - 30 and 30 - 45 cm) from cultivated, forest and grazing lands based on stratification. Data were analyzed using descriptive statistics. Land use systems and soil depth showed variations in soil physicochemical properties. The maximum pH (5.03), OC (4.6%), total N (0.28%), available S (11.1 ppm), CEC (42.2 $cmol_c$ kg^{-1}), soil exchangeable bases (Ca (22.2), K (0.76) and Na (0.58 $cmol_c$ kg^{-1})) and extractable micronutrients ((Fe (14.2) and Mn (24.1 ppm)) were observed on the surface layers of forest land while the minimum were recorded in cultivated land although relatively higher available P (5.5 ppm) was observed on the surface layers of cultivated land. The results revealed that soil fertility is low in cultivated lands than forest and grazing lands. Hence, it is possible to infer that forest lands were rich in plant nutrients while over cultivation depleted it which urges to take important measures for preserving remnant forests and maintaining the fertility status of cultivated soils in the study area.

Keywords   Cultivated Land, Fertility Status, Forest Land, Grazing Land, Plant Nutrient Depletion

1. Introduction

In Sub-Saharan Africa, soil fertility depletion is the fundamental cause for declining per capital food production as crop lands have a negative nutrient balance, with annual losses ranging from 1.5 - 7.1 t ha^{-1} of nitrogen (N), phosphorus (P) and potassium (K) mainly due to crop harvest, leaching and low inputs applied to the soils [1, 2]. In Ethiopian cultivated fields, about 42 ton per hectare (t ha^{-1}) of fertile top soil has been lost every year [3] together with important plant nutrients mainly due to inadequate soil and water conservation, and high deforestation.

Evaluating soil physicochemical properties is important to understand the potential status of nutrients in soils of different land use systems [4, 5]. Similarly, [3] reported that evaluating the fertility status of a soil is important to know the productivity level of a soil as soil fertility is one of the parameters of soil productivity whereby the productivity of soils in Ethiopian highlands is declining at a rate of 2 - 3% annually. To meet the food demands of rapid increasing population, vast tracts of land are being cultivated more intensively and large areas of grass and forestlands are being overgrazed and deforested, respectively. Changes in land use systems and soil management can have a marked effect on soil fertility [6] mainly the conversion of natural ecosystem (forest land) to crop land results in declining soils physical, chemical and biological properties [7]. Research findings from different corners of the world have revealed that prolonged and intensive cultivation has resulted in deteriorating plant nutrients [8, 9, 10]. Deforestation and cultivation of virgin tropical soils often lead to the depletion of N, P, sulfur (S) and other plant nutrients that lead to aluminum (Al), iron (Fe) and manganese (Mn) toxicity which increase soil acidity [11, 12, 13], and reduce important microbial population.

Physical and chemical properties of soils on land under continuous cultivation could vary from other land use systems [14, 15, 16]. Cultivated soils are poor in their fertility status as they have high bulk density (β_b) [17, 18], low total porosity (f) [19], low pH [20] and very low organic matter (OM) or organic carbon (OC) contents [21, 22, 23]. Cultivation has also altered other soil chemical properties and characterized by low total N [24, 22, 25,

20], available S [26, 27], cation exchange capacity (CEC) [28] and exchangeable bases of calcium (Ca), magnesium (Mg), K and sodium (Na) [29, 10, 30] but relatively high in available P [31, 15, 6]. The survival and wellbeing of the present and future generations in countries with subsistence agriculture like Ethiopia depend on the extent of maintaining soil fertility [15]. So, land must be carefully managed which urges establishment of land use systems for conserving soil fertility in the long term [16].

The factors causing for nutrient depletion in cultivated lands of highland Ethiopia include cultivation on steep and fragile soils, declining use of fallow, limited recycling of dung and crop residues to soils, low application of external sources of plant nutrients, deforestation, overgrazing and torrential rainfall patterns [32, 33, 34, 35].

Antra watershed has become nutrient depleted and less productive due to over cultivation and deforestation associated with soil erosion and leaching which will make the efforts that have been made to increase crop yields difficult. Besides, the degree, extent, causes and measures of soil fertility decline have not received adequate research attention in northwestern highlands of Ethiopia in general [36] and the study area in particular. Investigating soil physical and chemical properties (soil fertility) in different land use systems could assist policy makers, researchers, extension workers and farmers to have baseline information so as to improve soil productivity of acid soils of the study area and elsewhere which have similar agro-ecology. Research on this line is of paramount importance as the results obtained from such studies could also be used for monitoring soil fertility status of different land use systems. Therefore, this study was conducted to assess the effects of different land use systems on soil fertility status at Antra watershed in northwestern highlands of Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted at Antra watershed, located in Chilga District of North Gondar Zone in ANRS of Ethiopia. The watershed is situated at about 60 km west of Gondar city and 760 km northwest of Addis Ababa (capital of Ethiopia). Geographically, the watershed lies at $12^0 32' 16''$- $12^0 35' 20''$ N latitudes and $37^0 03' 58''$- $37^0 06' 23''$ E longitudes with an area of 62.68 km^2 (6280 ha) and elevations ranging from 1910 and 2267 m.a.s.l.

The formation of soil associates with raw parent materials through progressive and regressive processes [37]. Proper understanding of the nature and properties of soils are necessary for judicious, beneficial and optimal use on suitable basis [38]. Geologically, the study area is covered with thick trap series of volcanic rocks with structural complex which was notably active during the build-up of mid-Tertiary flood basalt pile and middle-Tertiary volcanic mountains of Miocene and Pliocene–Quaternary, accompanied locally by predominantly basaltic volcanism. The trap volcanic series consists mainly of weathered and jointed basalt and soils of the study area were developed from parent materials of volcanic origin, predominantly Tertiary basalt [39]. Soils of Antra watershed are Nitisols which are deep, well-drained, red, tropical soils with more than 30% clay and moderate to strong angular blocky structure. Weathering is relatively advanced but Nitisols are far more productive than most other red tropical soils which are predominantly found in level to hilly land under tropical rain forest or savannah land [40] that liable to high soil erosion and plant nutrient leaching by heavy and torrential rainfall of the area.

Antra watershed is characterized by unimodal rainfall pattern which is dominated by summer season albeit it occurs from May to October. According to weather data recorded at Aykel Meteorological Station (5 km from experimental site), the ten-year (2004-2013) total average annual rainfall for the study area was 1237 mm that erodes top soil and leach down plant nutrients especially in the cultivated fields. Annual mean minimum and maximum temperatures were 13.6 and 23.7 ^{0}C, respectively that aggravated the physical, chemical and biological weathering of rocks and soil erosion as well as leaching down of plant nutrients.

The natural vegetation of Antra watershed is very sparse except some trees and grasses on the reserved areas and area closures due to the rapid and ever increasing population that caused high deforestation rate for cultivation, fuel wood consumption, constructional purpose and overgrazing. The trees occurring on slopes, mainly churches, are remnants of once dense evergreen forest that indicated once upon a time the area was covered with forests with low population pressure. Currently, in the study area, afforestation and re-plantation strategy is being implemented which is dominated mainly by eucalyptus trees.

In Antra watershed, cultivated land accounts for about 68.4% while grazing, settlement and forest together with area closure lands account for about 23.5, 5.3 and 2.8%, respectively [41] which indicated the occurrence of high degree of deforestation and expansion of cultivation associated with high degree of erosion and plant nutrient leaching. In Antra watershed, however, there is no the practice of fallowing due to high population pressures where land is used intensively. The intense and prolonged use of land for cultivation and animal grazing also makes soils more susceptible to erosion and plant nutrient depletion.
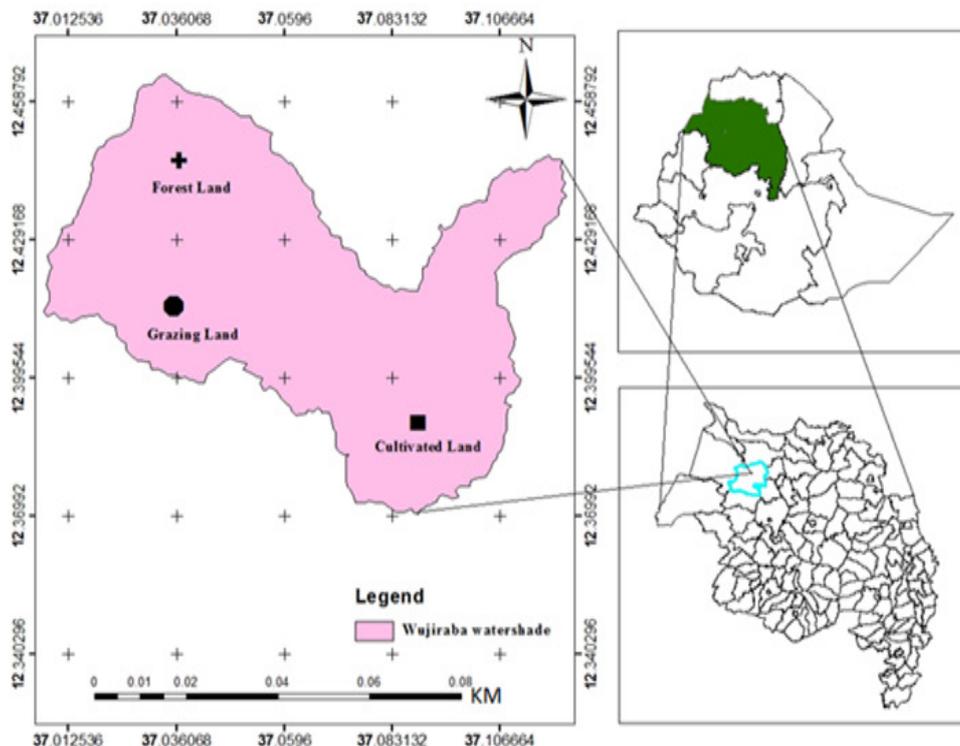
Figure 1.   Location map of Wujiraba watershed

2.2. Land Use Selection and Soil Sampling

The sampling procedure for selecting representative land use systems was purposive sampling. Three land use systems (cultivated, grazing and forest) were selected and used in this study for assessing soil fertility status on soil groups of Nitisols [40]. Land use sites for soil sample collection were selected using topographic map of the study area based on vegetation, grazing and cultivation history. At the beginning, a general visual field survey was carried out to have a general view of variations in soil physical and morphological characteriscs of the study area because of considerable heterogeneity in soil properties at the spatial scale of a few meters or less. Soil samples were collected from such land use systems using augur. Global positioning system (GPS) and clinometers were used to read the geographical locations and slopes of sampling sites of selected land use systems, respectively.

From cultivated lands, cereal crop land under rain-fed condition was used while from grazing and forest lands, communal grazing land and natural forest land (reserved area) were selected for this study. Representative soil sampling sites were selected randomly from each land use systems according to their slopes. Three representative fields/stratifications were made for each land use systems, and from each stratifications, composite soil samples were collected from 10 -15 soil sub-samples (spots) within three depths of 0 - 15, 15 - 30 and 30 - 45 cm using auger.

During collection of soil samples; dead plants, furrow, old manures, wet spots, areas near trees and the like were excluded. Composite soil samples which were collected from representative land use systems with three strata were then air-dried and ground for analyzing selected soil physicochemical properties. Separate core soil samples from each sampling depth were taken with a core sampler for analyzing bulk density.

2.3. Soil Analysis

Soil physicochemical analysis was carried out at Bahir Dar Soil Testing and Fertility Improvement, and Amhara Design and Supervision Works Agency Soil Laboratory Centers using standard laboratory procedures. Soil texture was determined using hydrometer [42]. Bulk density was determined from undisturbed soil samples using core sampler [43] while particle density (β_s) was measured using psychnometer [44]. Total porosity (*f*) was calculated from the values of β_b and β_s as:

$$f = \left(1 - \frac{\beta b}{\beta s}\right)100$$

Soil pH was measured in a suspension of 1: 2.5 soils to potassium chloride (KCl) solution ratio [45] using a pH meter. Total N was determined by micro-Kjedahl method [46] while available P by extraction with Bray II method [47] using 0.03 M NH_4F and 0.1 M HCl solution. Soil CEC and exchangeable Ca, Mg, K and Na were extracted with 1 M NH_4OAc at pH 7. Exchangeable Ca and Mg in extracts were analyzed using Atomic Absorption Spectrophotometer, while Na and K were analyzed by

flame photometer [48, 49]. Percentage base saturation (PBS) was calculated as percent of sum of exchangeable bases (Ca, Mg, K and Na) to CEC. Organic carbon was determined by chromate acid oxidation method [50] and available S by Turbidimetric method [51]. Available micronutrients (Fe, Cu, Zn and Mn) were extracted by Diethylene Triamine Pentaacetic Acid (DTPA) as described by [52] and all these micronutrients were measured by Atomic Absorption Spectrophotometer.

2.4. Statistical Analysis

Data were analyzed using descriptive statistics to compare the selected soil physicochemical properties in different land use systems. Correlation analyses were also conducted among soil parameters.

3. Results and Discussion

3.1. Effects of Land Use on Selected Soil Physical Properties

In this study, selected physical properties of soil such as texture, bulk density, particle density and total porosity are analyzed (Table 1). Sand, silt and clay fractions showed variations by land use system and soil depth interactions. The average textural class of the watershed is clay loam. The maximum (33.9%) mean sand was observed on the surface layer (0 - 15 cm) of forest land followed by the surface layer of grazing land (26.6%) while the minimum (8.5%) in the sub-surface (15 - 30 cm) layer of cultivated land with an increase of 298.8% although the overall mean is 19.7%. These high sand and silt contents of forest land might be associated with lower sand and silt erosion by surface runoff on the surface layer of forest land due to low intensity of rainfall via leaf interception of forests. Although the overall mean clay content of the watershed is 48.2%, the highest (73.4%) mean was recorded in the sub-surface (30 - 45 cm) layer of cultivated land while the lowest (25.2%) on the surface layer of forest land by showing an increase of 191.3% which might be due to the high leaching (lessivage) of clay particles down profile in cultivated land and complexing agent of humus (OM) on the clay particles of forest land that reduce its leaching in suspension. However, in all land use systems, clay content increased while sand and silt contents decreased with increasing soil depths. These findings are in line with that of [53] who reported that overall mean soil depth showed higher sand and lower clay contents in 0 - 40 cm than in the 40 - 60 cm soil depths at Tera Gedam watershed, northwestern Ethiopia. [54] As cited in [5] also elucidated that one of the main processes that could likely lead to textural differentiation in soil profiles is the downward movement of clay particles suspended in percolating soil water. The overall textural class of the watershed is mainly of clay loam.

Although the bulk density of Antra watershed is low with an overall mean of 1.15 g cm^{-3}, it also showed differences by the interaction effect of land use and soil depth where relatively higher (1.3 g cm^{-3}) mean bulk density was observed on the surface layer of grazing land followed (1.27 g cm^{-3}) by the surface layer of cultivated land while lower (0.9 g cm^{-3}) on the surface layer of forest land (Table 1) with a difference of 0.4 g cm^{-3}. This variation in bulk density might be due to relatively high compaction by grazing animals in grazing and high OM content (more pores) in forest lands. These results are in agreement with that of [55, 5] who stated that lower bulk density was observed in forest land compared to cultivated and pasture lands. Similarly, [17, 18, 7] reported that virgin forest soil produced lower bulk density than the crop and pasture lands because of the well-developed fine-medium granular structure and high OM contents.

As per the classification rating suggested by [56], bulk density of the soil is rated as very low (< 1 g cm^{-3}), low (1 - 1.3 g cm^{-3}), medium (1.3 - 1.6 g cm^{-3}), high (1.6 - 1.9 g cm^{-3}) and very high (> 1.9 g cm^{-3}). Accordingly, the bulk density of Antra watershed is low. Besides, according to the proposals set by [57], the critical values of bulk density for plant growth at which root penetration is likely to be severely restricted for textural classes of sandy loam is (1.8 g cm^{-3}), fine sandy loam (1.7 g cm^{-3}), loam and clay loam (1.6 g cm^{-3}) and clay (1.4 g cm^{-3}). Based on this proposal, the average bulk density (1.15 g cm^{-3}) of the soils of Antra watershed which has clay loam textural class is below the critical values for plant growth.

The particle density of the study area is generally low which might be due to its high clay particle contents (clay loam textural class). There were slight variations in particle density as a result of land use and soil depth interactions (Tables 1) in the watershed even though the overall average is 2.26 g cm^{-3}. Relatively higher (2.3 g cm^{-3}) mean particle density was recorded on the surface layer of cultivated land and the 2nd higher (2.29 g cm^{-3}) was observed in the sub-surface (30 - 45 cm) layer of forest land while lower (2.21 g cm^{-3}) in the sub-surface (30 - 45 cm) layer of grazing land with a difference of 0.11 g cm^{-3} between the maximum and minimum mean values. Such high content of particle density on the surface layer of cultivated land might be due to its high sand contents and presence of heavy minerals of Fe and Mn with high charge density (Table 4) which are in agreement with the findings of [15].

Table 1.   Mean values for effects of land use and soil depth on particle sizes, bulk density, particle density and total porosity

Treatments	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk Density (g cm⁻³)	Particle Density (g cm⁻³)	Total Porosity (%)
C,D1	16.2	35.5	48.3	Clay loam	1.27	2.32	44.4
C,D2	8.5	23.8	67.8	Silt loam	1.11	2.27	51.2
C,D3	10.2	16.4	73.4	Silt loam	1.09	2.22	50.4
F,D1	33.9	40.9	25.2	Clay loam	0.95	2.25	57.8
F,D2	20.2	38.4	41.3	Clay loam	1.16	2.28	48.9
F,D3	15.4	37.2	47.4	Silty clay loam	1.25	2.29	46.2
G,D1	26.6	35.7	37.7	Clay loam	1.274	2.24	43.0
G,D2	24.3	31.0	44.7	Clay loam	1.15	2.24	48.3
G,D3	22.3	30.0	47.7	Clay loam	1.1	2.21	50.1
Mean	19.7	32.1	48.2	Clay loam	1.15	2.26	48.9

The mean total porosity (48.9%) of the study area is high although it showed great differences by land use and soil depth interactions (Table 1).The highest (57.8%) mean total porosity was observed on the surface layer of forest land and the lowest (43.0%) on the surface layer of grazing land with an increase of 34.4% which might be due to high OM contents in forest land and relatively high compaction with high bulk density in grazing land. The results are in agreement with that of [19] who reported that conservation tillage management resulted in a better pore connectivity than conventional system. [58] Also reported that OM influences soil physical properties by encouraging granulation, assisting aggregate stability (soil structure), helping aggregation of soil particles, improving aeration and water holding capacities and reducing plasticity and cohesion. There was high significant (P ≤ 0.001) and very strong negative correlation (r = - 0.97) between total porosity and bulk density in the study area which indicated compaction acts as a strong impediment for soil porosity, aeration and root penetration of crops.

3.1.1.Effects of Land Use on Soil Chemical Properties

3.1.1.1. Soil pH, organic carbon, total nitrogen, available sulfur and phosphorus

In the study area, soil pH showed variations by the interaction effects of land use and soil depth (Table.2) although it is almost on the same range. Relatively higher (5.03) mean pH was observed on the surface layer of forest land and lower (4.45) on the surface layer of cultivated and grazing lands with an increase of 13% albeit the overall mean value is 4.83. This variation in pH could be due to high OM with organic anions on the surface layer of forest land, and continuous removal of basic cations by harvested crops and animal grazing on the surface layers of cultivated and grazing lands, respectively. furthermore, the low pH in cultivated lands might be also due to the fact that of very high leaching of basic cations and clay particles from the exposed surfaces

of cultivated lands and H^+ ion released by nitrification of NH_4^+ sourced chemical fertilizers, legume roots during N_2 fixation (nitrification) and roots of crops to soil solution with low OM contents on the surface layer of cultivated land.

Similar research results are found by [59, 60, 20] who stated that soil pH values were significantly lower on the surface layer for cultivated soils when compared to non-cultivated soils due to the application of NH_4^+ sourced fertilizers to cultivated lands that nitrifies NH_4^+ and the uptake of basic cations by crops. Besides, the presence of higher pH in forest land might be accredited to the ameliorating effect of high content of OM that form Al and Fe-OM complexes and release of hydroxyl ions as well as deposition of basic cations [5]. Besides, in sub-tropical environments, excessive disturbance of soils at seedbed preparation caused high rate of OM turnover and decomposition; through the process of oxidation, reaction of CO_2 with H_2O forms both organic (H_2CO_3) and inorganic acids (H_2SO_4, HNO_3) which are potential suppliers of H^+ ions in soils and encouraging the development of acidic cations [61].

However, opposite findings are reported by [62] who stated that high pH values were recorded for croplands as compared to grazing and forest lands in Bale mountain areas of Ethiopia. [35] Also reported oppositely that soil pH decreased with increasing soil depth for the land use systems in Central highlands of Ethiopia. In this study, besides the highly significant (P ≤ 0.001) and strong positive association (r = 0.63) between pH and exchangeable Mg, the pH was also significantly (P ≤ 0.01) and positively correlated (r = 0.5, 0.55 and 0.58) with CEC, PBS and exchangeable Na, respectively (Table 5) which might be due to the fact that as pH decreases exchangeable bases such as Mg, Na decrease associated with the decrease in CEC and PBS by leaching. Based on the ratings set by [63], pH value is rated very strongly acid (< 4.5), strongly acid (4.5 - 5.25), moderately acid (5.3 -

5.9), slightly acid (6.0 - 6.6) and neutral (6.7 - 7.3). According to his proposed rating, the pH of the watershed is ranging from very strongly acid in cultivated to strongly acid in forest lands. Therefore, the soils of the watershed are difficult for growing acid sensitive crops unless proper management strategies are used to reduce the magnitude of acidity to a suitable range.

The watershed is medium in its OC contents with the overall mean of 2.25%. However, there was great variation in OC content by the interaction effects of land use and soil depth (Table 2). The highest (4.6%) mean OC was observed on the surface layer of forest land and the lowest (1%) in the subsurface layer of cultivated land with an increase of 347.6% which might be due to high OM content on the surface layer of forest land and OM oxidation in cultivated lands. [64, 65, 53] reported that lower levels of soil OM content was observed in cultivated land. [21, 22] also indicated that clearing tropical forests and conversion into farmland lowered soil OM by 20 - 50% as cultivation generally aerates soil and increases OM oxidation rates. Similarly, [66, 23] indicated that soils lost 42 - 59% of their soil OC stock upon conversion from forest to crop land in the northeastern China and other areas. Organic carbon showed a decrease with the increase in soil depth in all land use systems (Table 2) which might be due to the fact that of the reduction in root residue and thereby OM contents of the soil down the profile.

Organic carbon was highly significantly (P $\leq$ 0.001) and strongly positively correlated (r = 0.86, 0.77, 0.73 and 0.7) with total N, Zn, Fe and Ca, respectively in this study (Table 5) which might be due to the fact that all of such nutrients are derived from OM (OM is the store house of macro and micro-nutrients such as OC, total N, available P and S, exchangeable bases and micro-nutrients of Fe, Zn and Mn). [67] Elucidated that OM improved OC status and available N, P, K, S and CEC in soils. As per the classification rating suggested by [62], OC for forest land (3.2%) qualified as high while grazing (2.3%) and cultivated (1.4%) lands medium and low status, respectively for the study area. According to him, OC content of the soil is rated as very low (< 0.5%), low (0.5 - 1.5 %), medium (1.5 - 3%) and high (> 3%). Furthermore, according to [68], OC content of the soil is rated as extremely low (< 0.4%), very low (0.4 - 0.6%), low (0.6 - 1.0 %), moderate (1.0 – 1.8%), high (1.8 - 3.0%) and very high (> 3.0%) where the study area is felt in the high OC range based on this rating.

Similar to OC, total N also indicated great variations by land use and soil depth interactions (Table 2) in the watershed in spite of the fact the overall mean value is 0.16%. The overall mean C: N ratio of the soils of the watershed is also narrow (about 14:1) that indicated low OM content and high degree of OM oxidation/N mineralization. The highest (0.28%) mean total N was recorded on the surface layer of forest land and the lowest

(0.12%) in the subsurface layer of cultivated land with an increase of 133.3% which might be due to high OM content with high microbial population in the rehizosphere of forest land, and its rapid oxidation/mineralization with nitrate leaching in cultivated land, respectively. In all land use systems, total N decreased with increasing soil depth which might be again due to the reduction in OM contents, microbial biomass and N mineralization down the profile. According to the ratings suggested by [56], the C: N ratio of < 10 very low, 10 - 15 low, 15 - 25 medium, 25 -70 high, 70 - 100 very high, 100 extremely high and 860 approximate end point. Based on this proposal, the soil of Antra watershed is rated as medium in C: N ratio.

These results are in agreement with that of [22, 20] who reported that changes in soil OM could lead to changes in total N and long term cultivation without organic fertilizers usually leads to a decrease in soil OC and total N contents because organic forms generally account for more than 95% of soil N. Similarly, [24, 69, 25] elucidated that the contribution of OM to the total N is high and soil N content decreased by 64 and 55% in cultivated sites compared to native forest and rangelands, respectively by which afforestation also increased total N. However, [55] reported that pasture soil contained the highest N stocks than forest and cultivated lands on the top 5 cm layer. [59] Also reported that total N was high on the surface layer of forest land but reduced with increasing soil depth by 50% for each subsequent depth increment in both cultivated and non-cultivated soils.

In this study, total N was negatively correlated (r = -0.21) with soil pH which might be due to slow rate of OM oxidation or N mineralization as microorganisms especially nitrifying bacteria (*Rhizobium*) are sensitive to the acidic environments and/or H^+ release (protoniization) by nitrification when high ammonium sourced N fertilizer is applied to the soils (Table 5). Based on [70], total N content is rated as low (< 0.15%), medium (0.15 - 0.25%) and high (> 0.25%). Therefore, according to the ratings suggested by him, forest (0.22%) and grazing (0.19%) lands qualified for medium while cultivated (0.14%) land qualified low in its total N status in this study although the overall mean (0.16%) is rated as medium. Furthermore, [71], proposed rates of total N as very low (< 0.05%), low (0.05 - 0.15), medium (0.15 - 0.25%), high (0.25 - 0.50%) and very high (> 0.5%).

Soils of Antra watershed are low in its available S contents with an overall mean of 5.7 ppm. However, high variation was observed in available S by the interaction effects of land use and soil depth where the highest (11.1 ppm) mean was observed on the surface layer of forest land and the lowest (2.8 ppm) in the subsurface layer of cultivated land that showed an increase of 293.9% which might be due to high OM contents and pH values on the surface layer of forest land (Table 2). Besides, the low content of available S in cultivated land might be due to its low pH value and high clay content for sulfate fixation,

leaching/soil erosion, low OM contents and crops uptake as well as management problems. Available S had shown slight reduction with increasing soil depth in all land use systems (Table 2) which might be due to the reduction in OM contents, and its high solubility and rapid leaching beyond the soil depths that were studied. [72] Revealed that deforestation of natural forests and subsequent cultivation invariably led to large losses of organic S in sub-humid Ethiopian highlands.

These results are also supported in one way or another by [73] who stated that FYM application increased OC and S contents of soil in which up to 98% of total soil S may be present as organic S compounds. [15] Also reported that the highest total S was observed on the surface layer of virgin land and decreased with soil depth due to low OM contents. Similarly, [26, 27] reported that intensive cropping resulted in higher S removal and depletion in soils. Furthermore, [74] elucidated that since much of S is held in organic fraction of soils, maintenance of OM at an adequate level in soil is an effective practice in preventing S deficiency in the field crops.

Based on the report of [75], the critical level of available S is 6.5 ppm for optimum crop production although [76, 77] reported 10 ppm as the critical threshold value for most crops for available S (SO_4^{2-}) in the soil. Moreover, [78] reported that cereals do not respond to S application when S level in soil is in the range of 6 - 8 ppm, and overall adequate S levels for cereals may be around 7 ppm. Besides, 20 ppm SO_4^{2-}-S content is the critical limit adopted for Ethiopian soils [79]. Cultivated soil of the study area, therefore, is below the critical level that needs S sourced fertilizers mainly organic sources as soils of the watershed is acidic with low OM contents. In this study, available S was also highly significantly (P ≤ 0.001) and strongly positively correlated (r = 0.68 0.73 and 0.78) with OC, CEC and Zn, respectively (Table 5). This might be due to the fact that OM is the source or store house of all of these and other essential plant nutrients when it decomposes by microbial activities of the soil. [80] Reported similar

results that the profile of organic S content generally follows the pattern of OM in soils with soil depth.

Available P contents of the soils of Antra watershed is very low with an overall mean of 3.5 ppm and showed variations by the interaction effects of land use and soil depth (Table 2). The highest (5.5 ppm) mean available P was recorded on the surface layer of cultivated land and the lowest (2.2 ppm) in the subsurface of cultivated land with an increase of 150% which might be due to the application of DAP fertilizer (although its rate of application is low), its release from adsorbed colloidal surfaces, and mychorhizal fungi activity on the surface layer and its less mobility to the subsoil layer of cultivated land. These results are in agreement with that of [15, 6] who indicated that available P in cultivated land was higher than grazing and forest lands. Similarly, [19] reported that mineral P fertilization resulted in the building up of plant available P on top soils compared to non-fertilized plots and decreased with increasing soil depths [81, 59]. Furthermore, [82] estimated that only 20% of applied P fertilizer is taken up by crops in the year of application and the remainder is fixed in soils in various degrees of availability to the succeeding crops. [83, 84] reported that threshold soil test for Olsen P values for agronomic and environmental purposes are 12 and > 50 ppm.

There was significant (P ≤ 0.01) and positive correlation (r = 0.58) between available P and total N as shown in Table 2 which might be due to the fact that as N increase in the soil, plants grow luxuriously with high remains of roots that act as additional source of soil P by microbial decomposition. Based on the rating set by [85] of Bray test, the available P content of cultivated (3.9 ppm), forest (3.5 ppm) and grazing (3.2 ppm) lands of the watershed is low that urges high application of P sourced fertilizers (inorganic or organic). According to this suggestion, available P content of the clay loam soil is rated as low (0 - 10 ppm), medium (10 - 20 ppm) and high (> 20 ppm).

Table 2. Mean values for effects of land use and soil depth on pH, organic carbon, total nitrogen, available phosphorus and sulfur

Treatments	pH	Available sulfur (ppm)	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (ppm)
C,D1	4.45	2.9	1.84	0.16	5.5
C,D2	4.86	2.9	1.27	0.15	4.1
C,D3	4.98	2.8	1.03	0.12	2.2
F,D1	5.03	11.1	4.61	0.28	3.8
F,D2	4.93	10.1	2.45	0.19	3.7
F,D3	4.95	9.1	2.00	0.18	3.0
G,D1	4.45	4.4	2.90	0.27	2.9
G,D2	4.84	4.3	2.18	0.16	3.1
G,D3	5.00	4.1	1.93	0.14	3.5
Mean	4.83	5.7	2.25	0.16	3.5

3.1.1.2. Cation exchange capacity, exchangeable bases (Ca, Mg, K and Na) and percentage base saturation

Although the overall mean CEC of the watershed is high, there was variation in CEC by the interaction effects of land use and soil depth in the watershed (Table 3). The highest (42.2 cmolc kg^{-1}) CEC was recorded on the surface layer of forest land while the lowest (31.6 cmolc kg^{-1}) on the surface layer of cultivated land with an increase of 33.5% which might be due to high OM content and pH on the surface layer of forest land, and low OM, high leaching and uptake of basic cations as well as leaching of clay particles from cultivated land with lower pH. [86, 17, 29] reported that when humus is combined with clay, it increased soil CEC, and plant residues with OC content of 40 - 50% have increased soil's negative charge while low pH reduces CEC. [87, 88] stated that CEC is highly and positively correlated with OM, clay and pH but affected negatively by intensive cultivation. There was significant (P ≤ 0.01) and positive correlation (r = 0.58) between CEC and OC in this study. Analogous to OC, there was also significant (P ≤ 0.001) and strong positive associations (r = 0.76, 0.73, 0.65 and 0.66) between CEC, and exchangeable Ca, available S, exchangeable Mg and available Zn, respectively (Table 5). These high associations between CEC and OC as well as other nutrients might be due to the fact that OM is the reserve of all these nutrients through its decomposition by microorganisms besides to the store house of basic cations (which are base for CEC).   According to the suggestions made by [89], the CEC of the soil is rated as very low (< 5 cmolc kg^{-1}), low (5 - 15 cmolc kg^{-1}), medium (15 - 25 cmolc kg^{-1}), high (25 - 40 cmolc kg^{-1}) and very high (> 40 cmolc kg^{-1}).   Based on this rating, soils of the study area is high in CEC content with an overall average of 36.4 cmolc kg^{-1}.

Exchangeable Ca also showed variations in Wujiraba watershed by the interaction effects of land use and soil depth (Table 3) with an overall mean of 15.2 cmolc kg^{-1}. The highest exchangeable Ca (22.2 cmolc kg^{-1}) was observed on the surface layer of forest land where as the lowest (8.6 cmolc kg^{-1}) on the surface layer of cultivated land with an increase of 158% which might be due to high OM content with colloidal surface and store house of basic cations as well as relatively high pH on the surface layer of forest land, and exchangeable Ca leaching and crop uptake from the surface layer of cultivated land. In cultivated land, exchangeable Ca showed an increase with the increase in soil depth while in forest land it decreased down the profile (Table 3) which might be due to the fact that of its high leaching in cultivated land, and low leaching by high rainfall interception of leaves as well as high OM contents (strong reserve of exchangeable Ca) of forest land, respectively. Analogous findings are reported by [29, 30] who elucidated that cultivation led to the reduction, uptake and leaching of exchangeable cations, especially in acidic tropical soils.

In this study, exchangeable Ca showed highly significant (P ≤ 0.001) and strong positive correlation (r = 0.7 and 0.9) with OC and PBS, respectively (Table 5) which might be due to its source from OM and it is one of the most abundant basic cations surrounding the colloidal soil surface with higher charge density and shorter radi. According to the ratings recommended by [89], the soil is ranged medium in cultivated land to very high in forest land in its exchangeable Ca content. Based on this proposed rating, exchangeable Ca of the soil is rated as very low (< 2 cmolc kg^{-1}), low (2 - 5 cmolc kg^{-1}), medium (5 - 10 cmolc kg^{-1}), high (10 - 20 cmolc kg^{-1}) and very high (> 20 cmolc kg^{-1}).

There was also variation in exchangeable Mg content in the watershed by the interaction effect of land use and soil depth where the highest (8.1 cmolc kg^{-1}) was observed in the subsurface layer of forest land and the lowest (1.4 cmolc kg^{-1}) on the surface layer of cultivated land (Table 3) that indicated a decrease of 82.7% which might be due to low OM content, low pH, high plant uptake and leaching of exchangeable Mg from cultivated land. [10] Reported that the lowest exchangeable Mg was recorded in cultivated land which could be due to high intensity of cultivation and abundant crop harvest with little or no use of inputs. Exchangeable Mg had increased with increasing soil depth in all land use systems (Table 3) which might be due to the effect of its leaching down the profile. The value of exchangeable Mg in the study area was highly significantly (P ≤ 0.001) and strongly positively correlated (r = 0.65 and 0.73) with CEC and PBS, respectively (Table 5) which might be due to the fact that exchangeable Mg is part of exchangeable bases for increasing CEC and PBS in any soil. According to [89] rating, soils of the study area are rated medium in cultivated land and very high in forest land in its exchangeable Mg content. Based on this proposed rating, exchangeable Mg of the soil is rated as very low (< 0.3 cmolc kg^{-1}), low (0.3 - 1.0 cmolc kg^{-1}), medium (1.0 - 3.0 cmolc kg^{-1}), high (3.0 - 8.0 cmolc kg^{-1}) and very high (> 8.0 cmolc kg^{-1}). Based on the suggestions set by [90], the Ca: Mg ratio of the soil is rated as Ca deficient (< 1), low Ca (1 - 4), balanced (4 - 6), low Mg (6 - 10) and Mg deficient (> 10). According to this proposal, the Ca: Mg ratio (2.98 : 1) of the soils of Antra watershed is qualified under low exchangeable Ca level.

Although the overall mean of exchangeable K of the watershed is 0.56 cmolc kg^{-1}, difference was observed in exchangeable K by the land use and soil depth interactions (Table.3). The highest (0.76 cmolc kg^{-1}) exchangeable K was recorded on the surface layer of forest land while the lowest (0.31 cmolc kg^{-1}) in the subsurface layer of grazing land which might be due to low plant uptake on the forest land and relatively high compaction or bulk density in grazing land that restricts its downward movement as well as its uptake by freshly growing grasses. Exchangeable K content of cultivated land is somewhere in between forest

and grazing lands although it is mined by growing crops. This result is in agreement with that of [29, 15] who found lower exchangeable K contents in cultivated and grazing lands than forest land. [91] reported that the critical level of exchangeable K in the soil for most crops for K fertilizer requirement is 0.38 cmolc kg^{-1} and therefore, the content of exchangeable K is above the threshold level in the soils of the study area for crop growth with no K fertilizer requirement in the plow layer of cultivated lands which might be due to volcanic (ash) sources of basaltic sourced soils. Similarly, [92] reported that crop responses to K fertilization are rare in Africa due to high exchangeable K contents in many parts of Africa including Ethiopia. Furthermore, according to the suggestions set by [89], exchangeable K of the soil is rated as very low (< 0.2 cmolc kg^{-1}), low (0.2 - 0.3 cmolc kg^{-1}), medium (0.3 - 0.6 cmolc kg^{-1}), high (0.6 - 1.2 cmolc kg^{-1}) and very high (> 1.2 cmolc kg^{1}).

Exchangeable Na indicated variations in the watershed by the land use and soil depth interactions (Tables 3) although the overall mean is 0.37 cmolc kg^{-1}. The highest exchangeable Na (0.55 cmolc kg^{-1}) was recorded on the surface layer of forest land and the lowest (0.19 cmolc kg^{-1}) on the surface layer of cultivated land that increased by 205.3% which might be due to low erosion/leaching in forest land by leaf interceptions of the high rainfall intensity and high leaching (longer radi and lower charge density) in cultivated land. According to [89] rating, soils of the study area qualified as low (0.23 cmolc kg^{-1}) in cultivated land and medium (0.46 and 0.44 cmolc kg^{-1}) in forest and grazing lands, respectively for their exchangeable Na contents. Based on the ratings of this source, exchangeable Na of the soil is rated as very low (< 0.1 cmolc kg^{-1}), low (0.1 - 0.3 cmolc kg^{-1}), medium (0.3 - 0.7 cmolc kg^{-1}), high (0.7 - 2 cmolc kg^{-1}) and very high (> 2 cmolc kg^{-1}).

The binding is stronger the higher the charge of ions (charge density) i.e. trivalent cations are more strongly bound than divalent cations, which in turn are more tightly held than monovalent cations on the colloidal surfaces. Exchangeable Ca and Mg, therefore, were by far higher than exchangeable K and Na in all land uses of the study area since divalent cations (shorter radii) were higher than monovalent once which was similar to the report of [30]. Similarly, [93] elucidated that as a result of small energy of adsorption of K and Na, it is more likely to exist in soil solution than colloidal sites and be removed from soil by leaching. [16] Also reported that deforestation, leaching, limited recycling of dung and crop residues, declining fallow periods and soil erosion have contributed to depletion of basic cations and reduction of CEC in cultivated land as compared to adjacent forest land.

Percentage base saturation also showed variations in the watershed by the land use and soil depth interactions (Table 3) albeit the overall mean is high (57.5%). In this study, the highest PBS (73.5%) was observed in the subsurface layer of forest land whereas the lowest (34.4%) on the surface layer of cultivated land with an increase of 67.2% which might be due to relatively high OM and clay contents (soil colloidal sites and storehouse of exchangeable bases) in the subsurface layer of forest land compared to the surface layers of cultivated and grazing lands. According to the ratings proposed by [94, 56], the average PBS (57.5%) of Antra watershed is moderate as the proposed ratings of them indicates that PBS of 0 - 20% very low, 20 - 40% low, 40 - 60% medium, 60 - 80% high and > 80% very high. Similarly, based on the ratings set by [95], PBS as a criterion of leaching, soils are rated as very weakly leached (70-100%), weakly leached (50-70%), moderately leached (30-50%), strongly leached (15-30%) and very strongly leached (0-15%). Accordingly, the overall mean of the PBS (57.5%) of soils of the watershed is rated as weakly leached while cultivated land (46.1%) is qualified as moderately leached.

Table 3. Mean values for effects of land use and soil depth on cation exchange capacity, exchangeable bases and percentage base saturation

Treatments	Cation exchange capacity (cmol(+) kg^{-1})	Exchangeable bases (cmol(+) kg^{-1})				Percentage base saturation (%)
		Calcium	Magnesium	Potassium	Sodium	
C,D1	31.6	8.6	1.4	0.71	0.19	34.4
C,D2	33.5	11.1	4.5	0.48	0.21	48.7
C,D3	35.1	12.1	5.6	0.45	0.28	52.3
F,D1	42.2	22.2	6.3	0.77	0.55	70.5
F,D2	37.4	19.3	7.1	0.58	0.49	73.5
F,D3	39.9	15.2	8.1	0.59	0.33	60.6
G,D1	34.8	14.1	2.2	0.68	0.31	49.8
G,D2	36.0	17.2	4.9	0.47	0.50	63.9
G,D3	37.2	17.1	5.9	0.31	0.51	63.9
Mean	35.4	15.2	5.1	0.56	0.37	57.5

3.1.1.3. Micronutrients (extractable iron, manganese, copper and zinc)

Variations were shown in the extractable micronutrients of Fe, Mn and Zn content in Antra watershed by the interaction effects of land use and soil depth where the highest (14.2, 24.1 and 2.9 ppm) were observed on the surface layer of forest land (Table 4), respectively which might be due to high OM concentrations that acted as a chelating effect and source of such nutrients as well as low pH (strong soil acidity) of the area. Difference was also observed in the Cu content by which the highest (2.7 ppm) was recorded on the surface layer of forest land that might be also due to its high OM contents. [16] Reported that OM may promote the availability of such nutrients by supplying soluble complexing agents or carbonic (H_2CO_3) and nitric (HNO_3) acids (product of OM oxidation) that interfere with their fixation. These results are also supported by [15, 6] who stated that micronutrients content increased with the increase in OM contents. [96] Also notified that OM such as FYM have traditionally been used and supplied all major nutrients necessary for plant growth, as well as micronutrients (Fe, Mn, Cu and Zn). However, [97] reported that available Fe, Mn, Cu and Zn status of fertilized plots with macronutrient elements were depleted as such nutrients were utilized from the soils to meet the requirements of crops. In this study, available Fe, Mn, Cu and Zn had significant ($P \leq 0.05$) and strong positive correlation (r = 0.73, 0.44, 0.57 and 0.77) with OC in their orders (Table 5) which might be due to the fact that OM is the store house/reserve of micronutrients and OC via microbial decomposition.

The range in critical level values of extractable micronutrients has been given by [98] as Fe (2.5 - 5.0 ppm), Mn (1.0 - 5.0 ppm), Cu (0.1 - 2.5 ppm) and Zn (0.2 - 2.0 ppm). Extractable Cu of 0.9 ppm is the critical limit adopted for Ethiopian soils [79]. Based on the suggestions made by them, soils of the study area are affected by Fe (10.2 ppm) and Mn (13.7 ppm) toxicity but not by Cu (2.1 ppm) and Zn (0.93 ppm) metals for producing crops in these acidic soils. [61] Also indicated that the solubility, availability and plant uptake of micronutrient cations (Cu, Fe, Mn and Zn) are more under acidic conditions (pH of 5.0 to 6.5) than alkaline soil reaction just like that of soils of the study area.

Table 4. Mean values for effects of land use and soil depth on extractable iron, manganese, copper and zinc

Treatments	Available iron (ppm)	Available manganese (ppm)	Available copper (ppm)	Available zinc (ppm)
C,D1	7.2	21.2	2.38	0.89
C,D2	6.4	13.7	1.81	0.49
C,D3	4.5	12.6	1.61	0.41
F,D1	14.2	24.1	2.71	2.85
F,D2	11.8	16.9	2.58	1.34
F,D3	12.8	14.8	2.46	1.07
G,D1	12.6	14.1	2.23	0.38
G,D2	11.1	3.5	1.60	0.55
G,D3	11.2	2.8	1.55	0.39
Mean	10.2	13.7	2.1	0.93

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Table 5. Pearson's correlation matrix for various soil physicochemical parameters

	β_b	f	pH	CEC	OC	TN	Av P	Av S	Ca	Mg	K	Na	PBS	Fe	Mn	Cu	Zn
β_b	1.0																
f	-0.97***	1.0															
pH	-0.51**	0.47	1.0														
CEC	-0.46*	0.48**	0.5**	1.0													
OC	-0.32	0.34	0.04	0.58**	1.0												
TN	-0.08	0.08	-0.21	0.42*	0.86***	1.0											
Av P	-0.46	-0.08	-0.24	0.3	0.11	0.58**	1.0										
Av S	-0.23	0.31	0.33	0.73***	0.68***	0.55**	-0.06	1.0									
Ca	-0.52**	0.49**	0.45*	0.76***	0.7***	0.45*	-0.25	0.68***	1.0								
Mg	-0.34	0.4*	0.63***	0.65***	0.05	0.12	-0.37	0.59**	0.47*	1.0							
K	0.01	0.05	0.37	0.13	0.57**	0.74***	0.29	0.47*	0.03	-0.16	1.0						
Na	-0.35	0.28	0.55**	0.59**	0.51**	0.24	-0.16	0.48*	0.8***	0.34	-0.22	1.0					
PBS	-0.48*	0.46*	0.58**	0.64***	0.44*	0.18	-0.35	0.66***	0.9***	0.73***	-0.14	0.72**	1.0				
Fe	-0.06	0.08	-0.03	0.61***	0.73***	0.65***	-0.07	0.68***	0.7***	0.33	0.31	0.44	0.59**	1.0			
Mn	-0.06	0.15	-0.21	0.14	0.44*	0.51**	0.4*	0.45*	-0.03	-0.07	0.88***	-0.27	-0.15	0.08	1.0		
Cu	0.03	0.08	-0.18	0.26	0.57**	0.59**	0.3	0.62***	0.21	0.07	0.74***	-0.08	0.77***	0.48	0.77	1.0	
Zn	-0.46*	0.53**	0.2	0.65***	0.77***	0.58**	0.21	0.78***	0.57**	0.33	0.59**	0.31	0.68***	0.5**	0.68***	0.3	1.0

***Significant at $P = 0.001$; ** significant at $P = 0.01$; * significant at $P = 0.05$ levels; TN = total nitrogen; Av. P = available P; Av. S = available S

4. Conclusions

Land use systems have strong effects on the soil fertility status of an area where cultivated field showed nutrient depletion. Forest land should have been given special attention as it is the base for keeping soil more fertile by serving as the store house of nutrients. In this study, forest land was found to be low in bulk density, high in total porosity and better in OC, total N, and available S, CEC, exchangeable bases and extractable micronutrients content especially on its surface layer than grazing and cultivated lands. Although it is clay loam in texture and relatively better in available P than grazing and forest lands, cultivated land is poorer in plant nutrients content which has become constraints for crop production. This signals the great need for plant nutrient amelioration measures such as integrated nutrient management (application of organic and inorganic fertilizers), growing of N_2 fixing crops and application of agro-forestry into farming systems so that soil total porosity, pH, OC, total N, available S and P, CEC, exchangeable bases and micronutrients content will be improved for enhanced production of sufficient food for farm households by minimizing nutrient depletion and keeping such acidic soils fertile.

There should be an improvement of the fertility status cultivated lands by applying nutrient rich amendments such as organic matter which have environmentally friendly, socially acceptable and economically feasible. In order to increase its fertility and carrying capacity of the grazing lands, there should not be used in overgrazing but in control grazing by dividing the area in to blocks by making fences that allow fallowing. The forest lands should be also conserved in different ways such as making area closure, game reserves and the like to make an area ecologically conducive.

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