

Effect of Land Use Change on Soil Carbon Stock in Bubisa Watershed Adea Berga District, Central Ethiopia

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Abstract: Land use change is one of the primary constraints affecting carbon stock in Ethiopia. The shift from natural forest and grazing lands to crop land is the main direction of change. Knowing this fact, a study was conducted in 2021/2022 to assess the effect of land use change on soil carbon stock in the study area. In order to achieve this objective three different land use types (crop, grazing and forest lands) were selected and twenty four (24) core and composite soil samples were collected from 0-20, 20-40, 40-60 and 60-80 cm to determine the soil carbon stock of each layer of land uses. The results of the study showed that land use change analysis applied for two periods (1981 - 2001 and 2001 - 2021) decreased soil OC and TN from 3.96 to 1.69% and from 0.22 to 0.17% in forest to crop land soils, respectively. The effect of land use change can be seen not only in terms of soil OC, but also in terms of climate change in which carbon stock and emission vary from one land use to the other land uses. SOC storage potential of crop land (5.88Mg/ha) was almost more than 3 times lower than that of forest land (20.8Mg/ha). From these findings, one can conclude that the forest land is the major reservoir of SOC and sinks of CO₂e and plays a significant role in mitigating climate change. Based on the findings and conclusions of this study, it can be recommended that, huge potential of soil OC which affect global climate change, SOC storage improvement strategies should be incorporated in policies of green economy and SOC sequestration incentives should be encouraged. Furthermore, studies should be considered to provide more conclusive recommendation for having sustainable natural ecosystems and mitigated climate change.

Keywords: Land Use, Soil Physicochemical Properties, Carbon Stock, CO₂ Sequestration

1. Introduction

Land use change is one of the primary constraints affecting agricultural production by changing soil physicochemical properties in Ethiopia [9]. It is occurring when one land use type changes to another either to destruct or maintain it. Several studies in the past have shown that deforestation and cultivation of virgin tropical soils often lead to depletion of nutrients and soil organic carbon stock [6, 5]. Moreover, the conversion of natural forest land to grazing and cultivated lands are examples of land use change in which land resources are exposed to degradation processes [48]. Long year deforestation without replacement of trees, uncontrolled overgrazing, erosive rainfall patterns, inadequate investment on soil conservation, reduced fallow period, limited use of

organic residues, low vegetative cover and unbalanced crop and livestock have been confirmed to be a major cause for soil degradation processes in Ethiopia [24].

In most cases, land use change affects the magnitude and rates of soil degradation and has a significant impact in deteriorating the physical and chemical properties as well as the biological activities of the soil [44, 46]. Further, an alarming increase in human population and the need for larger areas for agricultural production and fuel wood collection were the major influence for land use change thereby causing soil fertility decline in Ethiopia [37]. This is becoming difficult to feed the currently increasing population with the traditional agricultural system [4]. Even though, the consequence of land use change is very serious; it is not received as much research attention as soil erosion and other forms of land degradation. Most recently, only few studies [2] have considered the effect

of land use change and their management practices on soil physicochemical properties that influence soil fertility.

On the other hand, conversion of natural forest to cultivated land, driven by shortage of agricultural land in most parts of Ethiopian highland is becoming very crucial problem. [42] reported that, the rate of deforestation in Ethiopia was 163,000 to 200,000 ha per year. Due to this, natural forest cover in Ethiopia has declined approximately from 40% to just less than 3% during the last 100 years [38]. According to [27], between the years 2005-2010 about 140,882 ha of forests are harvested annually in Oromia region for expansion of farmland, shifting cultivation, commercial agriculture, fuel wood collection and logging, urbanization and for construction purposes. Additionally, it reduces the organic carbon storage of the terrestrial ecosystem by increasing the release of carbon from the biomass and soil carbon pool; which may significantly increase the concentration of greenhouse gas (GHG) in the atmosphere [33]. Carbon dioxide is one of the GHG that emitted from the land-use land-cover change, deforestation and burning of fossil fuels like coal, oil, and natural gas [30]. Since huge amount of carbon is stored in the biomass and soil of the terrestrial ecosystem (forests, agro-forests, grazing land, exclosure areas, and agricultural land), [28], unwise use of this ecosystem releases more carbon dioxide into the atmosphere than they are storing [12].

The livelihood of population at the study area (Bubisa watershed) is based on agricultural activities. The area has low soil fertility status and less productive due to long-term cultivation and deforestation associated with soil erosion and leaching which will make the efforts to increase agricultural

production difficult. This problem may be alleviated through the prevention of further land degradation, rehabilitation of the degraded ones and preparation of a rational land use planning for agriculture [10]. Hence, these indicate the importance of monitoring land use changes and evaluating ecological responses of soils to land use changes in Adea Berga district particularly at Bubisa watershed. In this regard, little or no scientific information pertinent to the magnitude and direction of land use change and its effect on soil properties and carbon stock in the study area. Therefore, the objective of this study was to estimate the effect of different land use changes on the soil carbon stock and equivalent CO₂ sequestration potential of each land use.

2. Materials and Methods

2.1. Description of the Study Area

2.1.1. Location and Area Coverage

The study was conducted at Bubisa watershed in Adea Berga district, which is located at a distance of 67 km from Addis Ababa in Oromia National Regional State (ONRS). The district is found in West Shewa Zone and geographically located at latitude of 9°12" to 9°37" North and longitude of 38°17" to 38°36" East. It is bounded by Mulo and Sululta district on the East, Degem and Kuyu district on the North, Yaya Gulele district on the North East, Meta Robi district on the West and Ejere and Welmera district on the South. The total area coverage of Adea Berga district and Bubisa watershed is 94,995.5 and 206.3 ha, respectively.

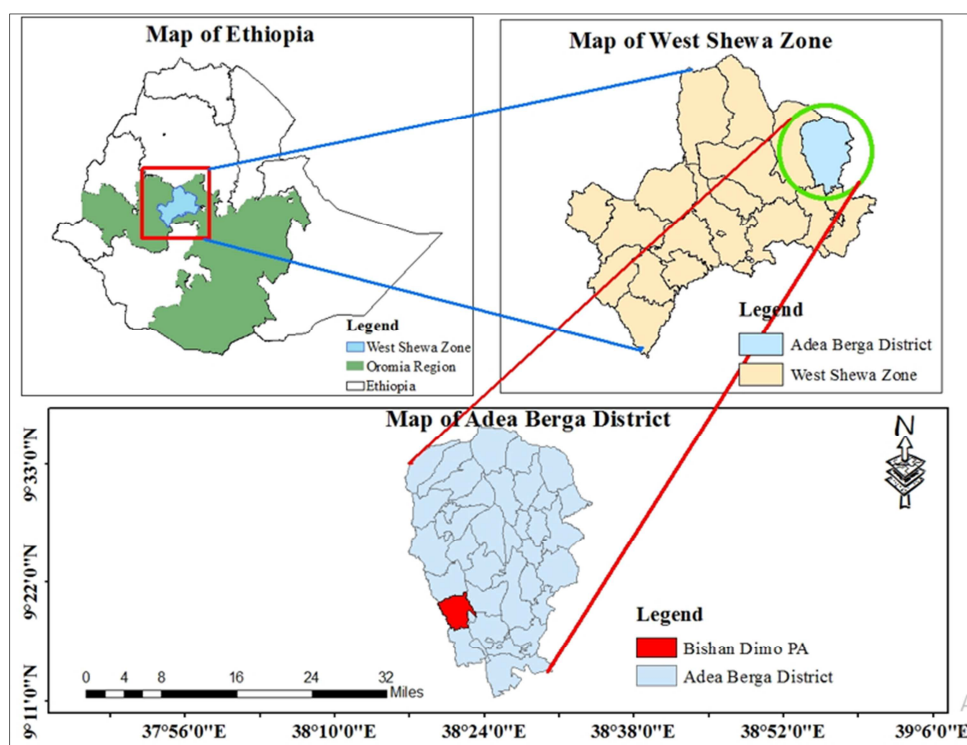


Figure 1. The geographical location of Adea Berga district in Ethiopia.

2.1.2. Climate and Physical Features

Adea Berga district has three agro-ecological zones (Dega, Woyna Dega and Kola) of which Woyna Dega dominates the agro-ecological zones. The area is characterized by unimodal rain fall type and the main rainy season occurs in summer from mid-June to Mid-September covers about 80% of the annual rain fall. The mean annual rain fall of the district is 1180.5 mm. The minimum and maximum temperatures of the study area are 6.12 and 24.99°C, respectively. The study area (Bubisa Watershed) is dominated by undulating land forms with different slope categories [8]. Its altitude ranges from 1160 to 3238 meters above sea level (masl).

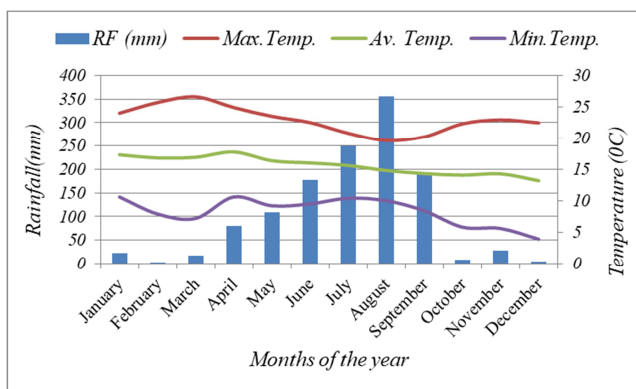


Figure 2. Mean monthly rainfall and temperatures of the study area (from 2010-2021).

2.1.3. Soil Types and Geological Parent Materials

The dominant soil type of Adea Berga district is vertisols (guracha- dalacha or black- brown) with inherent characteristics of vertic horizons. These are heavy clay soils with a high proportion of expanding clays (smectites) which are formed from parent materials of fine-grained rocks [17]. The smectite clay swells and shrinks upon wetting and drying. During the dry season, the clay shrinks, becomes very hard and forms wide and deep cracks [7]. The parent material of the soils in the study area is mainly of basaltic rocks.

2.1.4. Population and Farming System

The total population in Adea Berga district is 174,433 (87,186 men and 87,247 women) of which 147,169 are rural dwellers and about 27,264 are urban dwellers. More than 85% of farmers in the study area are mostly practicing traditional mixed crop-livestock farming system that involves crop production and animal husbandry. The dominant crops grown in the study area are wheat, teff, barley and maize, whereas the major livestock includes; cattle (137712), sheep (56431), goats (30216), mule (1519), donkey (21208) and horses (17154). Grazing land use for livestock production and traditional farming systems are very popular in the district.

2.2. Method of the Study

2.2.1. Study Approach and Data Collection Methods for Land Use Change

Among different approaches used in studying land use

dynamics, spatial analogue method was selected in which spatial selection of different land uses but operating within a similar location and on similar soil types for this study. All important data (both primary and secondary) concerning the study area land use changes were collected. Primary data about the present and past history of land changes in the study area were collected through personal interviews with respondents (local communities and government officials in the study area) and using questionnaire. Moreover, secondary data were collected from various published and unpublished materials such as research paper, reports and relevant documents of governmental offices of the study area. Geographical location coordinates; elevation and slope variations of the study area were measured using Geographical Positioning System (GPS) of model (G.72H) and clinometric instrument for each land use, respectively.

2.2.2. Site Selection, Soil Sampling and Preparation for Laboratory Analysis

The study was carried out on the representative land use types (forest, grazing and crop lands) of the watershed. Three stages of stratified soil sampling methods were used. In the first stage, the study area (watershed) was stratified into three land uses (nearly homogeneous strata). In the second stage, based on measured slopes using clinometer, each land use type was partitioned into three segments with their sequential slopes [lower, middle and upper] and a field area of 120m × 120m size was marked as sampling field for each slope positions of land use types following a method applied by [3]. In the third stage, each slope category was represented by three sampling sites so that soil samples from each stratum would have provided representation of study area.

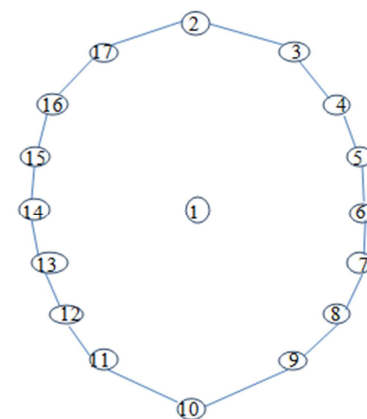


Figure 3. Sub sampling positions.

Then, the soils of the study area were identified into low, middle and upper slope [3] separately for the three land use types and three sampling sites were identified for each slope category. Accordingly, nine sampling sites for each land use soils were randomly assigned. Geographical Positioning System (GPS) of model (G.72H) was used to identify the geographical location of the sampling sites. A total of 24 core samples and composite soil samples were collected from selected sampling sites from four layers (0-20, 20-40, 40-60

and 60-80 cm) using core samplers and auger, respectively. One composite soil sample was formed from the seventeen subsamples for two layers (0-20 and 20-40 cm) soil depth as shown in figure 3 above. These soil subsamples were collected from the center of the sampling ring and from 16 points along the circular ring at 15 m radius from the center point. In order to compute the total soil organic carbon stored under each land use, organic carbon content and bulk density of the soil was determined from four depths (0-20, 20-40, 40-60 and 60-80 cm) as described by [16].

From representative sampling sites core samples and samples of 500 g for composite soil samples were weighed, labeled and kept in plastic bag, and submitted to Oromia Engineering Corporation and Batu Soil Research Center. The composite soil samples were air dried and ground to pass a 2 mm sieve for the analysis of selected soil physical and chemical properties and 0.5 mm sieve for total N and soil organic carbon content. All laboratory analyses were done following the general standard laboratory soil analysis procedures for the selected soil physical and chemical properties.

2.2.3. Soil Laboratory Analysis

(i). Soil Physical Analysis

Soil bulk density was determined from core sample using core method [19].

(ii). Soil Chemical Analysis

The pH of the soil was measured in water using pH meter at suspension of 1:2.5 (soil: liquid ratio) [29]. [43] wet digestion method was used to determine the soil organic

carbon content. Total N was analyzed using the Kjeldahl digestion, distillation and titration method as described by [18].

2.2.4. Estimation of Soil OC Storage, Equivalent CO₂ Sink and Its Momentary Value

To compute the amount of SOC (Mg C) sequestered in one hectare of land the approach proposed by [21] was used (Eq 1).

$$SOC \left(\frac{Mg\ C}{ha} \right) = \frac{OC\% * \rho b * Z}{10} \quad (1)$$

Where SOC (Mg C)/ha is the amount of carbon sequestered in one hectare of land. OC is organic carbon from soil laboratory results, ρb is bulk density of the soil ($g\ cm^{-3}$), Z is soil depth (cm), and 10 is correction factor for units ($10^8\ cm^2 / ha * Mg / 10^9\ mg$).

The soil organic carbon stored under each land use types (Lui) was also computed by applying equation 2:

$$Soc\ Lui\ (Gg) = \frac{\sum (Soc * Ai)}{1000} \quad (2)$$

To determine total Soc of watershed equation 3 was used:

$$Soc\ total = \sum_{i=1}^3 (Soc\ Lui) \quad (3)$$

To compute equivalent CO₂ sink (tones) and the currency value for the carbon-offset in the study watershed the equations formulated by [41] was applied (Eq 4 and 5).

$$Co2e = 3.67 * Soc\ total * 1000 \quad (4)$$

$$Market\ values\ in\ US\ dolar = Co2\ e\ (tone) * marketprize\ per\ tCo2\ e \quad (5)$$

2.2.5. Data Analysis and Interpretation

The laboratory determined soil physicochemical parameters were analyzed by using descriptive statistics. Soil physicochemical properties and carbon stock were compared among the three land uses (forest, grazing and cultivated lands). Likewise, comparisons of some soil physicochemical properties with their critical values were done.

3. Results and Discussions

3.1. Soil Organic Carbon

The soil organic matter is a nutrient sink, sourced from plant residues and animal wastes, used as source of nutrient and to improve soil physical properties. There was a variation of organic matter among the land uses of the study area. Across the land uses, the values of soil organic matter content were ranged from 1.17 to 2.43% (for crop land), 1.92 to 3.02% (for grazing land) and 3.42 to 4.51% (for forest land) (Table 1). Comparatively the highest (4.51%) and lowest (1.17%) mean values of organic carbon were recorded for soils under forest land and crop land, respectively (Table 1). At all points of land uses considered for this study the

highest soil organic carbon value was recorded for soil under forest land, while, the lowest soil organic carbon value was obtained from crop land use (Table 1).

The lower soil organic carbon value of soils under crop land might be attributed to the continuous and intensive tillage operation that aggravates organic matter deterioration and insufficient inputs of organic substances and total removal of residues through harvesting from the farm fields. In agreement with this, [14, 13] reported that intensive cultivation removes crop residues through rapid decomposition of organic residues from crop land. In contrary, the highest organic carbon content recorded for forest land could be due to high accumulation of organic residues with very slow decomposition as result of low aeration system in the forest land without tillage. In agreement with this, [20] reported higher organic matter content of forest land due to better accumulation of organic residues in forest land. In general, the most probable source of variation in soil organic carbon contents among the land uses could be due to difference in slope, organic inputs, moisture content, temperature, pH and management practices.

According to the rating suggested by [39], the soil organic

carbon content of the study area can be categorized under low to medium class (for crop land), medium class (for grazing land) and high class (for forest land). Most mean values of organic carbon contents of soil under crop land in the study area was under low class which might be due to intensive tillage operations under this land use as a result of shortage of land without fallowing. This form of land management aggravates rapid decomposition of the small amount of organic input returned to soils of the crop lands. Total removal of crop residues for other competent ends such as animal feed, fuel, construction and sell to others to as means of income is common practices in the study area. In consent with the findings of this study [23, 26] demonstrated that intensive cultivation results in rapid oxidation of soil OM. Moreover, [34] reported that the total removal of crop

residues for animal feed and as source of energy as being among the main reasons for low OM content in soils of Ethiopia. [31] also confirmed that most cultivated soils of Ethiopia are generally poor in OM content.

Considering the soil depth, the highest soil OC content was observed on the surface (0-20 cm) layer of forest land and lowest on the subsurface (20-40 cm) layer of cultivated land (Table 1). This could be due to high concentration of organic materials, abundant soil microorganisms that decompose organic materials and suitable aeration and moisture content on the surface layer of forest land and low input of organic materials and low activities of soil microorganisms for organic material decomposition of crop land. In agreement with this finding, [36] reported that the highest and lowest soil organic carbon under forest land and crop land, respectively.

Table 1. Mean values of pH, TN and OC in the study area.

Land use	Depth (cm)	Slope positions								
		pH (H ₂ O)			TN (%)			OC (%)		
		Upper	Middle	Lower	Upper	Middle	Lower	Upper	Middle	Lower
CL	0-20	5.65	5.75	5.86	0.15	0.17	0.21	1.4	1.76	2.43
	20-40	5.82	5.93	6.02	0.14	0.16	0.17	1.17	1.50	1.85
GL	0-20	6.27	6.39	6.37	0.17	0.17	0.21	2.23	2.26	3.02
	20-40	6.16	6.32	6.35	0.15	0.16	0.20	1.92	2.01	2.80
FL	0-20	6.22	6.38	6.51	0.20	0.21	0.22	4.04	4.34	4.51
	20-40	6.11	6.26	6.48	0.17	0.18	0.19	3.42	3.57	3.86

CL=Cultivated land, GL= Grazing land, FL= Forest land, pH= Power of hydrogen, TN= Total Nitrogen, OC= Organic Carbon

3.2. Estimation of Soil Organic Carbon Content, Carbon Stock and Equivalent CO₂ Sink

3.2.1. Soil Organic Carbon Content

As presented in Table 2 the difference in soil bulk density, depth wise soil organic carbon and area indicated that land use change affected soil organic carbon content in the 0-80 cm profiles. Conversion of land use from forest to crop land was accompanied by increase in bulk density from 1.05 g.cm⁻³ in forest land to 1.27 g.cm⁻³ in crop land and from 1.18 g.cm⁻³ in grazing land to 1.27 g.cm⁻³ in crop land. The lowest bulk density values in the forest land might be associated to highest organic carbon content which encourages aggregation. In agreement to this finding, [40] also reported significantly lowest bulk density values in the natural forest as compared to grazing and cultivated land uses. Soil bulk density was lowest in the top soil layer (0-20 cm) in all land uses considered and decreased with depth (Table 2).

Soil OC content is a key indicator of soil fertility. Soil OC content for this study was varied among land use types and change. Among the land uses, the values of soil OC content of were ranged from 0.93 to 4.51% (Table 2 and Figure 4). Relatively the highest (4.51%) and the lowest (0.93%) mean values of OC were recorded for forest and crop land uses, respectively. The lowest SOC in the crop lands could be due to repeated cultivation before sowing, complete removal of crop residues, and burning of crop residues during land preparation. In line with this [45] also reported the lowest

soil organic carbon of crop land relative to forest and grazing land uses. Similarly, [22] also reported high SOC in forests land compared with crop and grazing lands.

Moreover, land use change from natural forest to crop land and grazing to crop land result in lowering of soil organic carbon percentage due to disturbance of soil structure and oxidation of soil organic matter. For instance, conversion of forest to crop land resulted in a reduction of soil carbon from 3.41 to 1.62%. Similarly, conversion of grazing land to crop land resulted in reduction of soil carbon percentage from 2.34 to 1.62% (Table 2 and Figure 4). In agreement to this finding, [47] also reported reduction of soil organic carbon content due to conversion of forest land to crop and grazing land to crop land uses.

The results of study indicated that organic carbon content decreased with soil depth though substantial amount of carbon was found in the lower soil depths under forest land. In all land uses, about 61.59–66.15% of SOC was found in the 0–40 cm soil layer while 33.84–38.64% was recorded in 40–80 cm. The presence of high soil organic carbon content in the upper 40 cm of the soil indicates the large amount of carbon to be lost if the upper layer of the soil is disturbed, particularly in uncultivated lands. On the other hand, the presence of substantial amount of the organic carbon in the sub soil layers (40–80 m) indicates that the deeper layers of the soil are important pools in terms of preserving soil organic carbon for a long time. [35] also reported the presence of relatively higher organic carbon values in the upper layers of soils as compared with the lower layers.

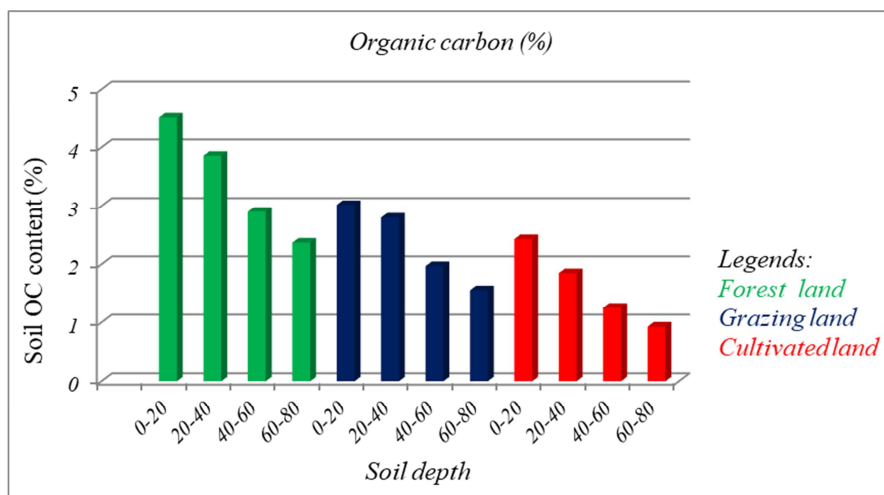


Figure 4. Organic carbon content (%) determined for different layers of land uses.

3.2.2. Soil organic Carbon Stock

The results of study described the carbon stock under three major land uses; natural forest, grazing land and cropland, involving samples from four soil layers. Comparing the three land uses, the highest soil organic carbon stock (20.86 Mg ha⁻¹) and the lowest (5.88 Mg ha⁻¹) were recorded, respectively, in the forest and crop lands. The highest soil OC stocks in forest lands might be due to their perennial nature which results in constant carbon inputs in the form of litter, modified microclimate which retard decomposition rate of organic matter and large quantities of carbon in the sub soil through root exudates decomposing deep root. In line with this, [49] also reported highest soil organic carbon stock in forest land than other land uses due to its perennial nature.

Table 2. SOC storage per each layer for the three land uses.

Land uses	Depth (cm)	BD (g/cm ³)	OC (%)	SOC stock (Mg/ha)
FL	0-20	0.99	4.51	8.93
	20-40	1.05	3.86	16.21
	40-60	1.06	2.90	18.44
	60-80	1.10	2.37	20.86
GL	0-20	1.01	3.02	6.10
	20-40	1.22	2.80	13.66
	40-60	1.24	1.97	14.66
	60-80	1.25	1.56	15.6
CL	0-20	1.21	2.43	5.88
	20-40	1.26	1.85	9.32
	40-60	1.29	1.26	9.75
	60-80	1.33	0.93	9.90

FL = Forest land, GL = Grazing land, CL = Cultivated land, OC = Soil organic carbon, CO₂e = Carbon dioxide equivalent.

The lowest soil OC stocks in crop land might be due to intense decomposition following soil plowing, removal of above ground biomass during harvest, biomass burning and low input of OM to the soil in crop land. In line with this finding, [11] also reported the lowest SOC stocks for crop land due to removal of organic residues through harvesting and fast decomposition of organic residues during intensive

tillage. Land use change from natural system (forest land) to crop land and grazing to crop land results in alteration of the carbon balance. For instance as a result of conversion of forest land to crop land the average soil organic carbon stock reduced from 16.10 to 8.71 Mg ha⁻¹ and for grazing to crop land 12.51 to 8.71 Mg ha⁻¹. SOC stock increases with increasing soil depth and the sequence of SOC stock in all 0-20, 20-40, 40-60, 60-80 cm layers were forest land > grazing land > crop land (Table 2). The highest (20.86 Mg C/ha) and lowest (5.88 Mg C/ha) value of SOC stocks were recorded on subsurface (60-80 cm) layer of forest land and surface (0-20 cm) layer of cultivated land, respectively (Table 2).

3.2.3. Soil Organic Carbon Sequestration

Land use types and change can adversely influence ecosystems through carbon sequestration. The total equivalent CO₂ sink recorded for the study watershed was 9110 tones (Table 3). Soil organic carbon sequestration of the study area watershed was differed among the land uses. The soil organic carbon sequestration was ranged from 1580 to 4400 tone (Table 3). Relatively, the highest (4400 tone) and the lowest (1580 tone) mean values soil organic carbon sequestration were registered for crop land and grazing land, respectively. The highest soil organic carbon sequestration of crop land might be due to the highest area coverage of crop land.

In the study area, the currency value of CO₂e was computed for different land use types under consideration and the variation of currency value were observed for the carbon-offset among the land uses. Comparatively, the highest (643.50\$) and lowest (348.41\$) currency values of CO₂e were obtained from forest land and crop land, respectively (Table 3). This might be due to conversion of forest and grazing lands to cultivated land, which may cause the release of soil organic carbon through high decomposition, fast degradation and mineralization of the available organic matter in cultivated land of the study watershed. In agreement with this finding, [15] stated as sustainable SOC management is an important economic

concern due to its critical value for crop production and providing a regulation of ecosystem service based on the avoided social cost of carbon emissions.

Therefore, the highest discount (avoided) rate (643.50\$) was observed in forest land to mitigate the cost of CO₂e emitted (released) to the atmosphere followed by grazing land (500.16\$) and the lowest (348.41\$) in cultivated land (Table 3) in the study area where the total currency value of the study watershed was (1492.07\$) as 1t CO₂e/ha was estimated to be 10\$ stated by [32].

Moreover, the currency value (\$) also highly varied with land use change and showed a decreasing trend (Table 3) due to high SOC capture and sequestering power of forest land and low SOC storage and release of cultivated land in the study area. In line with this result, [1, 25] stated that, native forests are appropriate ecological references for their high avoided cost of CO₂e sink (high currency value) in which cultivated land released about 59.0% of the organic carbon originally sequestered in the surface layers of native forest soil having lower currency value.

Table 3. Economic implications of CO₂e emissions reduced in each land use types.

Land uses	Area (ha)	SOC stock (Mg/ha)	SOC stock (Gg)	CO ₂ e sequestered (tone)	Currency value (\$)
FL	48.64	64.44	3.13	3130	643.50
GL	31.59	50.02	1.58	1580	500.16
CL	126.29	34.85	4.40	4400	348.41
Total	206.3	149.31	9.11	9110	1492.07

FL = Forest land, GL = Grazing land, CL = Cultivated land, SOC = Soil organic carbon, CO₂e = Carbon dioxide equivalent.

4. Conclusions and Recommendations

4.1. Conclusions

The results of this study showed that soils profoundly responded to these land use change and most of the soil physicochemical properties examined showed changes with conversion of forest and grazing land to crop land. On another hand, the results of this study revealed that organic matter content decreased from 3.96 to 1.69% and from 0.22 to 0.17% in forest to cultivated soils, respectively. The effects of land use change can be seen in terms of climate change in which carbon stock and emission vary from one land use to the other land uses. SOC storage potential of crop land (5.88Mg/ha) was almost more than 3 times lower than that of forest land (20.8Mg/ha). From these findings one can conclude that the forest land is the major reservoir of SOC and sinks of CO₂e and plays a significant role in mitigating climate change.

4.2. Recommendations

Based on the findings and conclusions of this study it can be recommended that the huge potential of soil OC which affect global climate change, SOC storage improvement strategies should be incorporated in policies of green economy and SOC sequestration incentives should be encouraged. Moreover, further studies should be considered to provide more conclusive recommendation for having sustainable natural ecosystems and mitigated climate change.

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