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Dynamics of soil fertility as influenced by different land use systems and soil depth in west Showa zone, Gindeberet district, Ethiopia

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Abstract: Land use change from natural forest to cultivated land, grazing land and subsequent changes in soil physicochemical properties was widespread in Ethiopia. Thus, assessing land use-induced changes in soil properties are essential for addressing the issues of agro-ecosystem transformation and sustainable land productivity. The aim of the study was to determine selected soil physicochemical properties of forest land, cultivated land and grazing land and make investigation among the soil properties. Standard procedures were employed for the analyses of soil parameters. One way ANOVA was employed to compare the soil parameters at particular and overall soil depth. Textural class of all land use types was clay indicating similarity in parent materials distribution of bulk density in all soil depths of cultivated land were higher compared to both forest and grazing land. Soil moisture content was significantly increasing with increasing soil depths. The highest soil pH in all soil depth was observed under forest land compared to both grazing and cultivated land. The highest soil OM contents were observed in the surface soils (0-10 cm) of forest land while least Figures were from subsurface (10-20 cm) layers of the cultivated land. TN, CEC, exchangeable (Ca, Na and Mg) of the forest land soil were improved when compared with both cultivated and grazing land soil.

Keywords: Land Use, Soil Fertility, Soil Physicochemical Properties

1. Introduction

Land use change is an important factor in global change phenomena. It is directly related to issues such as food security, water quality, soil quality and other important global life support issues [1]. Land use change and changes in soil fertility management often occur together resulting changes in soil quality including the activities of soil micro-organism [2]. As a consequence, one would expect close relationships between land use change and soil nutrient contents [3].

Land use change also affects the productivity of a soil. This manifests as changes in soil properties such as contents of available of macro and micro nutrient, organic matter and CEC [4]. Agricultural sustainability requires periodic evaluation of soil fertility status which is important in understanding factors that impose serious constraints to crop production under different land use types and for adoption of suitable land management practices [5].

Land use change affect the distribution and supply of soil nutrients by directly altering soil properties and influencing biological transformations in rooting zone. For instance, cultivation of forests diminishes the soil carbon within a few years of initial conversion and substantially lowers mineral stable of nitrogen [6]. Soil quality is a concept that integrates soil biological, chemical and physical factors into a framework for soil resource evaluation [7-9].

Soil properties such as water holding capacity, aeration, tendency to crust, and cation exchange capacity can be estimated from particle size distribution [10]. Differences in soil texture also impacts organic matter levels which broke down faster in sandy soils than in fine-textured soils this gives similar environmental conditions and fertility management because of a higher amount of oxygen available for decomposition in the light-textured sandy soils. The cation exchange capacity of the soil increases with percent clay and organic matter and the pH buffering capacity of a soil (its ability to resist pH change upon lime addition) is also largely based on clay and organic matter content [11].

Soil chemical properties are the most important among the factors that determine the nutrient supplying power of the soil to the plants and microbes. The chemical reactions that occur in the soil affects soil development and soil fertility build up. Plants are capable of absorbing and assimilating as many as forty or fifty different chemical elements. Sixteen of these chemical elements have been found to be essential to the growth of most plants. Therefore, this study was conducted with specific objective to assess and explore the status of soil physicochemical characteristics of three different land use systems along soil depth of representative area of Western Oromia Region. The result of this study expected to add value to the up-to-date scientific documentation of the status of soil fertility and soil quality of different land uses of the study area and other similar agro-ecological environments in the country.

2. Materials and Methods

2.1. Description of the Study Area

The study is situated in Gindeberet district, West Shewa Zone of Oromiya National Regional State, Ethiopia, between astronomical grids of $9^0$21'to $9^0$50' N and $37^0$37' to $38^0$08' E. The district town, Kachisi ($9^0$32'N and $37^0$49'E) is geographically located approximately at the centre of the district 193 Km west of Addis Ababa [12].

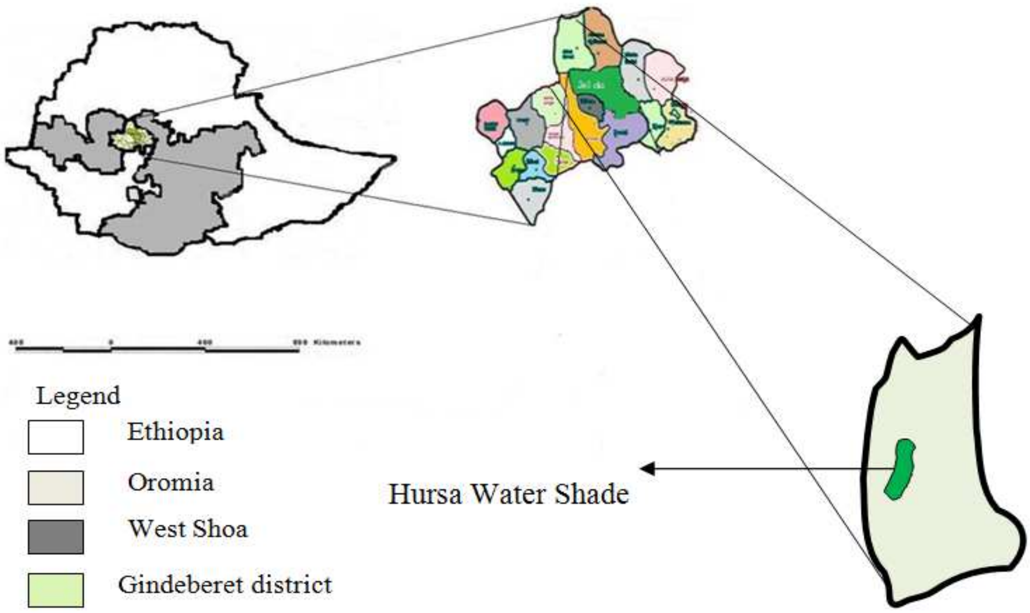

Figure 1. *Location map of study area.*

Ten years trends of rainfall distribution showed that there was no even distribution of rainfall in each year. Rather it was highly fluctuated between the ranges of 882-2039 mm. the same is true for temperature which was varied from 21 to 25.9 and 5.6 to 9.2°C for the maximum and minimum temperature respectively.

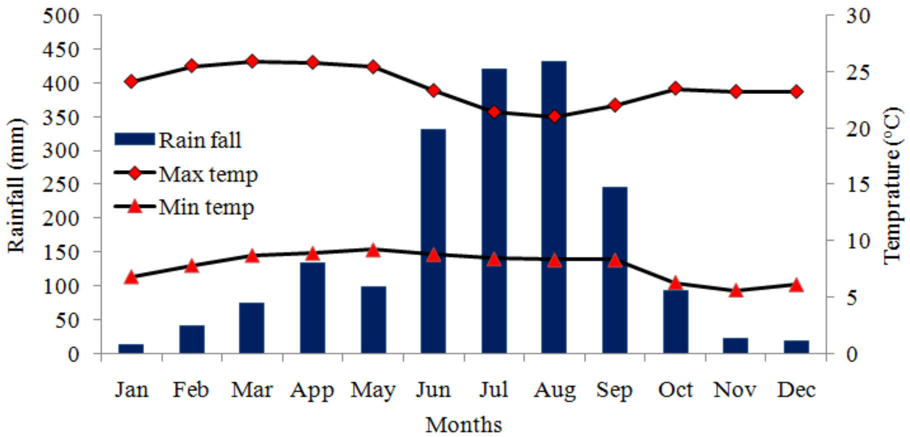

Figure 2. *Mean monthly rainfall and mean maximum and minimum temperatures of the study area.*

2.2. Soil Sampling and Analysis

In order to investigate soil fertility status through the analysis of some physical soil properties, Representative, intact soil samples was collected with a manual core sampler of known volume and weight, from each land-use practice unit plot in X design in five replicates from three blocks. Thus, samples were collected from four corners of a square of 20 X 20 plots, with one from the center. The samples were separated into 0–10cm, 10–20cm and 20 - 30cm horizons.

To determine the effect of different land uses on soil chemical properties, a total of 27 (3 land uses*3 soil depths*3 replicates) soil samples were taken. Then, the soil sample was taken from the pits by scuffing the wall of the soil profile for respective depth; the lowest first and the top soil at last to avoid contamination between the two layers. For each land use types and a soil samples, about 1kg of soil samples was taken. Then, the soil samples from each pit (the five) was bulked together to obtain composite soil samples for each replicates (the three blocks) in three depth interval and land use types. Soil clods in each composite sample was thoroughly broken to make a uniform mix, and then divided into four equal parts from which two diagonal parts was retained and the other two parts removed. This process was continued several times until the successive quartering reduced the weight of a composite sample to about 0.5 kg.

Samples were air dried ground and passed through 2 mm sieve for analysis. Analysis of soil samples were carried out at Chemistry laboratory of Ambo University based on their standard laboratory procedure. Particle size distribution and bulk density were determined by the hydrometer and the core sample methods respectively. Soil pH was determined in soil to water ratio of 1:2.5 (w/v). OC was determined by wet digestion method. Total N was determined by micro-Kjeldahl wet digestion and distillation method, while available P was extracted by the Bray II method and finally quantified by spectrophotometer. Cation exchange capacity (CEC) and exchangeable bases were extracted by 1M ammonium acetate (pH 7) method. Exchangeable bases (Ca, Mg, Na, and K) were extracted with 1M ammonium acetate at pH 7. Ca and Mg were analyzed by titrations using EDTA method. Exchangeable K and Na were measured by flame photometer.

2.3. Statistical Analysis

Soil physicochemical properties were subjected to analysis of variance using statistical analysis system version 9.0 [13]. Treatment means of the different land use types were compared according to Tukey test.

3. Results and Discussion

3.1. Impact of Land Use on Selected Physical Properties of the Soils along Depths

3.1.1. Soil Particle Size Distribution, Soil Bulk Density and Soil Moisture Content

Silt content across land use was not significant except for middle surface, which is significant (P = 0.05). High silt content was observed under forest land while low silt content was observed under cultivated land in all soil depths (Table 1). The distribution of sand across land use was not significant (P = 0.05) higher in all soil depths of grazing land than both forest land and cultivated land. Silt to clay ratio in the 0-10 cm depth was low and varied from 0.67, 0.32 and 0.49 for soils of forest, cultivated and grazing lands, respectively. While, Silt to clay ratio in the 20-30 cm depth was high and varied from 0.63, 0.99 and 1.09 for soils of forest, cultivated and grazing lands, respectively. Higher and lower silt to clay ratio recorded in the forest land and cultivated land respectively. High silt-clay ratio observed in the top surface horizons of forest land (0.63) may be attributed to the deposition of plant materials (litter) which are still undergoing decomposition. While, lower silt to clay ratio recorded in the cultivated land (0.32) attributed to the impacts of deforestation and farming practices [9].

Table 1. *Comparisons of soil physical properties in different land use types and soil depth. Results expressed as mean ± standard deviation.*

Variables	Depth (cm)	Land use Types		
		Forest land	Cultivated land	Grazing land
Sand (%)	0-10	24.26 ± 4.00^{ab}	22.60 ± 2.20^{b}	26.42 ± 3.78^{a}
	10-20	20.66 ± 4.76^{a}	19.72 ± 5.50^{a}	23.88 ± 1.99^{a}
	20-30	21.40 ± 1.56^{a}	18.93 ± 2.70^{a}	22.56 ± 2.34^{a}
Silt (%)	0-10	30.51 ± 2.26^{a}	18.78 ± 0.74^{b}	24.21 ± 3.04^{ab}
	10-20	29.67 ± 1.87^{a}	19.42 ± 3.03^{c}	25.65 ± 2.90^{b}
	20-30	33.52 ± 2.94^{a}	19.20 ± 1.64^{b}	20.66 ± 2.67^{b}
Clay (%)	0-10	45.23 ± 1.46^{b}	58.62 ± 6.25^{a}	49.37 ± 0.74^{b}
	10-20	49.67 ± 8.53^{b}	60.86 ± 7.14^{a}	50.47 ± 4.89^{b}
	20-30	45.08 ± 0.93^{b}	61.87 ± 2.95^{a}	56.78 ± 0.33^{a}
BD(g/cm^3)	0-10	1.08 ± 0.03^{b}	1.27 ± 0.03^{a}	1.22 ± 0.01^{a}
	10-20	1.11 ± 0.01^{b}	1.30 ± 0.02^{a}	1.27 ± 0.01^{a}
	20-30	1.13 ± 0.02^{a}	1.35 ± 0.02^{b}	1.29 ± 0.02^{c}
MC (%)	0-10	10.59 ± 0.21^{a}	8.65 ± 0.35^{b}	8.23 ± 0.22^{b}
	10-20	11.80 ± 0.20^{a}	8.66 ± 0.58^{b}	8.46 ± 0.20^{b}
	20-30	12.99 ± 0.16^{a}	9.14 ± 0.08^{b}	8.79 ± 0.25^{b}

Means within rows followed by different letters are significantly different (P =0.05) with land use.

Soil bulk density of both 0-10 cm and 10-20 cm soil depths was not significant (P = 0.05). While soil bulk density was significant at lower surface 20-30 cm of the soil depth. The distribution of bulk density in all soil depths of cultivated land were higher compared to both forest and grazing land. Soil bulk density was higher in the lower compared to 0-10cm and 10-20 cm soil depths in all land use types indicating the tendency of bulk density to increase with depth due to the effects of weight of the overlying soil and the corresponding decrease in soil organic matter content. The relatively lower bulk density in the top surface than in the lower layer may reflect organic matter concentration [9].

Soil moisture content of cultivated and grazing land was not significantly different (p=0.05) from each other at all soil depths while moisture content of forest land was statistically different from both cultivated and grazing land at all soil depths [14].

3.2. Impact of Land Use on Selected Soil Chemical Properties along Depths

Table 2. *Comparison of pH, OM, AV.P and TN in different land use types and soil depth, Results expressed as mean ± standard deviation.*

Variables	Depth (cm)	Land use types		
		Forest land	Cultivated land	Grazing land
pH	0-10	5.28±0.11[a]	4.24±0.29[c]	4.66±0.15[b]
	10-20	5.53±0.41[a]	4.41±0.17[c]	4.47±0.04[b]
	20-30	5.82±0.10[a]	4.63±0.20[c]	4.92±0.08[b]
OM (%)	0-10	2.31±0.50[b]	1.50±0.62[b]	1.93±0.15[b]
	10-20	1.71±0.31[a]	1.27±1.89[b]	1.76±0.04[a]
	20-30	1.33±1.18[b]	1.22±0.70[b]	1.55±0.08[a]
Av. P (ppm)	0-10	4.79±0.31[a]	2.34±0.01[a]	2.51±0.04[a]
	10-20	3.82±0.22[a]	2.12±0.01[b]	2.53±0.03[b]
	20-30	2.85±0.06[a]	1.71±0.02[b]	2.47±0.01[a]
TN (%)	0-10	0.12±0.03[a]	0.09±0.07[a]	0.10±0.01[a]
	10-20	0.11±0.01[a]	0.08±0.03[a]	0.09±0.03[a]
	20-30	0.10±0.01[a]	0.08±0.02[a]	0.08±0.04[a]

Means within rows followed by different letters are significantly different (*P* =0.05) with land use.

3.2.1. Soil pH, Organic Mater, Available Phosphorus and Total Nitrogen

The distribution of soil pH was significantly varies across all land use. The highest soil pH in all soil depth was observed under forest land compared to both grazing and cultivated land. On the other hand soil pH increase with increasing soil depths (Table 2). The reason can be the reduction of Ca and Mg ions along soil depth which lowers soil pH from top to down the soil layers [15].

The highest soil OM contents were observed in the forest land use type for both 0-10 cm and 20-30 cm soil depths while its content was high in grazing land for 10-20 cm soil depth (Table 2). At 0-10 cm soil depth the SOM content of forest land was significantly higher than cultivated land and grazing land at similar soil depth. This is attributed partly to the continuous accumulation of undecayed and partially decomposed plant and animal residues in the surface soils. In general, forest clearing followed by conversion into agricultural fields brought about a remarkable depletion of the soil OM stock. Hence findings of this study are in agreement with findings of similar studies by [16, 17].

Total N content was not significant in all land use types (P=0.05). The higher total N (0.31%) was found on the 0-10 cm depth range of forest land, whereas total N content of forest land was 0.28 % and 0.26% at 10-20 cm and 20 30 cm soil depths respectively. It is also known that in forest and grass dominated land, competition for nutrient is higher in the bottom surface layer due to the root biomass on this layer is much denser than the other layers [18].

The distribution of available soil phosphorus content of forest land use types in all soil depths were found to be higher compared to cultivated and grazing land. However, available phosphorus of grazing land at 10-20 cm soil depth was greater than the top surface 0-10 cm this could be attributable to the tillage practice which leads a relocation of clay separates and soil mix up which could increase phosphorus fixation by soil colloids [19].

3.2.2. Soil Cation Exchangeable Capacity and Exchangeable Cations

In this study, cation exchange capacity at 0-10 and 10-20 cm soil depth was not significant for both cultivated and grazing lands (Table 3). The CEC of the soil of all land use types at 20-30 cm was significantly higher than both 0-10 cm and 10-20 cm soil layers in all land use types, generally the present study found that, CEC of the soil of different land use types was low in the top layer except for forest land which was higher in 10-20 cm depth. The decrease in CEC from the bottom to the top soil layer might be attributed to the increase in clay contents with depth. As per the ratings recommended by [20] overall mean CEC value of forest land was moderate where as grazing land and cultivated land were classified as low status of CEC value.

Distributions of Ex. Ca and Ex. Mg across land use types were significantly influenced by soil depths (P=0.05). Generally, Ex. Mg and Ca distribution was decreased with increasing soil depths. The top 0-10 cm depth was higher in both Ex. Mg and Ca than the other two depths in all land use types. The higher content of Ex. Mg and Ca in the surface is probably due to forest litter and dead plant accumulation. [15] Stated that higher contents of Mg and Ca in the surface soil were due to the association of biological accumulation with biological activity and accumulation from plant. On the other hand, [21] stated that subsoil may be playing an important role as a nutrient storage.

Exchangeable potassium (Ex. K) contents of different land use systems were significantly affected by soil depths across all land use types in the study area while, distributions of exchangeable Sodium across land use type are not significant for both 10-20 cm and 20-30 cm depths [22].

In general, Deforestation, leaching, limited recycling of dung and crop residue in the soil, declining fallow periods or continuous cropping and soil erosion have contributed to depletion of basic cations on the cultivated land as compared to the adjacent forestland and grazing land. Although the farming system in Hursa water shade area of Gindeberet district is predominantly mixed crop-livestock, nutrient flows between the two are predominantly one sided, with feeding of crop residue to livestock but little or no dung returned to the soil.

Table 3. *Comparison of CEC (cmol($^+$) kg^{-1}) and Exchangeable cations (cmol($^+$) kg^{-1}) in different land use types and soil depth. Results expressed as mean ± standard deviation.*

Variables	Depth (cm)	Land use Types		
		Forestland	Cultivated land	grazing land
	0-10	14.63±0.15^a	8.70±0.10^c	12.53±0.30^b
Ex. Ca	10-20	13.43±0.21^a	8.03±0.15^c	11.70±0.20^b
	20-30	12.60±0.61^a	7.76±0.15^c	10.40±0.56^b
	0-10	5.60±0.10^a	3.86±0.06^c	4.80±0.20^b
Ex. Mg	10-20	5.40±0.30^a	3.50±0.10^c	4.50±0.10^b
	20-30	5.00±0.10^a	3.26±0.05^c	3.80±0.20^b
	0-10	0.67±0.03^a	0.23±0.01^c	0.51±0.05^b
Ex. K	10-20	0.71±0.02^a	0.29±0.05^c	0.54±0.05^b
	20-30	0.75±0.01^a	0.33±0.03^c	0.63±0.02^b
	0-10	0.71±0.01^c	0.21±0.03^a	0.40±0.04^b
Ex. Na	10-20	0.66±0.02^b	0.41±0.04^a	0.53±0.01^b
	20-30	0.89±0.04^a	0.46±0.01^a	0.78±0.03^b
	0-10	16.56±3.06^a	7.24±0.30^b	15.16±1.60^b
CEC	10-20	18.76±2.10^a	7.48±3.00^b	14.54±1.80^b
	20-30	14.28±1.01^a	8.16±1.60^b	13.54±1.00^c

Means within rows followed by different letters are significantly different at (P =0.05).

4. Conclusions

The soil chemical properties of the study area were significantly affected by land use types except Ex. Na, which was insignificantly influenced by land use types. SOM content was observed high in forest land but it was low cultivated land. TN content of cultivated land soil decreased by 15, 27.27 and 20 % at 0-10, 10-20 and 20-30 cm soil depths respectively when compared with soil of forest land. The analysis of soil pH of the cultivated land showed that it was more acidic than the grazing land. The exchangeable cations in the study area did not show similar trends along the land use types. Ex. Ca and Ex. Mg were decreases along with depth from top to bottom surface soil. But, Ex. Na and Ex. K were increase with increasing soil depths. On the other hand Ex. Ca and Ex. K were significantly influenced by different land use types while Ex. Mg and Ex. Na were insignificantly influenced by different land use types. Based on the study on the selected soil physicochemical properties the following recommendations are made. This study indicates that, there is an urgent need to improve soil fertility by developing sustainable land use/cover practices to reduce the rate of soil erosion and to ensure long-term sustainability of the farming system, as a result national efforts are urgently needed to protect the remaining forests and to implement extension programmes to ensure sustainable use of lands and conservation of forested areas.

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