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Fertility status of soils under different land uses at Wujiraba watershed, North-western highlands of Ethiopia

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Abstract: In Ethiopian highlands, land use changes, mainly, from natural vegetation to cultivated lands brought about rapid nutrient depletion. Intensive and continuous cultivation of land without proper management resulted in decline in soil physical, chemical and biological properties which aggravate crop yield reduction and food shortage. The present study, therefore, is designed to investigate the effects of different land uses on soil fertility status in the Nitisols of Wujiraba watershed. Twenty seven soil samples were collected randomly depth wise (0 - 15, 15- 30 and 30 - 45 cm) from the cultivated, forest and grazing lands. Data were analyzed using the two ways ANOVA in RCBD with three replications. Land use and soil depth showed a significant ($P \leq 0.05$) effect on soil physicochemical properties. The highest f (57.8%), OC (4.6%), total N (0.28%), available S (11.1 ppm), CEC (42.2 cmol+ kg^{-1}), exchangeable bases (Ca (22.2), K (0.76) and Na (0.58 cmol+ kg^{-1})) and available micronutrients (Fe (14.2), Mn (24.1) and Zn (2.9 ppm)) were recorded on the surface layer of the forest land while lowest pH/KCl(5.03) and highest available P (5.5 ppm) on the surface layer of cultivated land. The results revealed that soil fertility declines as land use changed from forest to grazing and cultivated lands. Hence, it is possible to infer that continuous and intensive cultivation depletes plant nutrients greatly which urge to take measures for maintaining its fertility status of the cultivated soils in the study area.

Keywords: Cultivated Land, Forest Land, Grazing Land, Land Use, Nutrient Depletion, Soil Fertility

1. Introduction

Soil productivity in Africa is declining as a result of soil erosion, nutrient and organic matter (OM) depletion [1]. 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 tons ha^{-1} (t ha^{-1}) of nitrogen (N), phosphorus (P) and potassium (K) mainly due to crop harvest, leaching and low inputs applied to the soil [2, 3]. In the Ethiopian cultivated fields, about 42 t ha^{-1} of fertile soils have been lost every year [4] together with essential plant nutrients mainly due to poor soil management.

Assessing soil physicochemical properties are used to understand the potential status of nutrients in soils of different land uses [5, 6]. To meet the food demands of rapid increasing population, vast tract of land are being cultivated more intensively and large areas of grass and forestlands are being overgrazed and deforested. Changes in land use and soil management can have a marked effect on soil fertility [7] mainly the conversion of natural ecosystem (forest land) to crop land which resulted in decline of soils physical, chemical and biological properties [8]. Research findings from different corners of the world have revealed that prolonged intensive cultivation and fertilization have resulted in the deterioration of plant nutrients [9, 10 - 11]. Deforestation and cultivation of virgin tropical soils often lead to 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 [12, 13, 7, 14].

Physical and chemical properties of the soils on land under continuous cultivation could vary from the other land uses [15, 16-17]. Cultivated soils are poor in its fertility status as it has high bulk density (β_b) [18, 19], low total porosity (f) [20], low pH [21] and very low OM or organic carbon (OC) content [22, 23-24]. Cultivation has also altered other soil chemical properties and characterized by low in total N [25, 23, 26, 21], available S [27, 28], cation exchange capacity

(CEC) [8] and exchangeable bases of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) [29, 11, 30] but relatively high in available P [31, 16, 7]. The survival and well being of the present and future generation in countries with subsistence agriculture like Ethiopia depend on the extent of maintaining soil fertility [16]. So, land must be carefully managed which urges to establish land use system for conserving its fertility in the long term [17].

The factors causing nutrient depletion in the cultivated lands of highland Ethiopia include cultivation on steep and fragile soils, declining use of fallow, limited recycling of dung and crop residues to the soil, low application of external sources of plant nutrients, deforestation, overgrazing and torrential rainfall patterns [32, 33 - 35].Using crop residues as livestock feed and dung as fuel instead of fertilizer for instance is estimated to reduce Ethiopia's agricultural gross domestic product (GDP) by 7% [36] where the study area is not escaped from these acute problems.

As soil physicochemical analyses results and its productivity level revealed that at present, Wujiraba watershed becomes nutrient depleted and less productive which make very difficult the efforts that have been made for improving crop yields. Besides, the degree, extent, causes and measures of the soil fertility decline have not received adequate research attention in the northwestern highlands of Ethiopia in general [37] and the study area in particular. Investigating soil physical and chemical properties under different land uses could assist policy makers, researchers, extension workers and farmers to have baseline information to improve the soil fertility and 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 changes in soil fertility and productivity. Therefore, this study was conducted to assess soil fertility status of the soils under different land uses and soil depths at Wujiraba watershed in northwestern highlands of Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted at Wujiraba watershed, located in Chilga District of North Gondar Zone in the ANRS (Figure 1). 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 and elevations ranging from 1910 and 2267 meters above sea level (m.a.s.l.). Three land uses were used for this study and such three land uses were cultivated, grazing and forest lands with soil groups of Nitisols [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 the mid-Tertiary flood basalt pile and middle-Tertiary volcanic mountains of the Miocene and Pliocene–Quaternary, accompanied locally by predominantly basaltic volcanism. The trap volcanic series consists mainly of weathered and jointed basalt, and the soils of the study area were developed from the parent materials of volcanic origin, predominantly Tertiary basalt [39].

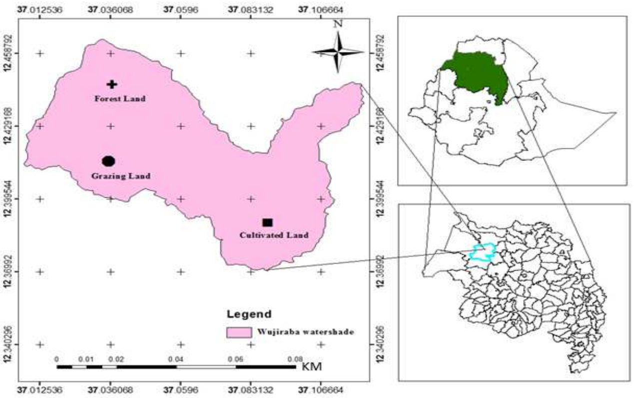

Figure 1. *Location map of the study area*

The watershed is characterized by unimodal rainfall pattern (Figure 2) that occurs from May to October. According to the weather data recorded at the Aykel Meteorological Station (3 km from the watershed), the ten years (2003-2012) total average annual rainfall for the study area was 1237 mm. The annual mean minimum and maximum temperatures were 13.6 and 23.7 ^{0}C, respectively.

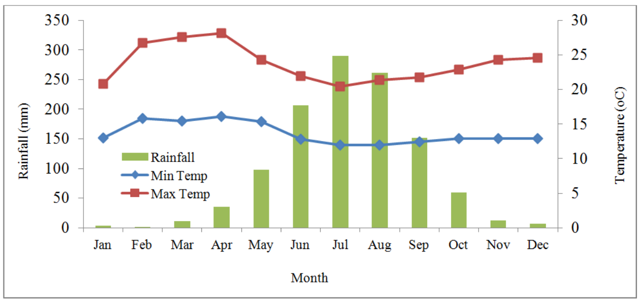

Figure 2. *Mean monthly rainfall and maximum and minimum temperatures of the study area*

The natural vegetation of Wujiraba watershed is very low except some trees and grasses on reserved areas. The trees occurring on slopes, mainly churches, are remnants of once dense evergreen forest. Currently, re-plantation strategy is being implemented dominated mainly by eucalyptus trees in the study area.

The economic activities of the local community of the study area are primarily mixed farming system that involves crop production and animal husbandry. In the Wujiraba watershed, the cultivated land accounts about 68.4% while the grazing, settlement and forest together with area closure lands account about 23.5, 5.3 and 2.8%, respectively. The watershed is suitable for growing large variety of crops such as cereals, oil seeds, pulses, etc. The crops are grown in rotation by rain fed system. The land management systems for cultivation of such crops in the watershed include terracing, repeated contour plowing, application of chemical fertilizers, weeding and so on for better yield. However, there is no the practice of fallowing due to high population pressure.

2.2. Land Use Selection and Soil Sampling

Soil samples were collected in three land uses (forest, cultivated and grazing lands). Land use sites for soil sample takings were selected using the 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 the variations in the study area. Regarding the history and management of the selected land uses, the cropland selected for this study has been under cultivation for more than a century whereas the grazing land was established on part of the former cropland 1981 onwards. The forest land was formerly a forest and then being a natural reserve (church) since 1941. Global positioning system (GPS) and clinometers were used to read the geographical locations and slopes of the sampling sites of selected land uses, respectively.

From the cultivated lands, cereal crop land under rain fed condition was used while from the grazing lands and forest lands, communal grazing land and natural forest land (reserved area) were selected. Representative soil sampling sites were selected randomly from each land use according to their slope. Three representative fields or blocks were selected from each land use, and from each block, composite soil samples were collected from thirteen soil sub-samples (spots) within three depths of 0-15, 15-30 and 30-45 cm using an auger.

During collection of soil samples; dead plants, furrow, old manures, wet spots, areas near trees and the like were excluded. The composited soil samples collected from representative land uses with three replications were then air-dried, ground and passed through a 0.5 for total N and OC and 2 mm sieve for the analysis of other selected soil physicochemical properties. Separate core soil samples from each sampling depth were taken with a core sampler.

2.3. Soil Analysis

The soil physicochemical analysis was carried out at Bahir Dar Soil Testing and Soil Fertility Improvement and Amhara Design and Supervision Works Agency Soil Laboratory Centers using the standard laboratory procedures. Soil texture was determined by the Bouyoucos hydrometer [40]. Bulk density was determined from undisturbed soil samples using core samplers [41] while particle density (β_s) was estimated by the psychnometer method [42]. 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 suspension of 1:2.5 soils to potassium chloride (KCl) solution ratio [43]. Total N was determined by micro-Kjedahl method [44], available P was determined by extraction with Bray II method [45] using 0.03 M NH_4F and 0.10 M HCl solution, CEC and exchangeable Ca, Mg, K and Na were extracted with 1 M NH_4OAc at pH 7. Exchangeable Ca and Mg in the extracts were analyzed using atomic absorption spectrophotometer, while Na and K were analyzed by flame photometer [46, 47]. Percentage base saturation (PBS) was calculated as the percent of the sum of the exchangeable bases (Ca, Mg, K and Na) to the CEC of the soil. Organic carbon was determined by the chromate acid oxidation method [48] and available S by Turbidimetric method [49]. Available micronutrients (Fe, Cu, Zn and Mn) were extracted by diethylene triamine pentaacetic acid (DTPA) as described by [50] and all these micronutrients were measured by atomic absorption spectrophotometer. Descriptions based on ratings of plant nutrients were also undertaken.

2.4. Statistical Analysis

Data was subjected to analysis of variance (ANOVA) with randomized completed block design (RCBD) method using SAS software [51]. A two-ways analysis of variance (ANOVA) was performed to assess the significance of differences in soil parameters between land uses, soil depths and their interaction effects. Treatment means were compared using least significant differences (LSD) by Fisher's test at 0.05. Correlation and regression 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, β_b, β_s and f were analyzed and presented in Table 1. Sand, silt and clay fractions were highly significantly ($P \leq 0.001$) affected by land use and soil depth interactions. The highest sand and silt fractions (33.9 and 40.9%) were observed on the surface layer (0-15 cm) of forest land while the highest clay content (73.4%) was recorded in the subsurface layer (30-45 cm) of cultivated land which might be due to high leaching (lessivage) of clay particles down the profile in cultivated land. In all land uses, clay content increased while sand and silt contents decreased with increasing soil depths. These findings were in line with that of Eyayu *et al.* [52] who reported that the overall mean soil depth showed higher sand and lower clay content in the 0 - 40 cm than in the 40 - 60 cm soil depths Tera Gedam watershed, north-western Ethiopia.

Bulk density was highly significantly ($P \leq 0.001$) affected by the interaction effect of land use and soil depth where the highest (1.3 g cm^{-3}) was observed on the surface layer of grazing land and lowest (0.9 g cm^{-3}) on the surface layer of forest land (Table 1) which might be due to the effects of high compaction by grazing animals in grazing and cultivated lands and high OM content in forest land. These results were in agreement with that of Puget and Lal [53]: [6] who stated that lower β_b was observed in forest land relative to cultivated and pasture lands. Similarly, Matersha and Mkhabela [18]: [19. 8] reported that virgin forest soil produced lower β_b than crop and pasture lands because of the well-developed fine-medium granular structure and high OM contents.

Although β_s was not significantly (P > 0.05) affected by land use, soil depth and their interactions (Tables 1), the highest (2.3 g cm^{-3}) was recorded on the surface layer of cultivated land which might be due to its high sand content and the presence of heavy minerals of Fe and Mn (Table 4) which was in agreement with the findings of [16]. However, β_s of the study area is generally low which might be due to its high clay particle contents.

Total porosity was significantly (P < 0.01) affected by land use and soil depth interactions (Table 1) where the highest (57.8%) was observed on the surface layer of forest land and lowest (43.0%) on the surface layer of grazing land which might be due to high OM in forest land and compaction with high β_b in grazing land. The results were in agreement with that of Iris *et al.* [20] who reported that conservation tillage management resulted in a better pore connectivity than the conventional system. Heluf [54] also reported that OM influences soil physical properties by encouraging granulation, assisting aggregate (structure) stability, 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 β_b in the study area which indicated compaction acts as a strong impediment for soil porosity, aeration and root penetration of crops (Table 5).

Table 1. *Interaction effects of land use and soil depth on particle sizes, bulk density, particle density and total porosity*

Treatments	Sand (%)	Silt (%)	Clay (%)	Bulk Density (g cm^{-3})	Particle Density (g cm^{-3})	Total Porosity (%)
C,D1	16.2d	35.5bc	48.3b	1.27a	2.32a	44.4cd
C,D2	8.5e	23.8e	67.8a	1.11c	2.27ab	51.2b
C,D3	10.2e	16.4f	73.4a	1.09c	2.22b	50.4b
F,D1	33.9a	40.9a	25.2d	0.95d	2.25ab	57.8a
F,D2	20.2cd	38.4ab	41.3bc	1.16abc	2.28ab	48.9bc
F,D3	15.4d	37.2ab	47.4b	1.25ab	2.29ab	46.2bcd
G,D1	26.6b	35.7bc	37.7c	1.274a	2.24b	43.0d
G,D2	24.3bc	31.0cd	44.7bc	1.15bc	2.24b	48.3bcd
G,D3	22.3bc	30.0de	47.7b	1.1c	2.21b	50.1b
R^2	0.92	0.92	0.95	0.79	0.55	0.75
CV (%)	14.73	8.99	8.46	5.68	1.94	6.31
F-test	***	***	***	***	NS	***
LSD (0.05)	5.03	4.99	7.06	0.11	0.08	5.34

Means with the same letter are not significantly different at P ≤ 0.05 according to Fisher's LSD; C = cultivated land, F = forest land, G = grazing land, D1 = soil depth 0 - 15 cm, D2 = soil depth 15 - 30 cm, D3 = soil depth 30 - 45 cm soils.

3.2. Effects of Land Use on Soil Chemical Properties

Soil chemical properties are the most important factors that affect soil fertility and determine the nutrient supplying power of soil to the plants and microbes. In this study, the most important soil chemical properties were analyzed and presented in Tables 2 - 4.

3.2.1. Soil pH, Organic Carbon, Total Nitrogen, Available Sulfur and Phosphorus

Soil pH/KCl was significantly (P ≤ 0.05) affected by the interaction effect of land use and soil depth where the highest (5.0) was observed in the subsurface layer of grazing land and lowest (4.45) on the surface layer of cultivated and grazing lands (Table 2). This could be due to continuous removal of basic cations by harvested crops and animal grazing on the surface layers of cultivated and grazing lands, respectively, and very high leaching of bases and clay particles from the exposed surfaces of cultivated lands as well as H^+ ion released by the nitrification of NH_4^+ sourced chemical fertilizers and legume roots during N_2 fixation on the surface layer of cultivated land.

Similar research results were found by Malo *et al.* [55]: [56, 21] 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 its uptake by the crops. Besides, the presence of higher pH in forest land might be accredited to the ameliorating effect of the high content of OM that form Al and Fe-OM complexes and release of hydroxyl ions as well as deposition of basic cations [6]. However, opposite findings were reported by Yimer *et al.* [57] who stated that high pH values were recorded for croplands as compared to grazing and forest lands in the Bale mountain areas of Ethiopia. Lalisa *et al.* [35] also reported oppositely that soil pH decreased with increasing soil depth for land uses in Central highlands of Ethiopia. In this study, besides high significant (P ≤ 0.001) and strong positive association (r = 0.63) between pH and exchangeable Mg, it was also significantly (P ≤ 0.01) and positively correlated (r = 0.5, 0.55 and 0.58) with CEC, PBS and Na, respectively (Table 5).

Organic carbon was highly significantly (P ≤ 0.001) affected by the interaction effects of land use and soil depth (Table 2) whereby the highest (4.6%) was observed on the surface layer of forest land and lowest (1.0%) in the subsurface layer of cultivated land that showed an increase of 347.6% which might be due to high OM content and its oxidation on the surface layer of forest and cultivated lands, respectively. Wakene and Heluf [58]: [59, 52] reported that lower levels of soil OM content was observed in cultivated land. Moscatelli *et al.* [22]: [23] also indicated that clearing tropical forests and conversion into farmland lowered by 20 - 50% in soil OM content as cultivation generally aerates the soil and increases OM oxidation rates. Similarly, Guo and Gifford [60]: [24 indicated that soils lost 42 - 59% of their soil OC stock upon conversion from forest to crop land in northeastern China and others. 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 all of them sourced from OM. As per the classification rate suggested by Tekalign [61], the OC for forest land qualified as high while grazing and cultivated lands medium and low status, respectively for the study area.

Total N was significantly ($P \leq 0.05$) affected by land use and soil depth interactions (Table 2) where the highest (0.28%) was recorded on the surface layer of forest land and lowest (0.12%) on the surface layer of cultivated land which might be due to high OM content in forest land and its rapid oxidation and/or mineralization in cultivated land. These results were in agreement with that of Tiejun *et al.* [23]: [21] 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, Lemma *et al*. [25]: [62, 26] elucidated that the contribution of OM to total N is high and soil N content decreased by 64 and 55% in cultivated sites compared to native forest and rangeland, respectively by which afforestation also increased total N. However, Puget and Lal [53] (2005) reported oppositely that pasture soil contained the highest N stocks than forest and cultivated lands in the top 5 cm layer. Malo *et al*. [55] 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 the cultivated and non-cultivated soils. In this study, total N was negatively correlated (r = -0.21) with soil pH which might be due to the slow rate of OM oxidation and/or N mineralization as microorganisms especially nitrifying bacteria (*Rhizobium*) are sensitive to acidic environments as shown in Table 5. According to the ratings suggested by Landon [63], forest land qualified for medium while grazing and cultivated lands low in its total N status in this study.

High significant ($P \leq 0.001$) difference was observed in available S by the interaction effects of land use and soil depth where the highest (11.1 ppm) was observed on the surface layer of forest land and 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 content on the surface layer of forest land (Table 2). These results were supported by Zhihui *et al.* [64] who stated that farm yard manure (FYM) application increased the OC and S content of the soil in which up to 98% of the total soil S may be present as organic S compounds. Wakene [16] 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, Balsa *et al.* [27]: [28] reported that intensive cropping has resulted in higher S removal and depletion in the soil. Based on the report of Blair *et al.* [65], the critical level of available S is 6.5 ppm for optimum crop production although [66] reported 10 ppm as the critical value for available S in soils. The cultivated soil of the study area, therefore, is below the critical level. In this study, available S was also highly significantly ($P \leq 0.001$) and strongly positively correlated (r = 0.68 0.73 and 0.78) with OC, CEC and Zn, respectively (Table 5) as all of these nutrients are mainly the result of OM decomposition. Probert [67] reported similar results that the profile of organic S content generally follows the pattern of OM in soils with soil depth.

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

Treatments	pH/KCl	Available sulphur (ppm)	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (ppm)
C,D1	4.45b	2.9d	1.84de	0.16d	5.5a
C,D2	4.86a	2.9d	1.27f	0.15d	4.1b
C,D3	4.98a	2.8d	1.03f	0.12d	2.2c
F,D1	5.00a	11.1a	4.61a	0.21a	3.8b
F,D2	4.93a	10.1ab	2.45c	0.19b	3.7b
F,D3	4.95a	9.1b	2.00e	0.18bc	3.0bc
G,D1	4.45b	4.4c	2.90b	0.27a	2.9bc
G,D2	4.84a	4.3c	2.18cd	0.16cd	3.1bc
G,D3	5.00a	4.1dc	1.93de	0.14d	3.5b
R^2	0.86	0.97	0.98	0.96	0.76
CV (%)	2.47	13.13	8.45	6.35	18.54
F-test	*	***	***	*	**
LSD (0.05)	0.21	1.3	0.33	0.019	1.13

Means with the same letter are not significantly different at $P \leq 0.05$ according to Fisher's LSD; C = cultivated land, F = forest land, G = grazing land, D1 = soil depth 0 - 15 cm, D2 = soil depth 15 - 30 cm, D3 = soil depth 30 - 45 cm soils.

Available P content of the soil was significantly ($P \leq 0.01$) affected by the combined effects of land use and soil depth (Tables 2) whereby the highest (5.5 ppm) was recorded on the surface layer of cultivated land which might be due to the application of DAP fertilizer. These results were in agreement with that of Tekalign *et al.* [31]: [16, 7] Wakene who indicated that available P in cultivated land was higher than grazing and forest lands. Similarly, Iris *et al.* [20] reported that mineral P fertilization resulted in the building up of plant available P in the top soil compared to non-fertilized plots and decreased with increasing soil depth [68, 55]. There was high significant (P ≤ 0.01) and positive correlation (r = 0.58) between available P and total N as shown in Table 5.

3.2.2. Cation Exchange Capacity, Exchangeable Bases (Ca, Mg, K and Na) and Percentage Base Saturation

Cation exchange capacity was highly significantly (P ≤ 0.001) affected by the interaction effects of land use and soil depth (Tables 3) where the highest (42.2 cmol(+) kg^{-1}) was recorded on the surface layer of forest land while lowest (31.6 cmol(+) kg^{-1}) on the surface layer of cultivated land which might be due to high OM content on the surface layer of forest land but low OM, high leaching of basic cations and clay from cultivated land. Henry [69]: [18, 8] 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. Gao and Chang [70]: [71] 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 high 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).

Table 3. *Interaction 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	31.6e	8.6f	1.4d	0.71ab	0.19c	34.4f
C,D2	33.5de	11.1ef	4.5c	0.48c	0.21c	48.7e
C,D3	35.1cd	12.1def	5.6bc	0.45cd	0.28c	52.30c
F,D1	42.2a	22.2a	6.3abc	0.77a	0.55a	70.5ab
F,D2	37.4bc	19.3ab	7.1ab	0.58bc	0.49ab	73.5a
F,D3	39.9ab	15.2cd	8.1a	0.59bc	0.33bc	60.6cd
G,D1	34.8cde	14.1cde	2.2d	0.68ab	0.31c	49.8e
G,D2	36.0cd	17.2bc	4.9c	0.47c	0.50a	63.9bc
G,D3	37.2bc	17.1bc	5.9bc	0.31	0.51a	63.9bc
R2	0.81	0.87	0.85	0.79	0.78	0.89
CV (%)	5.39	13.28	22.36	16.67	24.78	9.01
F-test	***	***	***	**	**	***
LSD (0.05)	3.4	3.4	1..98	0.16	0.16	8.9

Means with the same letter are not significantly different at P ≤ 0.05 according to Fisher's LSD; C = cultivated land, F = forest land, G = grazing land, D1 = soil depth 0 - 15 cm, D2 = soil depth 15 - 30 cm, D3 = soil depth 30 - 45cm soils

Exchangeable Ca was highly significantly (P ≤ 0.001) affected by the interaction effects of land use and soil depth (Table 3). The highest exchangeable Ca (22.2 cmol(+) kg^{-1}) was observed on the surface layer of forest land where as lowest (8.6 cmol(+) kg^{-1}) on the surface layer of cultivated land with an increase of 158% which might be due to high OM and relatively high pH on the surface layer of forest land and its leaching from the surface layer of cultivated land. Baker *et al*. [29]: [30] reported that cultivation led to reduction and leaching of exchangeable cations, especially in acidic tropical soils. In this study, exchangeable Ca showed high 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. According to the ratings recommended by FAO [72], the soil is ranged medium in cultivated land to very high in forest land in its exchangeable Ca content.

Exchangeable Mg was also highly significantly (P ≤ 0.001) affected by the interaction effect of land use and soil depth where the highest (8.1 cmol(+) kg^{-1}) was observed in the subsurface layer of forest land and lowest (1.4 cmol(+) 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 and high leaching of exchangeable Mg from the cultivated land. He *et al*. [11] reported that the lowest exchangeable Mg was obtained in cultivated land which could be due to the high intensity of cultivation and abundant crop harvest with little or no use of inputs. 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. According to FAO's [72] rating, soils of the study area are ranged medium in cultivated land to very high in forest land in its exchangeable Mg content.

Exchangeable K was significantly (P ≤ 0.01) affected by land use and soil depth interactions (Tables 3) whereby the highest (0.76 cmol(+) kg^{-1}) was recorded on the surface layer of forest land while lowest (0.31 cmol(+) kg^{-1}) in the subsurface layer of grazing land which might be due to high OM on the surface layer of forest land and high compaction or β_b in grazing land. This result was in agreement with that of Baker *et al*. [29]: [16] who found that lower exchangeable K contents in cultivated and grazing lands than in the forest land. Barber [73] reported that the critical level of exchangeable K in the soil for most crops for K fertilizer requirement is 0.38 cmol(+) 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. Similarly, Smaling *et al*. [74] reported that crop responses to K fertilization are rare in Africa due to high exchangeable K contents in many parts of Africa.

Exchangeable Na was significantly ($P \leq 0.05$) affected by land use and soil depth interactions (Tables 3). The highest exchangeable Na (0.58 cmol(+) kg^{-1}) was recorded on the surface layer of forest land and lowest (0.19 cmol(+) kg^{-1}) on the surface layer of cultivated land that increased by 205.3% which might be due to their high OM content and leaching, respectively. According to FAO's [72] rating, the soil was qualified as low in cultivated land and medium in forest and grazing lands, respectively for their exchangeable Na contents.

Exchangeable Ca and Mg were by far higher than K and Na in all land uses of the study area since divalent cations were higher in macro-aggregate fractions than the monovalent once which was similar to the report of [30]. Mamo [17] 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 in CEC in cultivated land as compared to the adjacent forest land.

Percentage base saturation was also highly significantly ($P \leq 0.001$) affected by land use and soil depth interactions (Table 3). In this study, the highest PBS (73.5%) was observed in the subsurface layer of forest land where as lowest (34.4%) on the surface layer of cultivated land 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.

3.2.3. Micronutrients (Available Iron, Manganese, Copper and zinc)

Table 4. *Interaction effects of land use and soil depth on available iron, manganese, copper and zinc*

Treatments	Available iron (ppm)	Available manganese (ppm)	Available copper (ppm)	Available zinc (ppm)
C,D1	7.2c	21.2a	2.38ab	0.89de
C,D2	6.4cd	13.7bc	1.81bc	0.49cd
C,D3	4.5d	12.6c	1.61c	0.41d
F,D1	14.2a	24.1a	2.71a	2.85a
F,D2	11.8ab	16.9b	2.58a	1.34b
F,D3	12.8ab	14.8bc	2.46a	1.07bc
G,D1	12.6ab	14.1bc	2.23ab	0.38e
G,D2	11.1b	3.5d	1.60c	0.55de
G,D3	11.2b	2.8d	1.55c	0.39e
R^2	0.90	0.95	0.74	0.94
CV (%)	13.69	14.42	16.17	27.16
F-test	***	***	**	***
LSD (0.05)	2.42	3.43	0.59	0.43

Means with the same letter are not significantly different at $P \leq 0.05$ according to Fisher's LSD; Note: C = cultivated land, F = forest land, G = grazing land, D1 = soil depth 0 – 15 cm, D2 = soil depth 15 – 30 cm, D3 = soil depth 30 - 45cm soil

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

	ρ_b	*f*	pH	CEC	OC	TN	Av P	Av S	Ca	Mg	K	Na	PBS	Fe	Mn	Cu	Zn
ρ_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

High significant ($P \leq 0.001$) differences were observed in available micronutrients of Fe, Mn and Zn contents by the interaction effect of land uses and soil depths where the highest (14.2, 24.1 and 2.9 ppm) were observed on the surface layer of forest land (Table 4) which might be due to high OM concentrations that acted as a chelating effect and source of such micronutrients. Significant ($P \leq 0.01$) difference was also observed in 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. Mamo [17] reported that OM may promote the availability of such nutrients by supplying soluble complexing agents or organic acids that interfere with their fixation. These results were also supported by Wakene [16]: [7] who stated that micronutrients content increased with the increase in OM and total N. 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).

Lindsay and Norvell [75] indicated that the critical levels of available Fe and Mn for crop production are > 40 and 48 ppm, respectively. Therefore, according to the suggestions made by them, the soil of the study area was below the toxicity level of Fe and Mn nutrients for producing crops.

4. Conclusions

Land use has significant impacts on soil physicochemical properties in the study area. Forest land, due to its strong protection, was found to be low in β_b, high in total porosity f, and better in OC, total N and available S, CEC, exchangeable bases and micronutrients content especially on the surface layer. Although it is clayey in texture and relatively better in available P, cultivated land was poorer in soil nutrients with lower pH which has become limiting for crop production. This signals the great need for soil 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 the farming systems so that soil total porosity, pH, OC, total N, available S and P, CEC, exchangeable bases and micronutrient contents will be improved and enabled production of sufficient food for the farm households by minimizing nutrient depletion and keeping such acidic soil fertile.

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