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ARTICLE

Physico-chemical Characteristics of the Soils in Three Church Forest of Central Ethiopia

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ABSTRACT

Physical and chemical properties of soils interact each other either positively or negatively depending on the condition. Vegetation has influence on the soil physico-chemical characteristics and use land cover changes are the main factors in the process of land resource degradation. The objectives of this study were to define the soil texture, bulk density and extent of organic carbon in church forests and adjacent croplands and to compare the values. Transect lines of 100 meter apart and plots of 20 m × 20 m were established to collect soil samples in the church forests and individual farm plots. The distance between plots was 100 m. Horizon based soil sampling was undertaken. Soil samples were collected on a diagonal position from 2 edges and the center from 2 soil horizons (H1 and H2) for soil texture and soil organic carbon (SOC) analysis. For bulk density (BD) soil core samplers were used. The data were analyzed using one way ANOVA in SPSS v20. Mean separation was undertaken by least significance difference. The results revealed the %clay content was significantly higher in croplands than church forests and the %sand was higher in church forests than croplands at ($p<0.05$). The SOC was significantly higher in H1 than H2 and in church forests than croplands at ($p<0.05$). The better soil characteristics were obtained in church forests than in croplands. Hence, it is recommended to conserve the natural forests as in the church forests to maintain better property of the soil through enhancing soil organic matter, soil organic carbon and by decreasing soil bulk density.

1. Introduction

Soil is composed of minerals, soil organic matter (SOM), water, air and the composition and the proportion of these components greatly influence soil physical properties, including texture, structure, bulk density (BD) and porosity [1,2]. Chemical properties of soils such as pH, nutrients, soil carbon, soil salinity and sodicity in turn, control nutrient availability and transformations and can affect physical properties and thus plant growth [2,3].

Soil BD is a basic soil property influenced by some soil physical and chemical properties such as SOM [4]. It is the oven-dried weight of that sample divided by the bulk volume of the soil sample and is normally expressed in g cm^{-3} [5]. BD is a dynamic property that varies with the

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structural condition of the soil and can be altered by cultivation, trampling by animals, agricultural machinery, and raindrop impact [4,6]. Moreover, vegetation influences the physical properties of soil to a greater extent and improves the soil structure, infiltration rate, water holding capacity, hydraulic conductivity and aeration which are directly related to the BD [7].

Soil organic matter levels have declined over the last century in some soils as a result of intense agricultural practices, over-grazing, deforestation and conversion of forest to cultivated farmland [8-10]. Soil resources are finite, non-renewable and prone to degradation through misuse and mismanagement [4,11]. The unsustainable land use and land cover changes are recognized as the main factors in the process of land resource degradation [12-15].

High SOM content increases the aggregate stability through cohesion of aggregates which in turn reduces the loss of fine soil particles [16]. SOM content also increases nitrogen mineralization and maintain the soil pH which in turn affect plant growth and soil quality as a whole [17,-19].

Agricultural cultivation is known to decrease carbon storage [20,21], and results in a net flux of carbon to the atmosphere [22,23]. On the other hand, there is evidence that primary forests and forests that are adequately managed (e.g. church forests) for diversity and multiple benefits are more resilient to disturbances and maintain healthy, stable soils, provide natural habitats for forest biodiversity and provide a more stable stock of carbon [24].

The present study church forests and their surroundings are facing a great problem of deforestation and erosion. Hence, the study aimed at determining some selected soil physical characteristics such as texture, bulk density and soil chemical characteristics (SOM and SOC) content. The aim of the study is to assess the impact of land use change (i.e. conversion of forest to cultivated lands) on soil physical and chemical properties. Therefore, the objective of the study was to determine the soil texture, BD and the amount of organic carbon in the two land use types and to compare the values between the two land uses.

2. Materials and Methods

2.1. The Study Areas

The study sites are selected areas of Ethiopian Orthodox Tewahdo Church forests and farmlands and villages adjacent to the church forests that are approximately surrounding 1 km radius from the edge of the forests. Site 1 (Assela Teklehaymanot) is 175 km far from the capital Addis Ababa (AA) and have an area of 25 ha. The elevation range was from 2521 to 2581 m.a.s.l.

As adopted from [25], highland areas are found in altitudinal range of 2300 to 3200 m a.s.l., midlands from 1500 to 2300 m a.s.l. and lowlands from 500 to 1500 m a.s.l.. Therefore, Site 1 is in the highland agro climatic zone accordingly. Site 2 (Etisa Teklehaymanot) is found 75 km far from AA and have an area of 23 ha. The elevation range was from 1500 to 2301 m.a.s.l and hence, it is in the mixed midland and lowland agro climatic zone. Site 3 (Saramba Kidanemhret) is found 200 km far from AA and have an area of 22 hectares. The elevation range for Site 3 is from 2164 to 2251 m.a.s.l. showing midland agro climatic zone (Figure 1.).

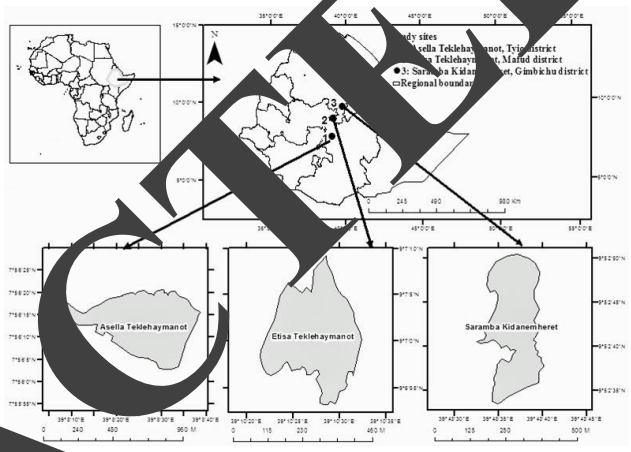

Figure 1. Location of the study sites in central Ethiopia

2.2 Materials Used for the Study

Transect lines and plots of 20 m × 20 m were established to collect soil samples in the church forest. A digging shovel was used to collect soil samples since the forest floor was not easy to use soil augur because of gravely rocks. A 50 cm plastic ruler was also used to measure the depth of the soil horizon. Soil core samplers were also used to collect soil sample for determining soil bulk density. Finally, a plastic bag container and paper made tags were used to store each soil sample and to differentiate one from the other.

2.3 Methods

Soil samples were collected from two soil horizons (H1: upper first and H2: Lower next to H1) for soil texture, SOM, and SOC analysis. According to [26] a vertical section of the soil in the land area exposes more or less distinct horizontal layers. It shows the distinctive characters of the soil profile. The surface layer is darker in color because of its higher organic matter contents such as litter, humus, minerals, residues of the dead flora and fauna. The study also identified soil color is often a reliable indicator of soil though color alone does not affect all soil charac-

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teristics [26]. Hence, the different soil colors were used to identify the consecutive soil profiles and the depth of the soil samples collected was determined by the depth of each horizon.

Soil samples were collected on the diagonal line one at each tip (end) of the diagonal and one at the center of the plot in each plot of 20 m × 20 m quadrant. Then, similar layers (horizons) from these three locations within the plot were mixed to form a soil composite in order to reduce the variability. The composite sample for each soil layer was mixed very well and again divided into 3 equal parts among which one was selected randomly for the subsequent laboratory analyses [27, 28]. The same procedure was undertaken on croplands those are adjacent to sampled church forests to compare soil properties. For BD analysis a soil core sampler of 5 cm diameter and 5 cm height for Site 2 and 3 and a core sampler of 8cm diameter and 8 cm height for Site 1 to collect soil samples from three diagonal positions in the center of 20 m × 20 m forest plots and adjoining cropland lands.

After the soil samples collected the soil was spread on plastic sheet, air-dried in a dust-free room, cleaned from extraneous substances and crushed to pass through 2 mm sieve. A part of the 2 mm sieved soil was further processed to pass through 0.5 mm sieve for the determinations of SOC content. Then the SOC was determined using wet digestion of [29] method in which the carbon is oxidized under standard conditions with potassium dichromate in the presence of concentrated sulfuric acid. The SOM content was estimated from the SOC content using the conventional factor of 1.724, assuming that SOM contains 58% of carbon [30]. The soil bulk density (gm cm^{-3}) was calculated as the ratio of oven-dry weight of soil sample (dried at 105°C for 48 h) to the volume of sampling cylinder.

2.4 Data Analysis

The SOM and SOC contents were analyzed both by the laboratory methods and using SPSS software v20. The statistical analysis was carried out on the replicates by using analysis of variance (ANOVA) to compare the differences for each soil horizon depth separately, between church forest soils and adjoining cultivated lands soils and again among the three sites. The result of the analysis was used to see whether the different land uses have significant differences on the soil physical and chemical characteristics. Mean separation was done by Least Significance Difference (LSD) for those attributes which produce a significant difference. Excel and statistical Package for Social Science (SPSS) v20 were used. Hence, the local level soil variation as affected by land use type was studied and analyzed.

3. Results

3.1 Soil Texture Analysis

Though it was assumed to get more than 3 soil horizons in both cultivated lands and church forests, the assessment obtained only two horizons (depending on change of soil color) in both land use types because of gravely nature of each sites with soil depth. More specifically under the church forests the stony layer comes within shallow soil depths. The mean clay percentage was higher in farm lands than in the church forests and also horizon 2 than horizon 1. The mean sand percentage consequently higher in church forests than farm lands. The silt percentage has shown no difference both between land use and between soil horizons (Table 1).

Table 1. Percent of sand clay and silt content between two consecutive soil horizons in Site 1 (Highland, Assela Teklehymanot), Site 2 (mixed midland and lowland, Etisa Teklehymanot) and Site 3 (midland, Saramba Kidnemhret), central Ethiopia

Land use type	Soil horizon	Soil texture class		
		% sand(Mean±St-dem)	% Clay(Mean±St-dem)	% Silt(Mean±St-dem
Farm land	H_1	21.39±2.25^{b}	42.18±2.82^{e}	32.27±1.73^{i}
	H_2	21.66±2.29^{b}	47.28±2.61^{g}	31.07±1.50^{i}
Church forest	H_1	36.01±2.15^{a}	27.63±2.09^{f}	36.40±1.53^{i}
	H_2	32.14±2.83^{a}	34.08±2.51^{h}	33.78±1.43^{i}
Overall comparison (p<0.05)	H1 vs H2	0.508	0.048	0.227

Note: 1. Different superscript letters show the difference is significant between soil horizons and between land uses and according to the textural triangle, Farm (H1 and H2) have silty clay and Church Forest (H1) have silt loam and church forest (H2) silty clay loam textural class. 2. Stdem=standard error of the mean.

According to the result of the ANOVA table, the two soil horizons, H1 and H2 were significantly different (P<0.05) in the mean clay percentage while no statistical difference was observed for sand and silt contents between the two soil horizons. The difference in the content of sand percentage, clay and silt between land use types (farmland and church forest) was highly significant (Appendix-Table A-6).

Among the three studied sites similarly the result table showed the sand percentage was higher in Site 3 and the %clay content was higher in Site 2. The mean %silt content was almost balanced in the 3 studied sites. Accordingly, the %sand content was significantly different between Site 3 and Site 1 and also between Site 3 and Site 2 but no significant difference between Site 1 and Site 2. A similar result found for %clay content. However, there was no

significant difference in %silt content in all the three sites (Table 2).

Table 2. Percent sand, clay and silt content among Site 1 (Highland, Assela Teklehymanot), Site 2 (mixed midland and lowland, Etisa Teklehymanot) and Site 3 (midland, Saramba Kidanemhret), central Ethiopia

Study site	Soil texture class		
	% sand(Mean±St-dem)	% clay(Mean±St-dem)	%Silt(Mean±St-dem)
Site 1(High-land)	23.27±1.55[b]	38.64±2.29[d]	35.82±1.26[g]
Site 2(Mid-land mixed lowland)	24.83±2.37[b]	42.70±2.75[d]	32.50±1.38[g]
Site 3(Mid-land)	39.56±2.49[a]	30.50±1.83[e]	29.94±1.12[g]
Overall Significan-ce(P<0.05)	0.000	0.07	0.08

Note: According to the textural triangle, Site 1 has silty clay loam soils, Site 2 has silty clay and Site 3 has clay loam soils

3.2. Soil Bulk Density

The soil BD was determined for all the three sites in the two land use types. The mean BD was higher in cultivated lands than church forests and it was also highest in Site 3 church forest than Site 1 and Site 2 church fore The result of the laboratory analysis and further analys using SPSS v20 produced the results shown in table 4.3 Hence, there was a significant differenc een land use types and among the three study sites a p<0.05) (Table 3).

Table 3. Mean bulk density of the two lan types in Site 1 (Highland, Assela T hymanot), Site mixed midland and lowland, Etisa hymanot) and Site 3 (midland, Saramba K danem central Ethiopia

Study sites	Land use type	Bulk density
Site 1(highland)	Farmland	0.11±0.006[a]
	Church forest	0.07±0.005[b]
Site 2 idland and low)	Farmland	0.27±0.016[a]
	Church forest	0.05±0.016[b]
	Farmland	0.25±0.01[f]
	Church forest	0.21±0.01[g]
Overa ficance (P	Farmland vs church forest	0.035
	Among sites	0.000

3.3. Soil Organic Matter and Soil Organic Carbon

The ANOVA have shown SOM and SOC were significantly different between the two soil horizons H1 and H2 at (F=10.733; P=0.001), and (F=10.724; P=0.001) respectively, with the topsoil (H1) showing higher values than the underneath soil (H2).

The SOM and SOC content was also compared between land use types and among the three study sites. The results have shown these two soil chemical properties were significantly different between land use types and among the three studied site. The SOM and SOC values were higher in church forests than adjoining croplands in all the three sites. The differences in SOM SOC content were highly significant amon e three s at (F=13.706; p=0.000, F=13.726; p=0.0 nd betw n land use types at (F=33.174; p=0 0, F=33. p=0.0 0) (Table 4).

Table 4. Soil organic matt OM) and s il organic carbon (SOC) cont nt in Site 1 hland Assela Teklehymanot) 2 and Site 3, al Ethiopia

Sites	rizon	SOM %	OC %
ite 1	H1	7.76±0.62[a]	4.50±0.36[a]
	H2	6.21±0.56[c]	3.60±0.32[c]
Site 2	H1	5.27±0.61[b]	3.05±0.36[b]
	H2	3.51±0.46[d]	2.04±0.27[d]
	H1	5.28±0.84[b]	3.06±0.49[b]
	H2	2.69±0.39[d]	1.56±0.23[d]
rall significance 05)	H1 vs H2	0.001	0.001

4. Discussion

4.1 Soil Physical Properties

In the present study the mean clay percentage was higher in farmlands than church forests. A similar result was observed on agricultural lands in Turkey [31]. The present study results were also in agreement with [32] which identified on average clay content was higher in cultivated land by 2.1% from the forest land. Another study by [15] identified sand content of three land use types, natural forest, natural forest and pasture land were greater than clay and silt content but clay content was greater in cultivated land compared to forest and pasture lands. The physical properties of soil play important role in the control of erosion and to increase the soil fertility [33]. It is also expected that soil properties may vary depending on management practices and land use types [31].

Accordingly, sandy soils allow a rapid entrance and passage of water through them. On the contrary, the high mean clay percentage of the cultivated land in the present study may aggravate soil erosion due to delayed infiltration rate but higher water holding capacity once the water is infiltrated. According to [34] adequate moisture is

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required for decomposer organisms to operate efficiently. Excessive moisture or anaerobic conditions resulting from prolonged inundation may impede the activity of soil flora and fauna and decomposition process. The soil texture, shape and size of particles in the soil and its physical condition, both of surface and profile layers affect vertical filtration and capability of soil to retain water. Therefore, the balanced clay percentage, sand percentage and silt percentage of the church forest soils in all the three studied church forests may create favorable conditions for both the activities of soil organisms and for plant growth as described by [35].

The present study results indicated the soil BD was higher in the cultivated lands than church forests with a significant difference at ($p<0.05$) asserting farming practices increase the compaction and expose soils to erosion. In a similar study in Ethiopia highest BD (0-15 cm depth of soil) was found in the cultivated lands and the lowest under the natural forest [36]. This result was also in agreement with that of [37]. Higher BD may cause restrictions to root growth, and poor movement of air and water through the soil. BD can be changed by crop and land management practices that affect soil cover, organic matter, soil structure, and porosity and weaken the natural stability of soil aggregates making them susceptible to damage caused by water and wind [6].

The lower soil BD in the church forests (0.16gm cm^{-3}) than cultivated lands (0.19gm cm^{-3}) of the present study indicated the suitable characteristic of the forest soil for plant growth and activity of soil fauna. A similar study in northern Ethiopia [32] showed that cultivated land had the highest average BD and forest land the lowest of all land use land cover types. Cultivated land had a 0.[illegible] gm cm^{-3} higher BD than forest land and a [illegible] gm cm^{-3} higher soil BD than grass land. Generally, the lower BD in the present study in church forests than their adjoining cultivated lands have shown the contribution of the church forests in maintaining better soil characteristics.

4.2 Soil Chemical Properties

The present study the comparison of SOM and SOC content has shown a statistically significant difference among the three study sites. Accordingly, Site 1 that is found in the highland area (2521 to 2581 m a.s.l.) comprised a vegetation of big trees and broad leaved shrubs and is well populated to cover the soil with enough litter fall have shown the highest SOM (8.83 %) and SOC (5.13 %) content than the other two sites. A similar situation is observed in the cultivated lands of this site that showed a mean SOM (5.13 %) and SOC (2.98 %) contents. This may also be attributed to a gradual decomposition and continuous accumulation of organic matter as the area is cooler than Site 2 and Site 3. The SOM and SOC contents in Site 2 and Site 3 seem almost alike with Site 2 having a slightly higher mean SOM and SOC of 5.45 % and 3.16 % respectively than Site 3 which have 5.32 % and 3.09 % respectively. A similar trend was ~~seen~~ observed on cultivated lands of Site 2 having mean values SOM (3.33) and SOC (1.93 %) and Site 3 having SOM (2.65 %) and SOC (1.54 %). These two sites had a nearly equal altitudinal range of (1500 to 2301 m.a.s.l.) and (2[illegible] to 2251 m.a.s.l.) for Etisa TH and Saramba KM, respectively. Hence, the similarity in the mean SOM and SOC content of these two sites may be attribute to their equivalent altitudinal range in addition to other factors which influence the amount of SOM and SOC content.

The present study has also compared the SOM and SOC content between the two land use types and as a result forest lands have higher measures. A similar study by [38] reported that conversion of natural forest to continuous cultivation had resulted in significant reduction of both the stock and concentration of SOM. [15] also asserted a sustained natural forest land contained a higher SOM than the cultivated and pasture land since deforestation and present microbial decomposition in the latter two exhausts organic matter from the soil. Deforestation and subsequent cultivation decreased organic matter by 48.8% [39]. According to [40], SOC is a powerful indicator for assessing soil potential productivity.

The study by [41] found that SOM content decreased down along the soil profile similar to the present study. The same study by Jaiyeoba also reported the conversion of forest to cultivated land significantly decreased SOM content. A number of similar studies also approved that forest soils contain higher SOM than cultivated land soils [42-45]. Generally, SOM is a critical loch in the carbon cycle and a storehouse of nutrients, and through its influence on many essential biological and chemical processes it plays a pivotal role in nutrient discharge and accessibility [46-49].

4.3 Conclusion

The findings of the study did not support the hypothesis that no observable differences will be discerned between different land use types. The lower BD value in church forests may be attributed to their higher organic matter and humus content. The mean SOM and SOC content on the other hand, was higher in church forest than the cultivated lands indicating land use change from forest to cultivated land conveys a higher loss of organic matter. The highland site has higher mean SOM and SOC content than the lowland and the midland sites which may be attributed to the slow rate of organic matter decomposition

prevalent in the highland site (Site 1) due to cooler soil temperature. Based on similar studies it can be concluded that organic matter content indicates the suitability of soil for plant growth and other important processes in the soil. The mean clay percentage and the mean SOM and SOC content have shown significant difference ($p<0.05$) between the two soil horizons (H1 and H2). H2 have shown higher clay percentage than H1 and both the mean SOM and SOC contents were higher in H1 than H2. The higher percentage of SOM and SOC in the upper soil horizon (H1) indicates the presence of higher accumulation of litter and/or crop residues. Therefore, conserving the natural forests as in the church forests for increasing the better quality of soil through enhancing SOM, SOC and decreasing soil BD is recommended.

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Conflict of Interest

The author declares no conflict of interest regarding the manuscript

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