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IMPACT OF LAND USE AND LAND COVER CHANGE ON SOIL PHYSICAL AND CHEMICAL PROPERTIES: A CASE STUDY OF ERA-HAYELOM TABIAS, NORTHERN ETHIOPIA

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ABSTRACT

The conversion of forest to other land use like agriculture is getting serious, especially in the dry afromontane forest of Ethiopia. These unsustainable land use and land cover changes are recognized as the main factors in the process of soil resource degradation. This study was intended to investigate the impact of land use and land cover change on the physical and chemical properties of soil in the Era-Hayelom tabias, Northern Tigray, Ethiopia. Soil samples were collected from four land use and land cover classes, bare land, farm land, grass land and forest land, which were forest land before 1986. The forest land was converted to other land use and land cover at 110 ha/year and grass land by 58 ha/year. The amount of farm land and bare land had consequently increased from 1986 to 2010. Land use and land cover change significantly affected the value of soil physical and chemical properties. The soil properties bulk density, pH and sand percentage were significantly higher in bare land and farm land than forest land. Clay percentage and cation exchange capacity were also higher in farm land compared to the others. But organic matter content, available phosphorus and total nitrogen were significantly higher in forest lands. With the reduction of natural vegetation cover the physical properties like bulk density and pH increased and reduced the availability of water and nutrients. The carbon stock of the soil at depth 0 - 30 cm had decreased by 6568 T/year on average from 1986 to 2010.

The overall impact of land use and land cover change degraded the quality of the soils and increased the loss of carbon stocks. Therefore, appropriate land use policy and proper land restoration practice is vital to maintain productivity of the land.

Key words: Land use and land cover change, soil physical properties, soil chemical properties, carbon stock, Era-Hayelom

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1. INTRODUCTION

Land degradation is defined as "a long-term decline in ecosystem functions and measured in terms of net primary productivity caused by disturbances from which land cannot recover unaided'' (Bai et al. 2008). This definition deals with the loss in land use productivity and ecological values. It is a decline in gains from land due to a mismatch between land quality and uses. Degradation is not a new thing and has been happening all over the world for centuries. It will continue to be a serious global issue due to its extensive spreading impact on agricultural productivity, environment and quality of life (Eswaran et al. 2001).

The major causes of land degradation are the combination of biophysical, socio-economic and political factors. Among socio-economic factors, population pressure plays a great role in the process through increasing deforestation, overgrazing, intensive cultivation and overexploitation of other natural resources (Geist & Lambin 2004). This diminishes potential productivity and the economic utility of land. Not only the size or density of the population but also how the people use the land increases land degradation (Mitiku et al. 2006). The deterioration in agricultural productivity reduces the economic value of the land and forces the farmers to invest in more input and cultivating marginal lands. The recent global land use change assessment estimates that the present 2% of 15 billion ha of land worldwide covered by buildings and infrastructures will increase to 4-5% and the 10% (1.5 billion ha) of present agricultural land will become 30% of the global land at the expense of forest land, particularly in tropical regions, by the year 2050 (Bringezu et al. 2014).

The unsustainable land use and land cover changes are recognized as the main factors in the process of land resource degradation (Nyssen et al. 2004). Land use and land cover changes are not synonyms but land use change affects the land cover condition. Land cover is defined as the physical and biological cover of the earth's surface such as vegetation, water, organisms, soil, and structures created by human activities (Lambin et al. 2003). The human activities in utilising and managing these land resources mainly affect the biophysical characteristics. The management governing utilization of resources is called land use and land use change is any change in the physical, biological or chemical conditions of the resources due to management to satisfy human interests (Quentin et al. 2006). This may include conversion of grazing to cropping, from traditional farming to modern and intensive cultivation, deforestation and planting exotic species, and conversion to non-agricultural uses**.** Globally, natural events like volcanic eruptions, flooding, fire, climate fluctuations, and ecosystem dynamics may modify the earth's land cover but the anthropogenic activities have more influence (Turner et al. 1994; Meyer 1995).

The land use and land cover change affect the magnitude and rates of soil degradation (Lemenih et al. 2005). The land use and land cover changes have a significant impact on deteriorating the physical and chemical properties as well as the biological activity of the soil (Bahrami et al. 2010; Kizilkaya & Dengiz 2010). All soils vary at all levels of observations from the macro- to the micro-level, horizontally across the landscape and vertically down into the soil profile (Crepin & Johson 1993; Lemenih et al. 2005). The sources of variations are not only the factors of soil formation like climate, the nature of parent material, the action of living organisms and topography (Hillel 1998) but also land use change, farming, the addition of soil nutrients and soil conservation practices (Lemenih et al. 2005). The major soil physical properties are colour, texture, bulk density, water holding capacity and chemical properties such as soil organic carbon, soil organic matter, pH, electrical conductivity, available phosphorus, total nitrogen, cation exchange capacity, and concentration of different nutrients in the soil (Sumner & Wilding 2000)**.**

Inappropriate land use and land cover change like deforestation, overgrazing, and expansion of agricultural lands has left the land barren, which reduces the biomass (vegetation cover) and results in a decline in soil organic matter content, availability of nutrients and soil moisture (Mao & Zeng 2010). The lower organic matter content decreases the moisture holding capacity and nutrient availability in the soil. The soil bulk density increases as organic matter decreases, which affects the aggregate stability of the soil and the movement of water and nutrients through it. This also affects plant root penetration and biological activities in the soil (Gardner et al. 1999). But as soil organic matter increases aggregate stability will be maintained by the increasing cohesion of aggregates, which reduces the loss of fine soil particles (Chenu et al. 2000). With the increasing organic matter content nitrogen mineralization also increases (Khormali et al. 2009; Mao & Zeng 2010). Organic matter may also maintain the soil pH. Soil pH manipulates the availability of essential soil nutrients which affect plant growth and soil quality as a whole (Wong 2003). In acidic soil as the pH lowers, the availability of micronutrients like aluminium and iron may be dominant and the toxicity of these nutrients may increase. In alkaline soils also the availability of calcium and magnesium may increase, but as the pH increases sodium toxicity may increase. The availability of phosphorus and other essential elements may be maintained when the soil is around a neutral pH condition.

Soil degradation is one of the major factors that hinder agricultural land productivity. It is the result of past land use changes and intensive agricultural practices (Hurni 1985). Due to the vegetation cover change which reduces organic matter and nutrients available to plants the productivity of the land will decrease. This reduction in vegetation cover may increase erosion of the fine and top layer soil, which may reduce effective soil depth. Soil properties are varying and complex, particularly from a fertility standpoint. Information about this plays an important role in managing the resources in a sustainable manner. To minimize the effect of land use and land cover change, understanding the major factors that govern the process is important (Gebrehiwet 2004).

Soils are the potential reservoir of soil organic carbon. The concentration of organic carbon influences the quality and productivity of the soil. Soil organic carbon also increases the fertility of the soil in terms of nutrient availability and biological functions (Diacono & Montemurro 2010). Change in the concentration of organic carbon in soils affects not only soils but the whole environment by its impact on the carbon cycle and the amount of atmospheric carbon dioxide (Xu et al. 2011a). This change in soil organic matter content has an impact on the amount of carbon stocks in the soil (Ross et al. 1999; Edmondson et al. 2014).

The conversion of forest to other land use such as agriculture is becoming a serious problem, especially in the dry afromontane forest of Ethiopia (Teketay 1997). According to Pankhurst (1995), the countryside, which was once covered with trees, has become progressively barer as forests have been steadily cut or burned down since the 19^{th} century. Deforestation took place mainly in areas of extensive settlement, and especially natural forest areas close to towns. However, small forests are found fragmented and restricted in inaccessible and sacred areas such as areas around churches (Wassie et al. 2005; Aerts et al. 2006). This is due to an alarming increase in population and therefore a need for larger areas for agricultural production and fuel wood collection. In addition, the different governmental regimes of

Ethiopia had their own management policies on land ownership and government controls. After the land proclamation of 1975 the land was redistributed among farmers. It was difficult to feed the increasing population with the traditional agricultural system and therefore forest and grazing lands are converted to agricultural land. The settlement programs are also done by changing forest and grass lands (Teka et al. 2013).

Most of the land in the Tigray region of Ethiopia is highly degraded and barren due to unwise utilization of land resources (Asefa et al. 2003). This makes the area prone to drought and famine. Together with the undulating nature of the land and the erratic and intense rainfall, the agricultural expansion and deforestation have caused soil degradation. Thus, soil erosion, nutrient depletion and soil moisture stress deteriorate the overall productivity of the land (Gebremedhin & Swinton 2003). In most areas the land is severely degraded and has been eroded for a long period of time because of the extensive utilization of land resources due to high population pressure (Hagos et al. 2002; Gebremedhin & Swinton 2003). Repetitive droughts are also a major factor of land degradation in the Tigray region (Gebreegziabher 1999; Nyssen et al. 2004).

The Desa'a forest area is one of the remaining fragments of dry afromontane forest found in the Eastern Tigray highlands. It was covered by natural forest and grass land but due to deforestation, overgrazing and expansion of agricultural land and settlements the area has become extremely barren (Sebhatleab 2012). At present, the area has extensively declined, both in terms of productivity and biodiversity (Aynekulu et al. 2012). Era-Haylom tabias is part of the Desa'a forest land.

Despite the high ecological values of the land it has been poorly studied. Only a few forest restoration ecology studies (Aerts et al. 2006; Aynekulu et al. 2011), forest cover change analysis (Sebhatleab 2012) in the enclosures and a management plan (Gebreegziabher 1999) report have been carried out and published. No detailed scientific investigation has been carried out in the study area on assessing the impact of land use change and deforestation on the rate of soil degradation. Hence, it has become important to assess and monitor soil resource degradation in the study area for sustainable management and conservation of natural resources in order to maintain the productivity of the land.

This study was initiated to investigate the impact of land use change on soil physical and chemical properties. The objective of the project was to compare soil physical and chemical properties among different land uses, elevations and soil depths. Further, to determine and map land use and land cover of the study area in the year 1986 and 2010 and to estimate below ground carbon stocks in different land uses.

2. MATERIAL AND METHODS

2.1 Description of study area

The study area is located at the eastern border of the eastern Tigray region, between 13° 40' and 13° 45' north latitude and between 39° 42' and 39° 54' east longitude (Fig. 1). It is composed of dry afromontane forest remnants which are situated in the eastern Tigray regions. The altitude of the area ranges from 900 m above sea level (a.s.l.) to about 3000 m a.s.l. at the plateau (Gebreegziabher 1999). About 45% of the area has a slope greater than 25% (Aynekulu et al. 2011).

Era-Hayelom tabias is part of the Desa'a dry afromontane forest which is between the escarpments of Tigray and the lowlands of the Afar region in Northern Ethiopia. It is found in a semi-arid agro-ecological zone (Gebremichael et al. 2005). Rainfall is erratic and most of the year remains dry except June to September. The mean annual rainfall of the Atsibi Wenberta District (13° 52.7'N and 13° 44.6'E), near to the study area is 618 mm and the monthly average temperature of the area is around 20°C (Fig. 2).

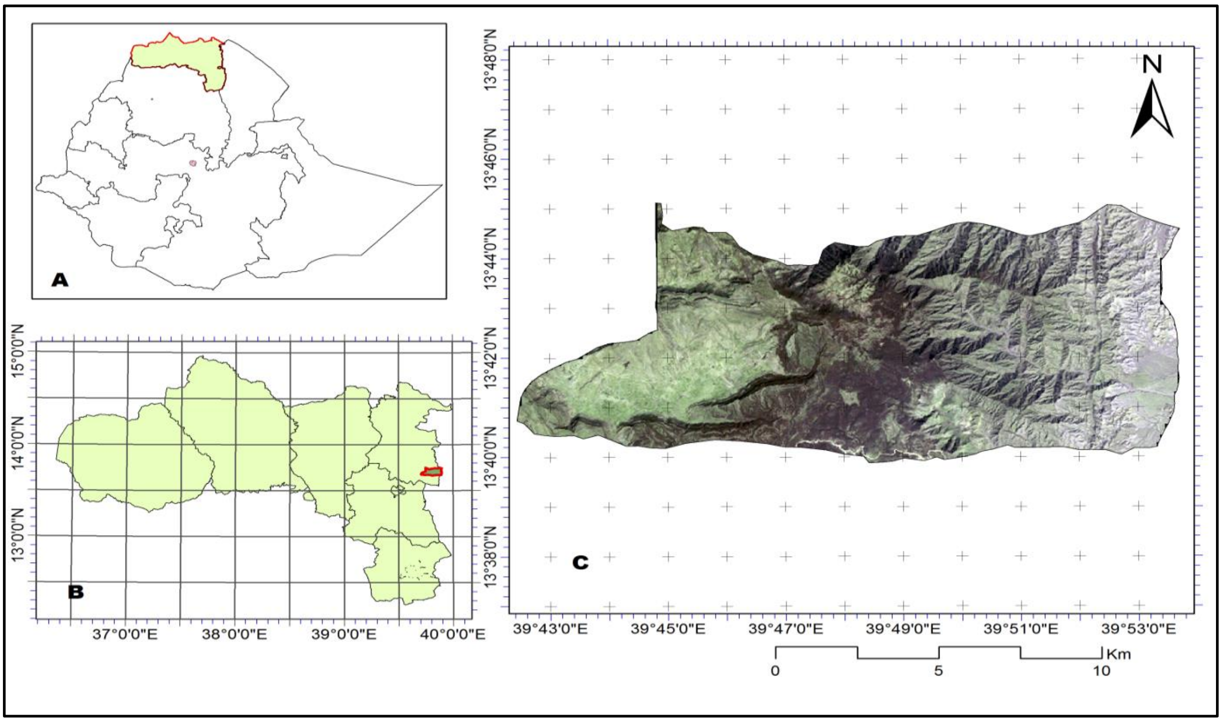

Figure 1. Study area map: A. Location of Tigray region within Ethiopia. B. Location of the study area within the Tigray zones. C. Era-Hayelom tabias research site.

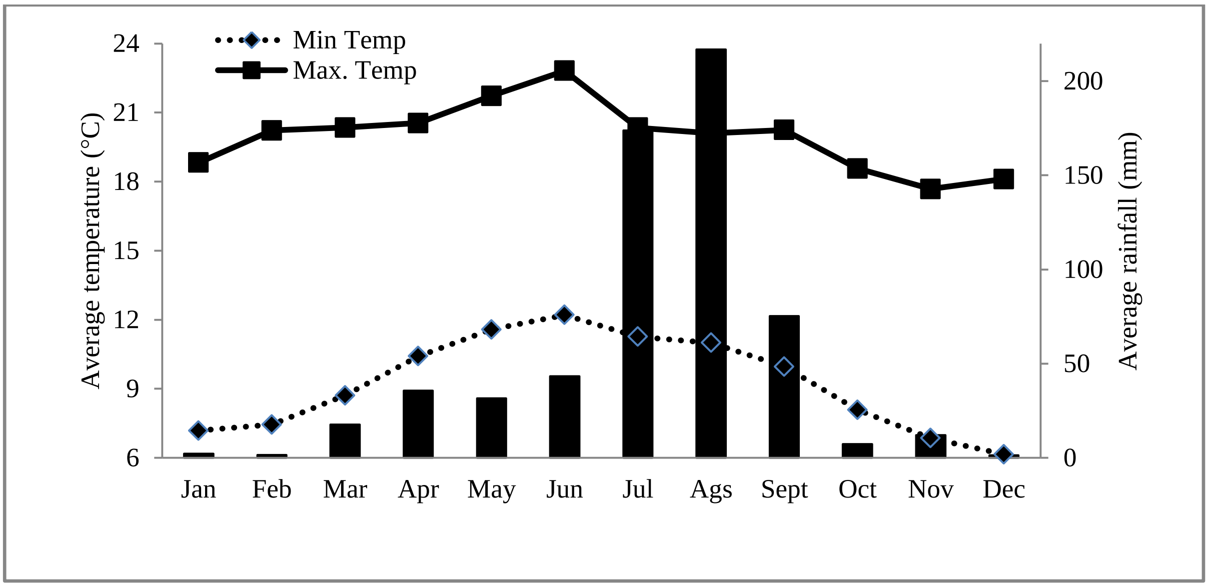

Figure 2. Monthly mean maximum and minimum temperature (°C) and average monthly rainfall (mm) of Atsib Wonberta District in 2006 - 2012.
(Source: data from Mekelle Metrological office, Atsibi Wonberta District)

2.2 Land use and land cover classification methods

Land use and land cover maps of the area were generated from satellite image data from 1986 and 2010. The satellite images are originally ortho-rectified and therefore did not require geo-referencing. However, as UTM projection and Adindan datum is used in Ethiopia images with WGS84 were re-projected. This is important because datum and projection conflict would certainly hinder the use of various layers. In this study, Landsat TM (path 168 row 51) from the year 1986 and Landsat ETM + (path 168 row 51) from the year 2010 were used for the analysis.

Pre-processing image enhancement was done on the ortho-rectified images. The purpose of this technique was to increase the visual distinction between features and extract information. After different image enhancement schemes were performed, the remotely sensed data was trained by taking GPS points and a previous map of the area as primary datasets and elders' prior knowledge as ancillary data. A supervised image classification scheme with the maximum likelihood classifier algorithm module of ERDAS 9.2 which leads to high classification accuracy (Asmala 2012) and ArcGIS 10.1 for mapping and measurements were used. Thus, the scenes for each year's data (1986 of TM and 2010 of ETM+) image were categorized into different land use and land covers. The major land use and land cover (LULC) types found in the area were forest, grass land, farm land and bare land and they are defined in Table 1.

Table 1. Land use and land cover (LULC) classes used in the classification scheme.

LULC	Description
Forest land	Forest vegetation including evergreen, deciduous, and dry afromontane forest vegetation.
Farm land	Characterized by high percentages of herbaceous vegetation and crops; including lands that are regularly tilled and covered with planted cropland.
Grass land	Land covers dominated by grass that includes sparsely grown patches of trees
Bare land	Areas of sparse vegetation cover; including clear cuts and barren rock or sand along river/stream beaches.

In addition, a digital elevation model (DEM) was generated from the SRTM image to construct a slope and elevation map. The maximum and minimum elevation of the study area was 2510 m and 929 m a.s.l., respectively (Fig. 3). The area was divided into two categories for elevation, above 1500 m as upper and below 1500 m as lower, as elevation is considered to influence soil properties.

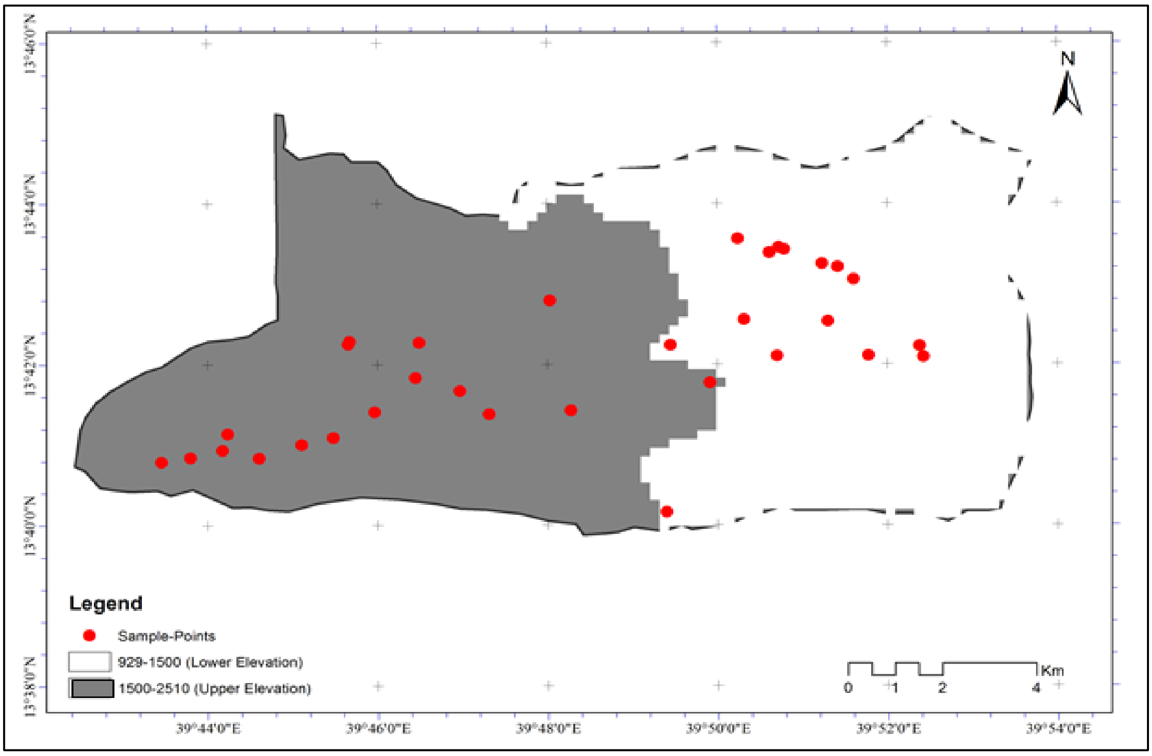

Figure 3. Soil sampling points and elevation class map of the Era-Hayelom area.

2.3 Soil sampling and analysis

From each determined land use and land cover classes for the year 2010 which were forest lands in 1986 and have a similar slope, 32 soil sampling points were selected and samples taken during the dry season in January 2014 from both elevation classes (Fig. 3). At each point, soil samples were taken using a 5 cm diameter auger at a depth of 0 - 30 cm and 30 - 60 cm, replicated four times. A total of 64 soil samples (4 LULC * 2 elevations * 2 depths and 4 replications) were taken and analysed in a soil laboratory for their chemical properties like pH, electrical conductivity, available phosphorus, soil organic carbon, soil organic matter, total nitrogen, cation exchange capacity and the physical properties of texture. Only 32 samples from the depth 0 - 30 cm were taken for bulk density.

The soil physical property of texture was analysed using a hydrometer method (Bouyoucos 1962). Bulk density (BD) was analysed using the core method; 32 soil samples were taken from the selected points at 0 - 30 cm depth using 100 cm^3 core samplers and analysed using a core method (Grossman & Reinsch 2002). Soil pH and electrical conductivity (EC) were analysed with a 1:5 soil water suspension using a pH meter and an EC meter, respectively. The Olsen method was used to determine the available phosphorus (AvP) content as the pH of all soils were around neutral and above (Watanabe & Olsen 1965). Soil organic carbon (SOC) was analysed using wet digestion with the Walkley-Black method and soil organic matter (SOM) was calculated by multiplying SOC by 1.724 assuming 58% of SOM is SOC (Nelson & Sommers 1982). But several reports indicate that this estimation widely varies (Sleutel et al. 2007). This research simply estimated SOM based on the assumption and focused on SOC as it is used to assess soil quality. Soil samples were digested in Kjeldahl apparatus and the amount of ammonia trapped was determined to calculate the total nitrogen in the soils (Bremner 1996). For cation exchange capacity (CEC), the sodium acetate method was used. To do this, 5 g of soil were treated by sodium acetate and ethanol, and then extracted by ammonium acetate solutions. The ammonium acetate extracts were used to measure the amount of sodium (Na^+) using a flame photometer to calculate the CEC of the soil (Thomas 1982). Based on the soil organic carbon (SOC) and bulk density data the soil carbon stocks (CS) were calculated for each LULC at a soil depth of 0 - 30 cm. The areal size of each LULC in 1986 and 2010 were multiplied by their average CS to find the total CS per LULC and compute the difference between 2010 and 1986. To estimate the total CS the following formula was used (Xu et al. 2011b):

$$CS = SOC*BD*H$$

where CS= soil carbon stock (t/ha)
SOC = soil organic carbon (g of carbon/100 g of soil)
BD = soil bulk density (g/cm^3)
H = soil depth (cm)

By multiplying the average carbon stock for each LULC by the area covered by the LULC in 1986 and 2010 the total amount of carbon stocks were calculated and the changes in carbon stocks were estimated.

2.4 Statistical analyses

The statistical software R (R Core Team 2014) was used to perform all the statistical analyses of soil physical and chemical properties. Analysis of variance (ANOVA) was used to test for a difference in soil properties (pH, EC, AvP, SOC, TN, and CEC, texture and BD) between land use, elevation and soil depth. The factors of land use, elevation, soil depth and their interactions were tested at $\alpha = 0.05$. If interactions were significant the analyses were done separately for elevation and/or depth. For those soil properties which were significantly affected by LULC change, Tukey's test (Tukey HSD) for multiple comparisons with a 95% family-wise confidence level was used to compare the averages between LULC classes.

3 RESULTS

3.1 Land use and land cover map

From the Landsat images of 1986 and 2010 for the Era-Hayelom study site LULC classification maps of forest land, grass land farm land and bare land were developed (Figs. 4 and 5) for both years. From the 1986 LULC map, the area coverage of forest land was higher than for the other LULC classes and farm land had a low proportion. But in 2010, the area of bare land became almost equal to forest land (Table 2). A comparison of the land use and land cover for each category between the years 1986 and 2010 showed that forest land had declined by 2759 ha and grass land by 1392 ha. However, farm land had increased 4.6 times and bare land by 70%. Over the 24 years from 1986 to 2010, forests were converted to other lands on average at the rate of 115 ha/year. Grass land had also declined by 58 ha/year, whereas farm land and bare land increased by 93 and 80 ha/year, respectively (Table 2).

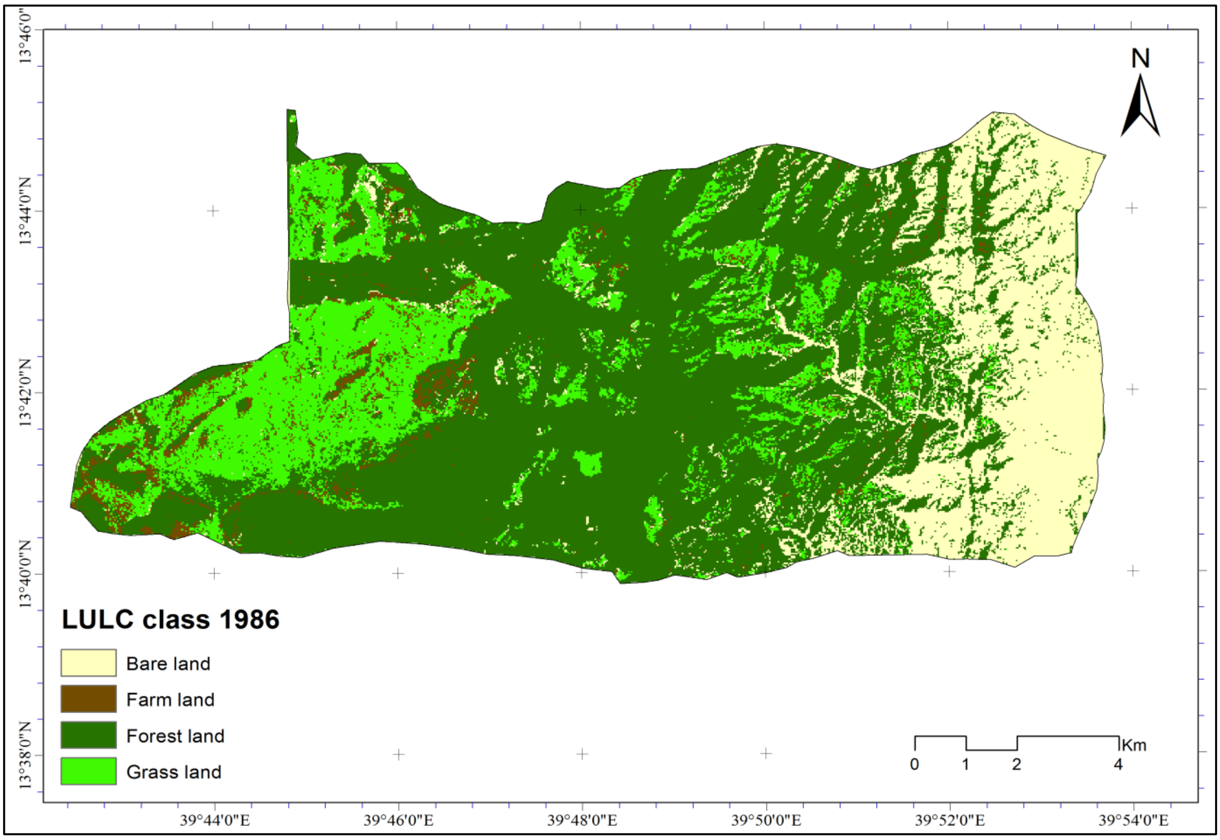

Figure 4. Land use and land cover (LULC) classification map of the Era-Hayelom tabias research site in 1986.

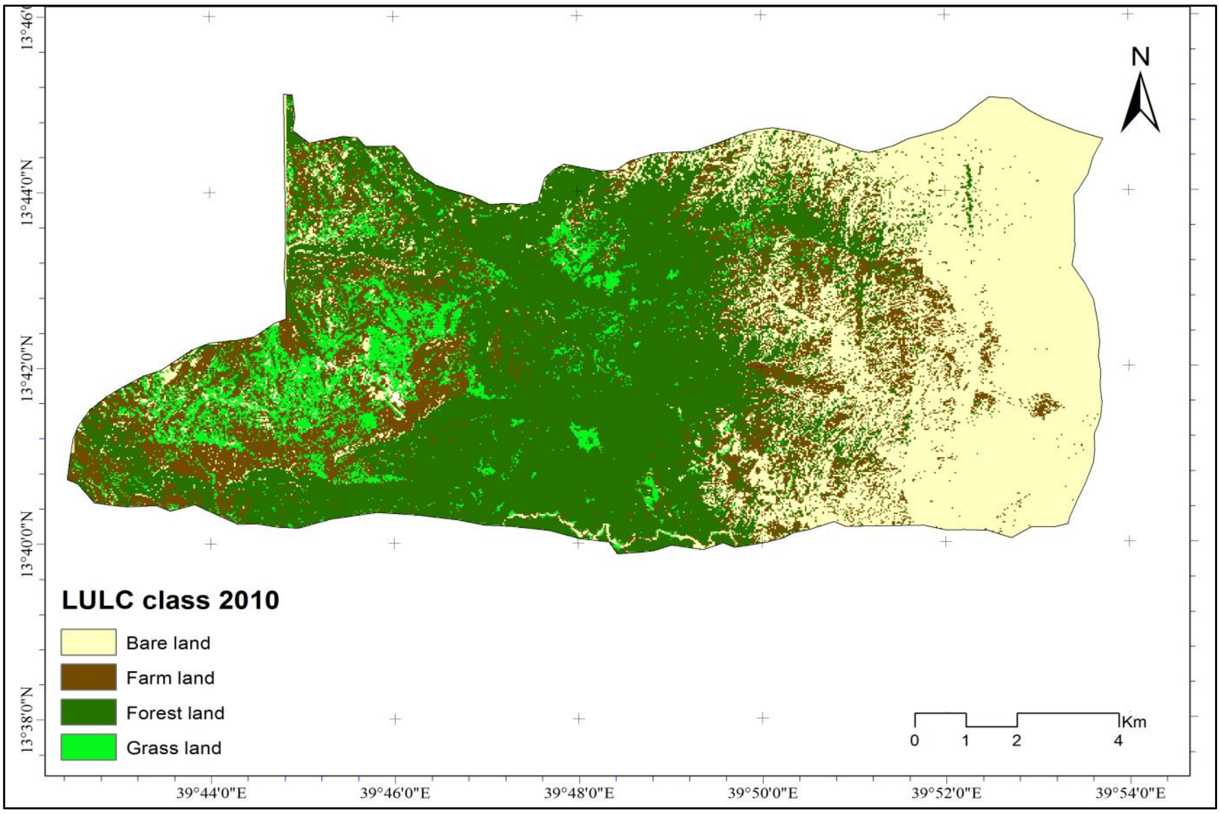

Figure 5. Land use and land cover (LULC) classification map of the Era-Hayelom tabias research site in 2010.

Table 2. Land use and land cover (LULC) area size and change detected from supervised classification of Landsat images of 1986 and 2010 for the Era-Hayelom tabias

LULC	1986		2010		Change (1986 – 2010)		Rate of cover change
	Area(ha)	%	Area (ha)	%	Area(ha)	%	ha/ year
Forest land	8205.3	58.9	5446.5	39.1	-2758.7	-33.6	-115.0
Grass land	2477.4	17.8	1085.3	7.8	-1392.1	-56.2	-58.0
Farm land	485.4	3.5	2708.4	19.5	2223.0	458	92.6
Bare land	2759.8	19.8	4687.6	33.6	1927.9	69.9	80.3
Total	13927.8	100	13927.8	100	0.0	0.0	

3.2 Soil physical and chemical properties

The soil analysis results for the total 64 samples (32 for bulk density and carbon stock) are statistically summarized in Table 3. The soil of the area has an average pH value of 7.75 and the EC was below 1 mS/cm. The overall average of SOC was 1.24 % but bare land was the lowest among the other LULC. On average the study area had 17 mg P/kg of soil and the CEC of the area ranged from 17.1 to 27.9 Cmol (+)/kg. The average CS of forest land and grass land soils was higher than for the others. The textural analysis result showed that the overall average sand percentage was higher than clay and silt, from 40 to 60 % (Table 3).

Table 3. Average result of all soil parameters per Land use and land cover (LULC) and overall statistical summary

Parameters	**Unit**	**LULC Means**				**Overall**			
		Forest	**Grass**	**Farm**	**Bare**	**Mean**	**Min**	**Max**	**Std. Dev**
PH		7.6	7.6	7.8	8.1	7.8	6.9	8.9	0.4
EC	mS/cm	0.2	0.2	0.1	0.1	0.1	0.1	0.8	0.1
SOC	%	1.8	1.7	0.9	0.6	1.2	0.3	2.6	0.6
OM	%	3.1	3	1.5	1.0	2.1	0.6	4.4	1.1
TN	%	0.3	0.2	0.1	0.1	0.2	0.1	0.6	0.1
AvP	mgP/kg Soil	21.9	15.9	16.8	14.5	17.3	4.0	35.0	6.9
CEC	Cmol(+)/kg soil	25.2	24.3	25.6	20.7	23.9	17.1	27.9	2.8
BD	g/cm^3	1.1	1.2	1.4	1.3	1.3	0.9	1.5	0.2
Sand	%	46.9	50.6	50.9	55.1	50.9	40.1	59.8	4.6
caly	%	19.1	20.0	21.2	19.2	19.9	16.2	29.2	2.7
Silt	%	34.0	29.4	27.9	25.7	29.3	18.5	41.7	5.2
CS	t/ha	71.6	66.1	40.9	21.3	50.0	11.9	102.3	23.5

3.2.1 Soil physical properties

<u>Bulk density</u>

Bulk density was only measured in the upper soil layer (0 - 30 cm). The ANOVA result indicates that there was a significant effect of LULC on bulk density ($p < 0.001$). Among the LULC classes bulk density for forest was significantly different from farm land ($p < 0.001$) and bare land ($p = 0.02$). Grass land was also significantly different from farm land ($p = 0.005$). The farm land had the highest average bulk density and forest land the lowest of all LULC types. Farm land had a 0.3 g/cm^3 higher BD than forest land and a 0.2 g/cm^3 higher BD than grass land (Fig. 6).

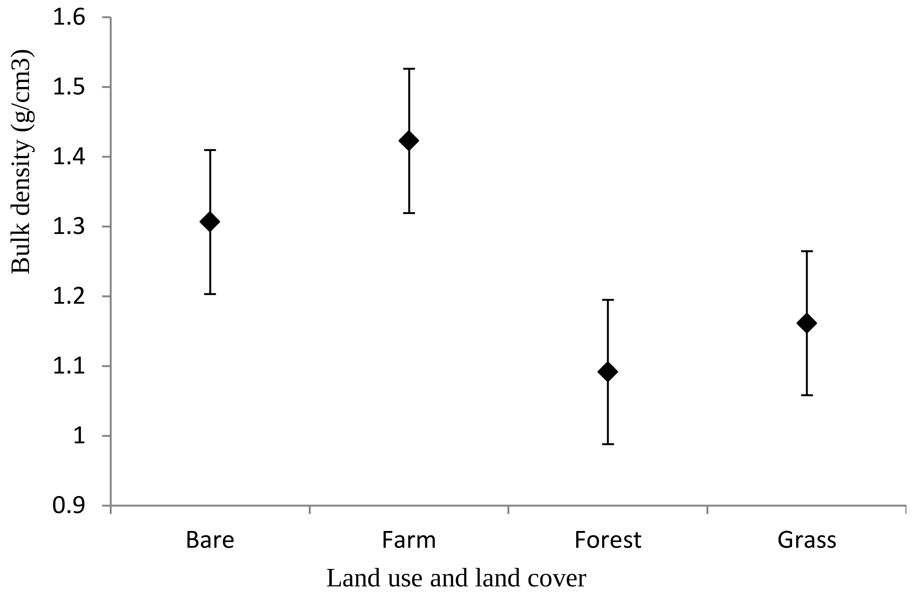

Figure 6. Mean bulk density at the Era-Hayelom tabias research site for each land use and land cover category (bare land, farm land, forest land and grass land) with 95% confidence intervals.

Soil Texture

The statistical analysis for sand percentage showed significant interaction between the LULC and elevation ($p = 0.004$) and therefore analyses were done separately for each elevation. At the higher elevation the LULC had a significant effect on the percentage of sand ($p < 0.001$). Among the land uses the sand percentage of bare land soil was significantly different from forest land ($p < 0.001$), grass land ($p = 0.016$) and farm land ($p = 0.008$). At lower elevation the LULC also had a significant effect on sand content ($p = 0.028$) but only the average sand content of bare land was significantly different from forest land ($p = 0.024$). Generally, the average sand percentage of bare land was higher than forest land by almost 28% in the study area.

There was a significant interaction between the LULC and elevation and the silt percentage of silt ($p = 0.001$). This means the difference between the LULC at the higher elevations was significantly different from the lower elevations. Further analyses were therefore done separately for each elevation. Both the LULC ($p < 0.001$) and depth ($p = 0.006$) had a significant effect on the silt percentage at the higher elevation. Tukey's multiple 95% comparison test showed that the forest significantly differed from bare land ($p < 0.001$), farm land ($p = 0.004$) and grass land ($p = 0.017$). Thus, forest land was 60% more than bare land and 30% more than both farm land and grass land at this higher elevation. But at the lower elevation, for silt there was a significant difference among the LULCs (Fig. 7).

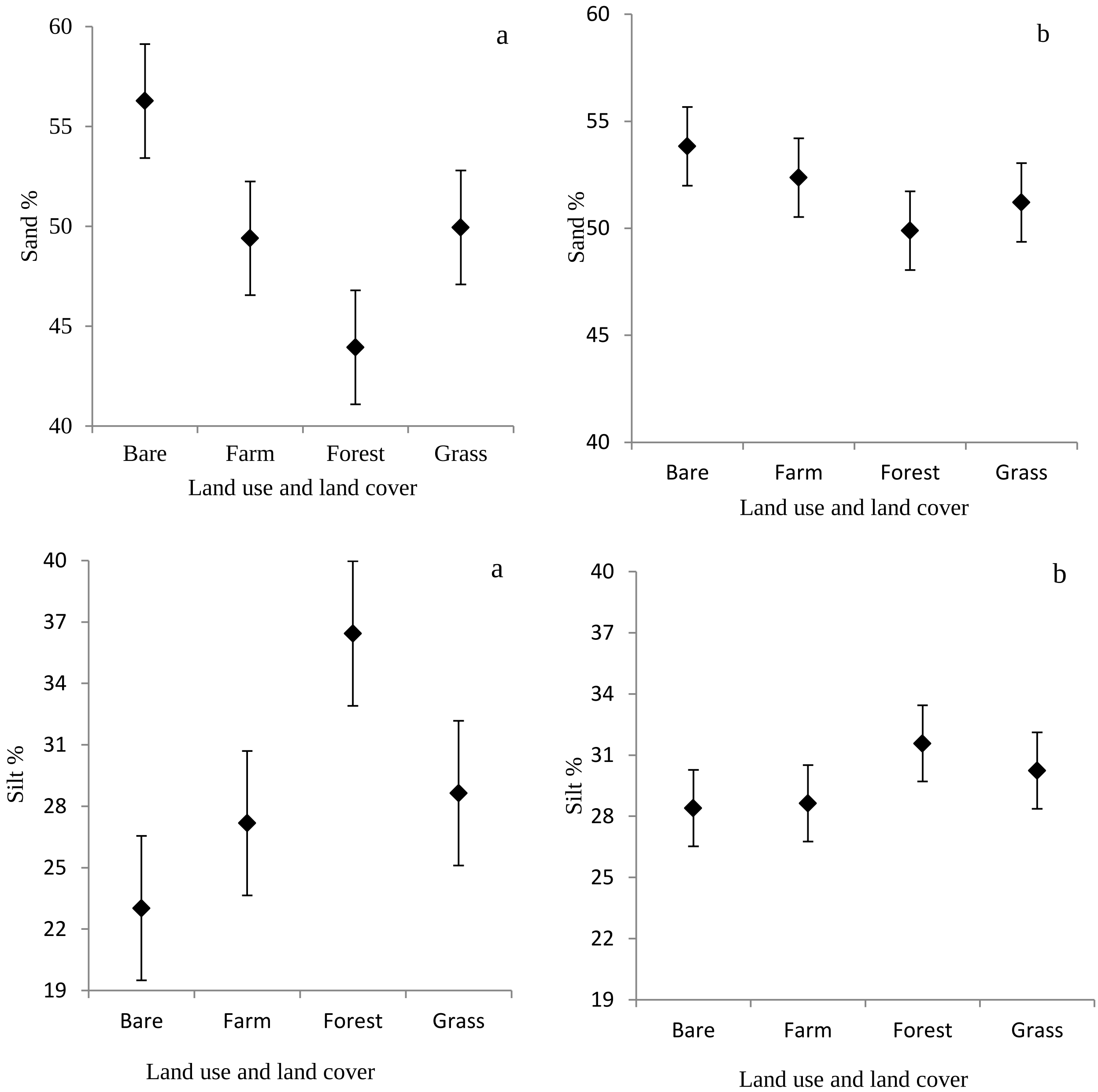

Figure 7. Average sand and silt percentage in soils at the Era-Hayelom tabias research site for each land use land cover category (with bare land, farm land, forest land and grass land) with 95% confidence interval for (a) upper elevation and (b) lower elevation.

On average clay content was higher in farm land by 2.1% from the lower clay content of the forest land. The ANOVA result for clay indicated that there was a significant interaction of the three factors, LULC, depth and elevation ($p = 0.027$). Analysis was then done separately for each depth and for a depth of 0 - 30 cm the interaction between land use and elevation was significant ($p = 0.028$). Therefore, further analysis was done separately based on elevation and the LULC was only significant for the upper elevation ($p = 0.016$). Farm land was significantly different from forest land ($p = 0.024$) and grass land ($p = 0.027$). At a depth of 30 - 60 cm there was a significant difference among the LULC categories ($p = 0.014$). At this depth only bare land was significantly different from grass land ($p = 0.025$) (Fig. 8).

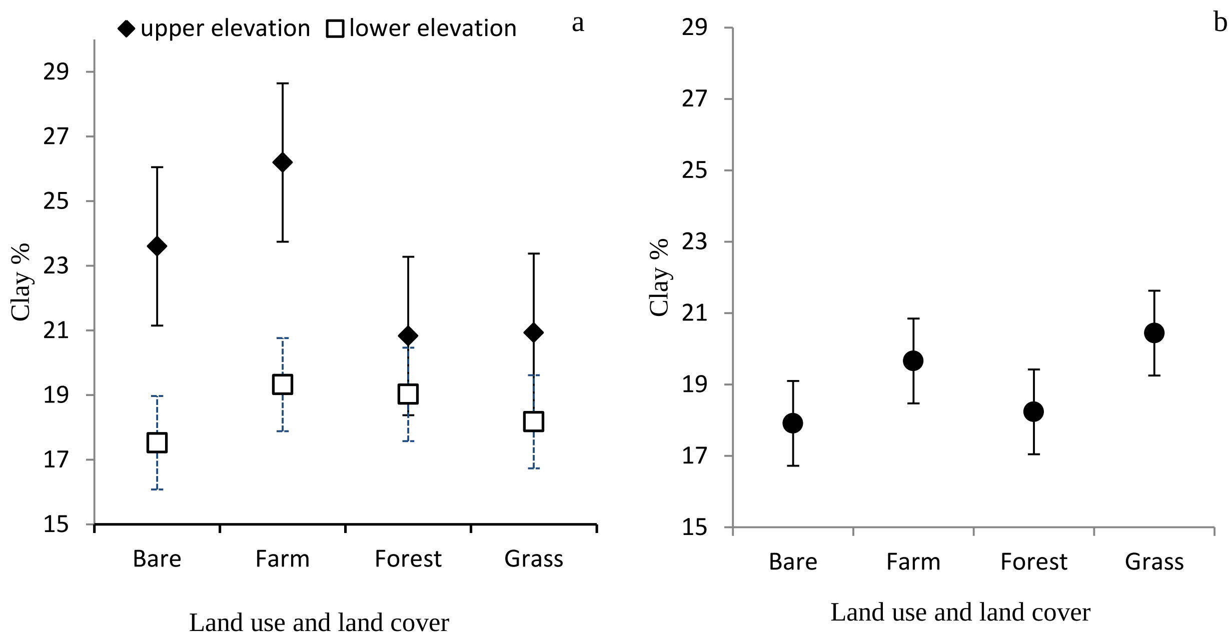

Figure 8. Average soil clay content at Era-Hayelom tabias research site for each land use land cover category (with bare land, farm land, forest land and grass land) with 95% confidence interval for (a) 0 - 30 cm soil depth, (b) 30 - 60 cm soil depth average for both elevations.

3.2.2 Soil chemical properties

<u>Electrical conductivity (EC)</u>

On average the EC value was 0.14 mS/cm. The ANOVA result showed that the factors LULC, elevation and depth did not significantly affect the electrical conductivity of the area.

<u>Soil pH</u>

There was a significant interaction between LULC and elevation for pH ($p = 0.003$). Analyses were done for each elevation separately and the LULC was a significant factor ($p = 0.004$) at the upper elevation (Fig. 9). Among the LULC categories grass land was significantly different from farm land ($p = 0.009$) and bare land ($p = 0.006$). At the lower elevation the LULC also had a significant effect on pH value ($p = 0.004$), and bare land was significantly different from forest ($p = 0.009$) and farm lands ($p = 0.006$).

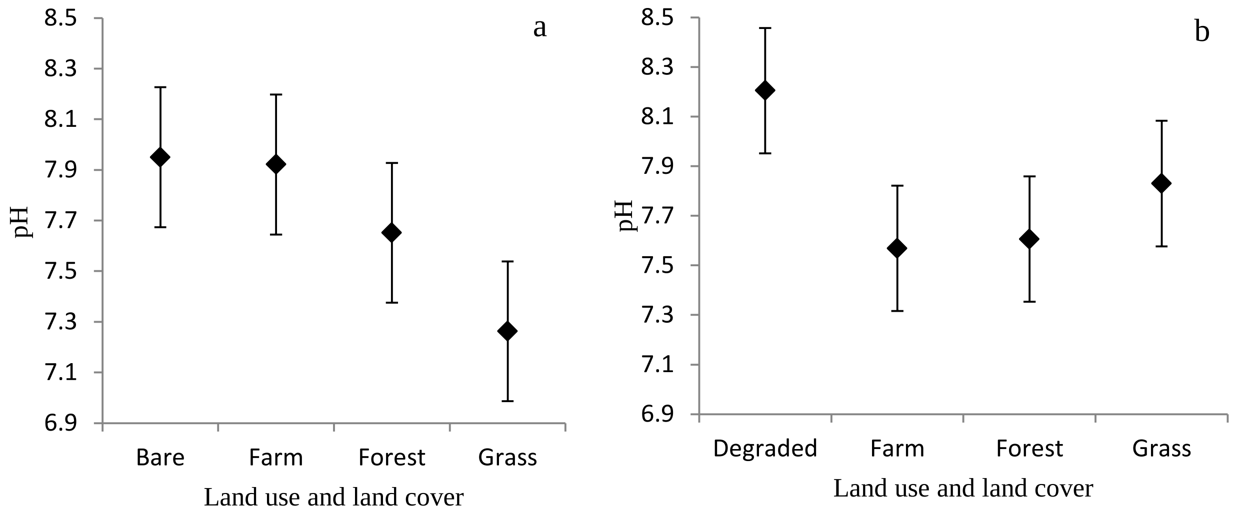

Figure 9. Soil pH value at the Era-Hayelom tabias research site for each land use and land cover category (bare land, farm land, forest land and grass land) with 95% confidence interval for (a) upper elevation and (b) lower elevation.

<u>Available phosphorus (AvP)</u>

The interaction of LULC and depth was significant for the content of available phosphorus ($p < 0.001$). Therefore, analyses were done separately for each depth. The level of available phosphorus differed significantly for the LULC categories at a depth of 0 - 30 cm ($p = 0.004$). Among the LULC categories the bare land was significantly different from forest land ($p = 0.004$) and grass land ($p = 0.022$). On average forest land soil had twice the level of phosphorus in bare land at a soil depth of 0 – 30 cm. At a depth of 30 - 60 cm the LULC categories also had a significant effect on the level of available phosphorus ($p < 0.001$). Within the LULC the forest land was different from grass land ($p = 0.001$) and farm land ($p = 0.032$). In addition, grass land was also different from bare land ($p = 0.012$) at a depth of 30 - 60 cm (Fig. 10). The overall average available phosphorus content of forest land was higher by 7.4 mg P/kg soils than bare land.

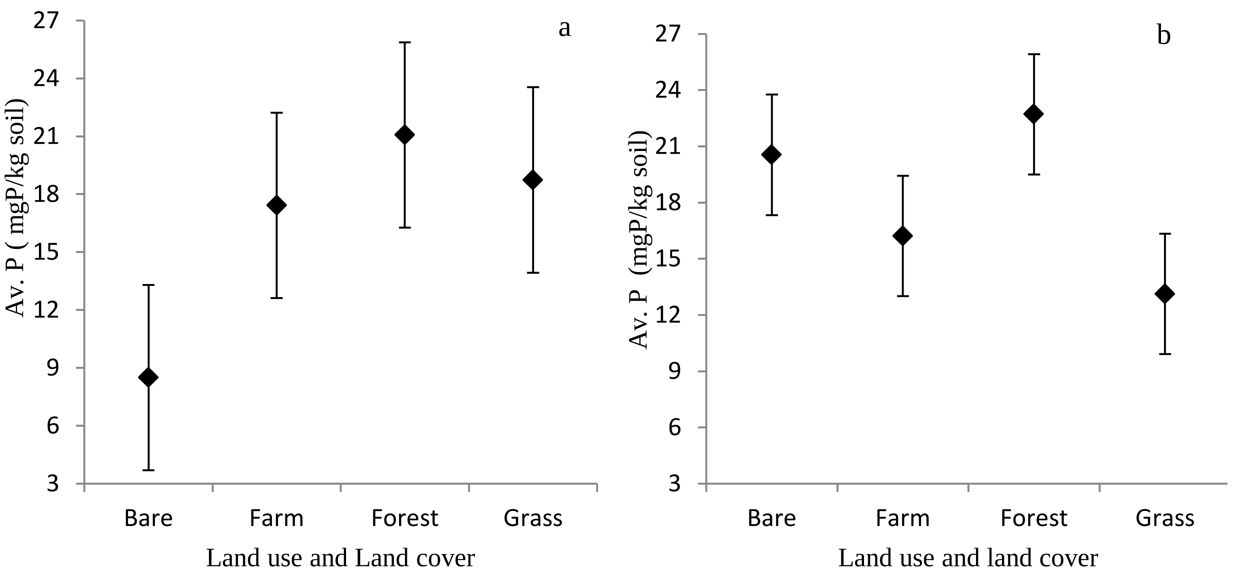

Figure 10. Average of available phosphorus at the Era-Hayelom tabias research site for each land use land cover category (bare land, farm land, forest land and grass land) with 95% confidence interval for (a) 0 - 30 cm soil depth and (b) 30 - 60 cm soil depth.

Cation exchange capacity (CEC)

The LULC, elevation and depth had a significant effect on the CEC value of the area and there was significant interaction among the factors ($p = 0.032$). Further analysis was done for each depth separately. The LULC was the significant factor at a soil depth of 0 - 30 cm. ($p = 0.002$). Bare land was significantly different from forest land ($p = 0.007$) and grass land ($p = 0.005$). At a soil depth of 30 - 60 cm the LULC was a significantly influential factor in the level of CEC ($p < 0.001$). Only bare land was significantly different from farm land, grass land and forest land ($p < 0.001$). Generally on average the CEC in bare land soils was lower by 5 Cmol(+)/kg at a depth of 0 - 30 cm and 7 Cmol(+)/kg at a depth of 30 - 60 cm from the farm land which was the higher (Fig. 11).

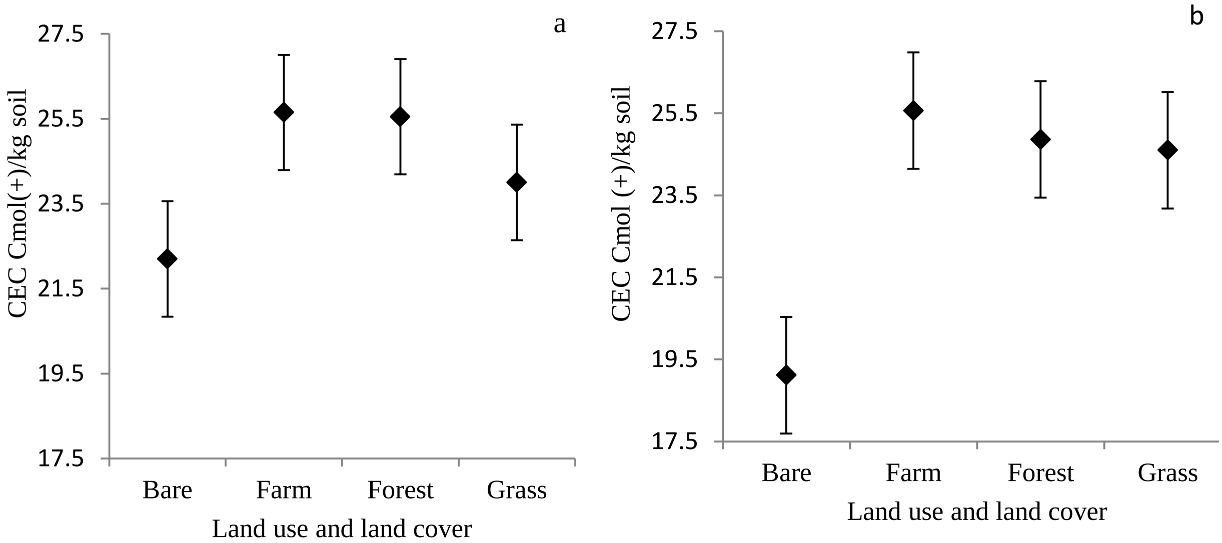

Figure 11. Average CEC at the Era-Hayelom tabia research site for each land use land cover category (bare land, farm land, forest land and grass land) with 95% confidence interval for (a) 0 - 30 cm soil depth, (b) 30 - 60 cm soil depth.

Total Nitrogen (TN)

As the interaction of all the factors was significant for the amount of TN ($p = 0.023$), analysis was done for each elevation separately. In the lower elevation TN was significantly different between LULC ($p = 0.043$) and only forest land was significantly different from bare land ($p = 0.05$) in TN content. In the upper elevation there was a significant interaction between the LULC and depth ($p < 0.001$). Further analysis was done separately for each depth. The averages of TN differed between the LULC categories at both depths ($p < 0.001$). At the 0 - 30 cm depth among the LULC, forests were significantly different from bare land ($p = 0.001$) and farm land ($p < 0.003$). Grass land also significantly different from bare land ($p < 0.001$) and farm land ($p = 0.001$). The grass land TN content was four times higher than bare land at 0 - 30 cm soil depth at the upper elevation. In 30 - 60 cm soil depth forest land was only significantly different from bare land ($p < 0.001$), farm land ($p < 0.001$) and grass land ($p < 0.001$) (Fig. 12).

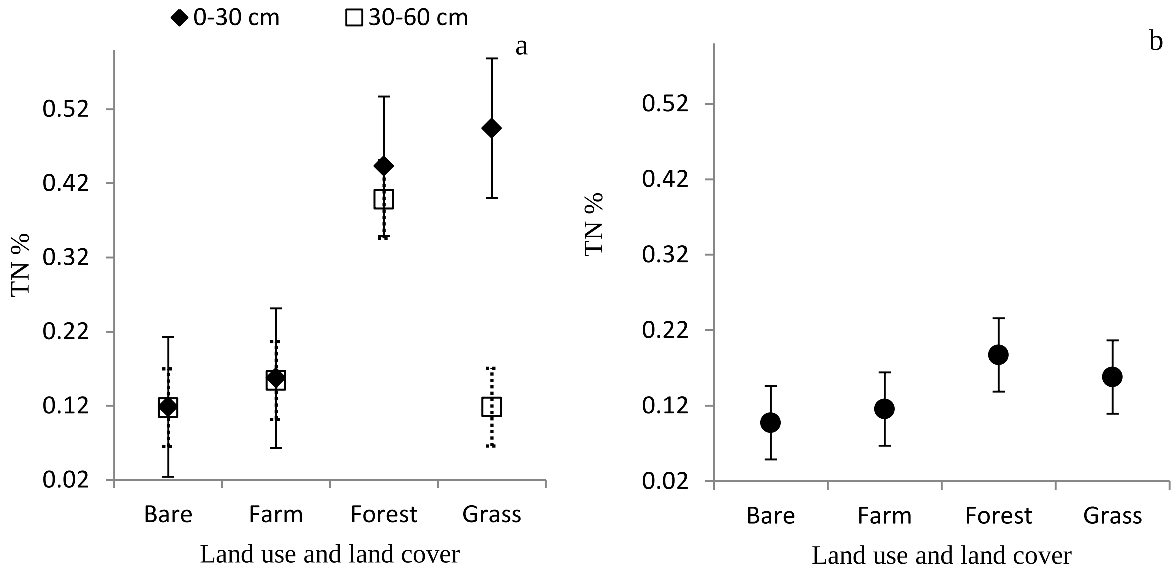

Figure 12. Average total nitrogen in soils at the Era-Hayelom tabia research site for each land use land cover category (bare land, farm land, forest land and grass land) with 95% confidence interval in (a) upper elevation for both soil depth and (b) lower elevation, averaged over depth.

Soil organic carbon (SOC)

The interaction between the LULC and depth was significant for SOC ($p < 0.001$). Analysis was done for each depth separately and SOC was significantly different between the LULC classes in the upper depth ($p < 0.001$). Among the four LULC classes forest land and grass land were both significantly different from bare land ($p < 0.001$) and farm land ($p < 0.001$). Farm land also was different from bare land ($p = 0.019$). On the upper surface at 0 - 30 cm depth, the SOC in grass land was three times higher than in bare land. At the lower depth, the LULC was significant ($p < 0.001$) and forest land was significantly different from bare land ($p = 0.001$) and farm land ($p = 0.003$), and grass land was also significant different from bare land ($p < 0.001$) and farm land ($p < 0.001$). But forest land was not significantly different from grass land at both depth classes (Fig. 13).

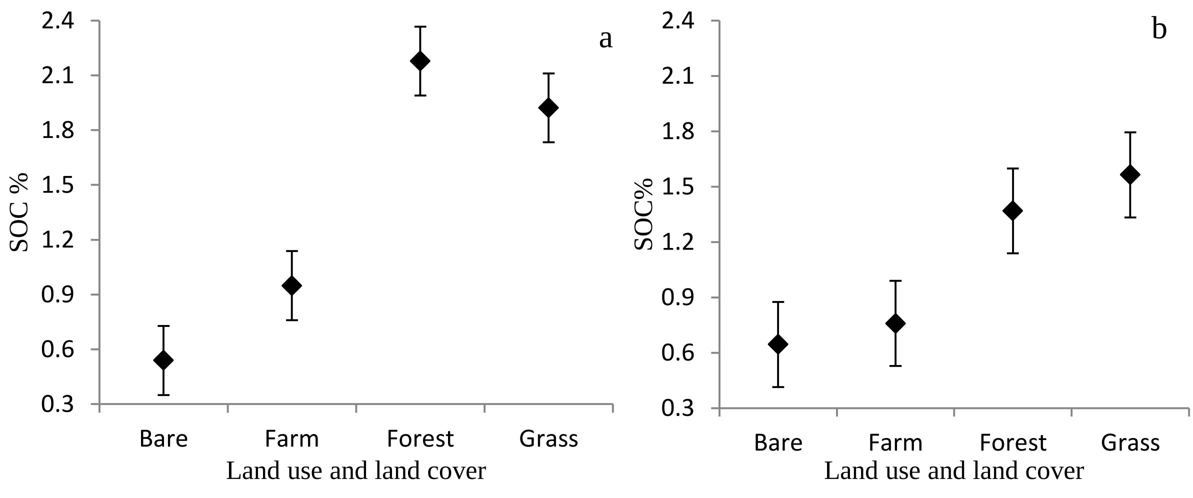

Figure 13. Average of soil organic carbon at the Era-Hayelom tabias research site for each land use land cover class (bare land, farm land, forest land and grass land) at all elevations with 95% confidence interval at (a) 0 - 30 cm soil depth and (b) 30 - 60 cm soil depth.

Soil carbon stock (CS)

The ANOVA result indicated that the amount of CS was significantly affected by the LULC ($p < 0.001$). Among the LULC the bare land and farm land were significantly different from forest land and grass land ($p < 0.001$). There was also a significant difference between farm land and bare land ($p = 0.014$) (Fig. 14).

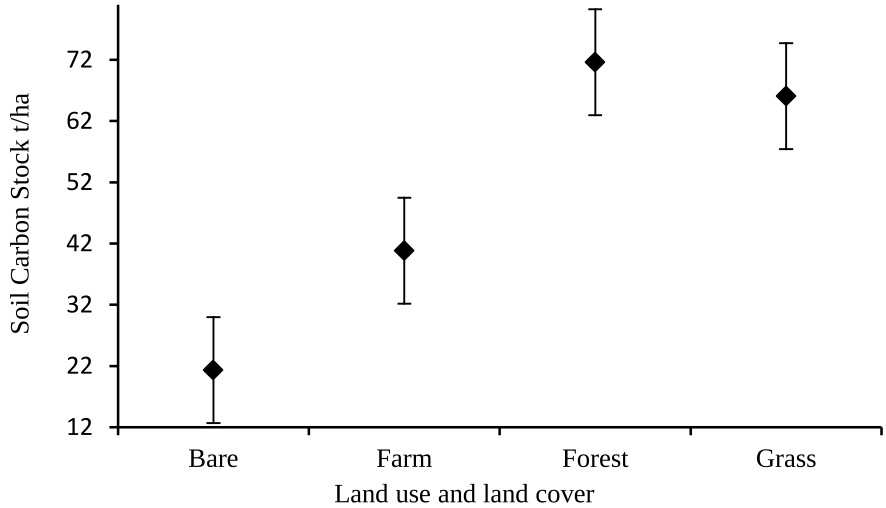

Figure 14. Average carbon stocks at the Era-Hayelom tabias research site for each land use land cover class (bare land, farm land, forest land and grass land) with 95% confidence interval at a soil depth of 0 - 30 cm at all elevations.

The total CS (T) for each land use was highest in forest land followed by grass land for the year 1986. But for the year 2010 grass land had a higher CS. Due to the LULC change the total carbon stocks lost from forest land by 2010 amounted to 19,758 T compared to 1986. Generally in the study site about 6570 T/year of carbon were lost (Table 4).

Table 4. The area and change in CS for each land use and land cover (LULC) class between the years 1986 and 2010 at the Era-Hayelom tabias research site.

LULC	Area(ha) 1986	Area(ha) 2010	Mean CS (t/ha)	CS (T) 1986	CS (t) 2010	Change CS (T)	Change rate CS (t/year)
Forest land	8205.3	5446.5	71.6	587661.4	390081.2	-197580.2	-8232.5
Grass land	2477.4	1085.3	66.1	163654.4	71691.6	-91962.8	-3831.8
Farm land	485.4	2708.4	40.9	19828.6	110637.7	90809.1	3783.7
Bare land	2759.8	4687.6	21.3	58838.5	99940.3	41101.8	1712.6
Total				829982.9	672350.8	-157632.1	-6568.0

4. DISCUSSION

4.1 Land use and land cover change

The negative rate of forest land and grass land cover change indicates that there was deforestation and conversion of land use and land cover. The forest land and grass land were converted to farm and bare lands. About 115 ha of forest land were changed to other lands per year. Studies on forest cover change from 1973 to 2010 in the Desa'a forest indicate that the overall rate of forest cover change was around 110 ha per year (Sebhatleab 2012). Similar studies in the southern part of Ethiopia indicate that the overall forest conversion was 87 ha/year (Aklilu 2010). This indicates that the Era-Hayelom tabias forest area declined seriously. In most areas of the country anthropogenic activity was the major factor for forest resource degradation (Gebreegziabher 1999; Shiferaw 2011). The major factor for the LULC change in the Desa'a forest was also the anthropogenic factors of cutting trees for firewood, overgrazing and expansion of agricultural lands (Sebhatleab 2012). The population pressure together with the unwise land management system may be generally the major factors for land use and land cover change in the study area.

4.2 Impact of land use change on soil physical proprieties

The higher sand proportion than clay and silt in all samples indicates a similarity of parent material and climatic conditions in the soil forming process. Those soil textural classes, sand, silt and clay, were significantly affected by change in the LULC. The significant interaction of the LULC with elevation and depth affect textural composition. Apart from the LULC difference the two elevations and depths show a difference in textural composition for each LULC. The significant difference for the sand and silt percentages of bare land with the other LULC at the upper elevation was reduced at the lower elevation. The difference in sand and silt between forest land and bare land at the upper elevation was higher than at the lower elevation. The reason for this may be that the differences in elevation in the study area influence the weathering processes with the action of topography and movement and accumulation of particles with vegetation cover. Soil particles proportions vary vertically in depth or horizontally due to the process of pedogenesis or soil formation (Moges et al. 2013). Pedogenesis may also be affected by the vegetation cover of the land.

The higher sand percentage and low silt percentage in bare lands may be due to vulnerability of the finer materials to erosion in less vegetated lands. It was observed in some studies that vegetation cover change influences the organic matter content and aggregate stability of the soil to resist erosion (Abbasi et al. 2007). Similar findings were observed by Tsehaye and Mohammed (2013), that silt content was higher in cultivated land and grass lands but forest land had shown a higher clay content compared to other areas. However, cultivation increases the weathering process of soil by moisture and temperature changes (Yimer et al. 2007). In this study area soil clay was also significantly affected by all factors and it was very high on average in farm lands. At the upper elevation clay content was significantly different between the depths of 0 - 30 cm and 30 - 60 cm in all land use types where there were more farming activities. This may be due to the cultivation process at the upper elevation where no more transported sand was accumulated, unlike the lower elevation.

Bulk density showed a significant difference between the LULC classes. Similar studies reported that bulk density was significantly affected by the type of LULC and depth (Gol 2009). The LULCs had differences in vegetation cover and management might bring a significant deference in organic matter accumulation on the surface of the soil. The organic matter content and bulk density have an inverse relationship (Avnimelech et al. 2001). Intensive cultivation could also increase bulk density due to compaction (Reicosky & Forcella 1998). Thus the forest and grass land have a lower bulk density than bare and farm lands due to the organic matter content difference and cultivation activities. As the forest land is converted to farm and bare land, bulk density will be increased. The higher bulk density may also reduce the porosity of the soil that hinders the movements of water and minerals in the soil. Generally, the increasing soil sand percentage and bulk density due to conversion of forest land or grass land to farm land and bare land may reduce the productivity of the land.

4.3 Impact of land use change on soil chemical proprieties

All chemical properties analysed in the study area showed significant differences due to the LULC except electrical conductivity. The mineralogical composition of soil parent material and availability of water affects the electrical conductivity (Voicea et al. 2009). Soil electrical conductivity may be affected by climatic situation differences in the development of the soil. However, the study area had a homogenous climatic situation and this insignificant difference in electro conductivity indicated that there was no difference in parent material and the soil forming process as a whole.

The soil pH values of the study site were generally slightly alkaline and lower pH values were observed in forest land and grass lands, not bare soils. This may have been due to the organic matter decomposition and moisture to mobilize the cations to neutralize the alkaline soil by reducing pH. Organic matter plays a large role in soil acidification and salt reduction (Ritchie & Dolling 1985). However, studies in acidic soils showed that pH increases to neutral value in forest land and grass land soils as the organic matter increases (Moges et al. 2013; Tsehaye & Mohammed 2013). The increasing pH in the bare land of the study area may have been caused by the increase in the dominancy of calcium and magnesium in the soil but a reduction in the availability of essential plant nutrients like phosphorus and nitrogen. This may have reduced the fertility of the soil and therefore productivity.

The lower organic matter in farm and bare lands compared to forest and grass lands was most likely because of the reduction in vegetation coverage. The rate of decomposition and accumulation of the organic matter may also vary in depth. The SOM in forest was accumulated more in the forest land surface 0 - 30 cm depth. But the percolation down of those fine materials to the lower soil depth of 30 - 60 cm was almost equal in grass land and forest land. Similar studies indicate that soil organic matter increased with increased vegetation coverage (Moges et al. 2013). The soil organic matter also influences the total nitrogen, available phosphorus, CEC and other chemical and physical properties (Yimer et al. 2007; Moges et al. 2013). Deterioration of the organic matter content may reduce the soil quality as well as productivity of the land. The reduction in forest land and grass land cover in the area may reduce the amount of organic matter and availability of most essential nutrients in the soil which in turn affect plant growth and the quality of the soil.

The total nitrogen of the area was significantly affected by the LULC and was higher in forest land and grass land compared to bare land. This can be related to the accumulation of organic residues on the soil where bare land and farm land had a lower soil organic matter content than grass land and forest land. Other studies indicate that the main sources of nitrogen in the soil are mineralization of the accumulated soil organic matter to ammonia and fixed atmospheric nitrogen by nitrogen fixing bacteria which convert nitrogen to ammonia (Galloway et al. 2004). The LULC change which reduces the vegetation cover and resulted in reduction of total nitrogen may affect the fertility and productivity of the soil as nitrogen is among the essential elements to plant growth. The vegetation cover and species dynamics are also affected by elevation deference (Aynekulu et al. 2012). This may affect the amount and process of nitrification from the SOM. The decomposition process and accumulation of nitrogen may also be affected by soil depth.

Available phosphorus in the study area was significantly affected by the LULC. But generally the amount of available phosphorus is very low in Ethiopian soils (Negassa & Gebrekidan 2003). The farm land and grass land were not significantly different from forest land but bare land was significantly different from all. However, similar studies on available phosphorus and total nitrogen did not show a significant difference between LULC classes (Girmay et al. 2008). The increasing pH and lowering organic matter content due to the LULC change in the area may reduce the availability of phosphorus. However, it is observed that farmers apply fertilizer on their farm land so the availability of phosphorus in farm land is not significantly different from forest land and grass land.

The soil CEC was significantly different due to the LULC and bare land had the lowest value and forest land the highest CEC. This may have been due to the organic matter and that farm land had a higher clay texture content. CEC may also depend on the percentage of finer soil, clay and organic matter due to the negative charge of clay colloids and humus. Similarly studies on the effect of land use on soil properties showed that there was a significant difference among the LULC for CEC (Tsehaye & Mohammed 2013). A decrease in the CEC value with a reduction in organic matter indicates a reduction in soil nutrient availability and productivity of the land. Thus the change from forest land and grass land to bare land degrades the CEC value and nutrient availability. The farm land also had a higher CEC than bare land due to the higher clay content in farm land. The CEC varies in depth and elevation for different LULCs due to the difference in clay percentage and SOM. This may be due to the pedogenesis process of loss and accumulation of fine particles which may be affected by LULC difference.

SOC and BD are used to calculate CS. These factors were significantly different among the LULCs. Even though the BD in forest and grass land were low due to the higher SOC in those LULCs the CS were higher. However due to a decline in area coverage of those LULCs (forest land and grass land) the total CS reduced from 1986 to 2010. Similar studies about CS in Ethiopia indicate that a decline in upper soil CS was observed when forest land was changed to farm land and other states (Girmay et al. 2008). In this study the CS were also reduced by 19% in the upper depth 0 - 30 cm from 1986 to 2010. This may have been due to the reduction in vegetated land forest and grass lands. The CS in farm and bare land soils was insignificant compared to forest land and grass land. Thus the loss in forest land and grass land by changing to farm and bare land affects the total CS which in turn affects the soil environment.

5. CONCLUSION

The study focused on the impact of LULC change on soil physical and chemical properties in the Era-Hayelom tabias in Tigray, Ethiopia. The LULC change from 1986 to 2010 indicates that a considerable amount of forest land and grass land was converted to farm and bare lands. This had a significant impact on soil properties together with the elevation and soil depth differences. The study showed that the change from forest land and grass land to farm land and bare land was a reduction in vegetation cover and therefore of organic matter content, available phosphorus, total nitrogen and CEC. This also had an impact on increasing the pH and percentage of sand. The overall impact of the LULC change degraded the quality of the soil and increased the loss of carbon stocks. Therefore, sustainable land use management and natural forest conservation should be practised to maintain soil quality, biodiversity and restore the degraded areas. Appropriate land use policy and proper natural resources management are vital for better land productivity and environmental conditions.

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REFERENCES

Abbasi, M. K., M. Zafar, and S. R. Khan. 2007. Influence of different land-cover types on the changes of selected soil properties in the mountain region of Rawalakot Azad Jammu and Kashmir. Nutrient Cycling in Agroecosystems **78:**97-110.

Aerts, R., W. Maes, E. November, A. Negussie, M. Hermy, and B. Muys. 2006. Restoring dry afromontane forest using bird and nurse plant effects: Direct sowing of *Olea europaea* ssp. *cuspidata* seeds. Forest Ecology and Management **230:**23-31.

Aklilu, H. 2010. Forest cover change and vulnerability assessment using GIS and Remote Sensing technique: The case of Wondo Genet Watershed. Master's Thesis. Addis Ababa University Addis Ababa, Ethiopia.

Asefa, D., G. Oba, R. Weladji, and J. Colman. 2003. An assessment of restoration of biodiversity in degraded high mountain grazing lands in northern Ethiopia. Land Degradation & Development **14:**25-38.

Asmala, A. 2012. Analysis of maximum likelihood classification on multispectral data. Applied Mathematical Sciences **6:**6425-6436.

Avnimelech, Y., G. Ritvo, L. E. Meijer, and M. Kochba. 2001. Water content, organic carbon and dry bulk density in flooded sediments. Aquacultural Engineering **25:**25-33.

Aynekulu, E., R. Aerts, P. Moonen, M. Denich, K. Gebrehiwot, T.-G. Vågen, W. Mekuria, and H. J. Boehmer. 2012. Altitudinal variation and conservation priorities of vegetation along the Great Rift Valley escarpment, northern Ethiopia. Biodiversity and Conservation **21:**2691-2707.

Aynekulu, E., M. Denich, D. Tsegaye, R. Aerts, B. Neuwirth, and H. Boehmer. 2011. Dieback affects forest structure in a dry afromontane forest in northern Ethiopia. Journal of Arid Environments **75:**499-503.

Bahrami, A., I. Emadodin, M. Ranjbar Atashi, and H. R. Bork. 2010. Land-use change and soil degradation: A case study, North of Iran. Agriculture and Biology Journal of North America **1:**600-605.

Bai, Z., D. Dent, L. Olsson, and M. Schaepman. 2008. Global assessment of land degradation and improvement. Identification by remote sensing. No. 2008/01 in. ISRIC-World Soil Information, Wageningen.

Bouyoucos, G. J. 1962. Hydrometer method improved for making particle size analyses of soils. Agronomy Journal **54:**464-465.

Bremner, J. 1996. Nitrogen-total. Pages 1085-1121 in D. Sparks, A. Page, P. Helmke, R. Loeppert, P. Soltanpour, M. Tabatabai, C. Johnston and M. Sumner, editors. Methods of soil analysis. Part 3-Chemical methods. Soil Science Society of America USA.

Bringezu, S., Helmut Schütz, Walter Pengue, Meghan O´Brien, Fernando Garcia, Ralph Sims, Robert W. Howarth, Lea Kauppi, Mark Swilling, and J. Herrick. 2014. Assessing Global

Land Use: Balancing Consumption with Sustainable Supply. A Report of the Working Group on Land and Soils of the International Resource Panel. United Nations Environment Programme, Nairobi, Kenya.

Chenu, C., Y. Le Bissonnais, and D. Arrouays. 2000. Organic matter influence on clay wettability and soil aggregate stability. Soil Science Society of America Journal **64:**1479-1486.

Crepin, J., and R. L. Johson. 1993. Soil Sampling for Environmental Assesment. Pages 5-19 in M. R. Carter, editor. Soil Sampling and Methods of Analysis. CRC Press, Boca Roton, Florida, USA.

Diacono, M., and F. Montemurro. 2010. Long-term effects of organic amendments on soil fertility: a review. Agronomy for Sustainable Development **30:**401-422.

Edmondson, J. L., Z. G. Davies, S. A. McCormack, K. J. Gaston, and J. R. Leake. 2014. Land-cover effects on soil organic carbon stocks in a European city. Science of the Total Environment **472:**444-453.

Eswaran, H., R. Lal, and P. Reich. 2001. Land degradation: an overview. Pages 20-35 in E. M. Bridges, I. D. Hannam, L.R. Oldeman, F.W. T.Pening De Vries, S. J. Scherr, and S. Sompatpanit, editors. 2nd International Conference on Land Degradation and Desertification, Khon Kaen, Thailand. Oxford Press, New Delhi, India.

Galloway, J. N., F. J. Dentener, D. G. Capone, E. W. Boyer, R. W. Howarth, S. P. Seitzinger, G. P. Asner, C. Cleveland, P. Green, and E. Holland. 2004. Nitrogen Cycles: Past, Present, and Future. Biogeochemistry **70:**153-226.

Gardner, C. M., K. Laryea, and P. W. Unger. 1999. Soil texture and structure. Pages 7-10 in H. Nabhan and A. R. Mermut, editors. Soil physical constraints to plant growth and crop production. Land and Water Development Division, Food and Agriculture Organization, Rome.

Gebreegziabher, Z. 1999. Dessa'a protected area: an assessment of human impact, evolutionary pattern and options for sustainable management. UNESCO MAB (Man and the Biosphere) Programme, Young Scientists Research Award Scheme, Mekelle, Ethiopia.

Gebrehiwet, K. B. 2004. Land use and land cover changes in the central highlands of Ethiopia: The case of Yerer Mountain and its surroundings. Master's Thesis. Addis Abeba University, Addis Abeba, Ethiopia.

Gebremedhin, B., and S. M. Swinton. 2003. Investment in soil conservation in northern Ethiopia: the role of land tenure security and public programs. Agricultural Economics **29:**69-84.

Gebremichael, D., J. Nyssen, J. Poesen, J. Deckers, M. Haile, G. Govers, and J. Moeyersons. 2005. Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray highlands, Northern Ethiopia. Soil Use and Management **21:**287-297.

Geist, H. J., and E. F. Lambin. 2004. Dynamic causal patterns of desertification. Bio-Science **54:**817-829.

Girmay, G., B. Singh, H. Mitiku, T. Borresen, and R. Lal. 2008. Carbon stocks in Ethiopian soils in relation to land use and soil management. Land Degradation & Development **19:**351-367.

Gol, C. 2009. The effects of land use change on soil properties and organic carbon at Dagdami river catchment in Turkey. Journal of Environmental Biology **30(5):**825-830.

Grossman, R. B., and T. G. Reinsch. 2002. Bulk density and linear extensibility. Pages 201-225 in H. J. Dane and G. C. Topp, editors. Methods of Soil Analysis Part 4 - Physical Methods. Soil Science Society of America, Inc, Madison, Wisconsin, USA.

Hagos, F., J. Pender, and N. Gebreselassie. 2002. Land degradation and strategies for sustainable land management in the Ethiopian highlands: Tigray region. Pages 14-26 in M. A. Jabbar, S. K. Ehui and S. J. Staal, editors. Socio-economic and Policy Research Working paper 25. ILRI (International Livestock Research Institute), Nairobi, Kenya.

Hillel, D. 1998. Environmental soil physics: Fundamentals, applications, and environmental considerations. Academic Press, USA.

Hurni, H. 1985. An ecosystem approach to soil conservation. Pages 759-771 in El-Swaify, M. Sa, Wc and A. Lo, editors. Soil Erosion and Conservation. Society of America, Ankey, Iowa.

Khormali, F., M. Ajami, S. Ayoubi, C. Srinivasarao, and S. Wani. 2009. Role of deforestation and hillslope position on soil quality attributes of loess-derived soils in Golestan province, Iran. Agriculture, Ecosystems & Environment **134:**178-189.

Kizilkaya, R., and O. Dengiz. 2010. Variation of land use and land cover effects on some soil physico-chemical characteristics and soil enzyme activity. Zemdirbyste-Agriculture **97:**15-24.

Lambin, E. F., H. J. Geist, and E. Lepers. 2003. Dynamics of land-use and land-cover change in tropical regions. Annual Review of Environment and Resources **28:**205-241.

Lemenih, M., E. Karltun, and M. Olsson. 2005. Assessing soil chemical and physical property responses to deforestation and subsequent cultivation in smallholders farming system in Ethiopia. Agriculture, Ecosystems & Environment **105:**373-386.

Mao, R., and D.-H. Zeng. 2010. Changes in soil particulate organic matter, microbial biomass, and activity following afforestation of marginal agricultural lands in a semi-arid area of Northeast China. Environmental Management **46:**110-116.

Meyer, W. B. 1995. Past and present land use and land cover in the USA. Consequences **1:**25-33.

Mitiku, H., K. Herweg, and B. Stillhardt. 2006. Sustainable land management–A new approach to soil and water conservation in Ethiopia. Mekelle University, Mekelle, Ethiopia, University of Berne, Berne, Switzerland.

Moges, A., M. Dagnachew, and F. Yimer. 2013. Land Use Effects on Soil Quality Indicators: A Case Study of Abo-Wonsho Southern Ethiopia. Applied and Environmental Soil Science **2013:**1-9.

Negassa, W., and H. Gebrekidan. 2003. Forms of Phosphorus and status of available micronutrients under different land-use systems of alfisols in Bako area of Ethiopia. Ethiopian Journal of Natural Resources. **5:**17-37.

Nelson, D. W., and L. E. Sommers. 1982. Total carbon, organic carbon, and organic matter. Pages 539-579 in A. Page, R. Miller and D. Keeney, editors. Methods of Soil Analysis. Part 2 - Chemical and Microbiological Proporties. American Society of Agronomy, Inc., Soil Science Society of America, Inc, Guilford Rd., Madison, USA.

Nyssen, J., J. Poesen, J. Moeyersons, J. Deckers, M. Haile, and A. Lang. 2004. Human impact on the environment in the Ethiopian and Eritrean highlands—a state of the art. Earth Science Reviews **64:**273-320.

Pankhurst, R. 1995. The history of deforestation and afforestation in Ethiopia prior to World War I. Northeast African Studies **2:**119-133.

Quentin, F., C. Jim, C. Julia, H. Carole, and S. Andrew. 2006. Drivers of land use change, Final Report: Matching opportunities to motivations, ESAI project 05116, . Department of Sustainability and Environment and primary industries, Royal Melbourne Institute of Technology, Australia.

R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for statistical computing, Vienna, Australia.

Reicosky, D., and F. Forcella. 1998. Cover crop and soil quality interactions in agroecosystems. Journal of Soil and Water Conservation **53:**224-229.

Ritchie, G., and P. Dolling. 1985. The role of organic matter in soil acidification. Soil Research **23:**569-576.

Ross, D., K. Tate, N. Scott, and C. Feltham. 1999. Land-use change: effects on soil carbon, nitrogen and phosphorus pools and fluxes in three adjacent ecosystems. Soil Biology and Biochemistry **31:**803-813.

Sebhatleab, M. 2012. Geo-spatial Tools for Forest cover change and Susceptibility Analysis: Cover Change Detection and Susceptibility Mapping using GIS and RS in Desa'a Dry Afromontane Forest, Northern Ethiopia. MSc Thesis. Bahirdar University, Bahirdar, Ethiopia.
Shiferaw, A. 2011. Evaluating the land use and land cover dynamics in Borena Woreda of South Wollo Highlands, Ethiopia. Journal of Sustainable Development in Africa **13:**1520-5509.

Sleutel, S., S. De Neve, B. Singier, and G. Hofman. 2007. Quantification of organic carbon in soils: A comparison of methodologies and assessment of the carbon content of organic matter. Communications in Soil Science and Plant Analysis **38:**2647-2657.

Sumner, M. E., and L. P. Wilding. 2000. Handbook of Soil Science. CRC Press, Boca Raton London.

Teka, K., A. Van Rompaey, and J. Poesen. 2013. Assessing the role of policies on land use change and agricultural development since 1960s in northern Ethiopia. Land Use Policy **30:**944-951.

Teketay, D. 1997. The impact of clearing and conversion of dry Afromontane forests into arable land on the composition and density of soil seed banks. Acta Oecologica **18:**557-573.

Thomas, G. W. 1982. Exchangeable cations. Pages 159-165 in A. Page, R. Miller and D. Keeney, editors. Methods of soil analysis. Part 2. Chemical and microbiological properties. American Society of Agronomy, Soil Science Society of America, Guilford Rd., Madison, USA.

Tsehaye, G., and A. Mohammed. 2013. Effects of Land-Use/Cover Changes on Soil Properties in a Dryland Watershed of Hirmi and its Adjacent Agro Ecosystem: Northern Ethiopia. International Journal of Geosciences Research **1:**45-57.

Turner, B., W. B. Meyer, and D. L. Skole. 1994. Global land-use/land-cover change: towards an integrated study. Royal Swedish Academy of Sciences **23:**91-95.

Voicea, I.-F., M. Matache, and V. Vladut. 2009. Researches Regarding the Electro-Conductivity Determination on Different Soil Textures from Romania, Before Sowing. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Agriculture **66**.

Wassie, A., D. Teketay, and N. Powell. 2005. Church forests in north gonder administrative zone, northern Ethiopia. Forests, Trees and Livelihoods **15:**349-373.

Watanabe, F., and S. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and NaHCO3 extracts from soil. Soil Science Society of America Journal **29:**677-678.

Wong, M. 2003. Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils. Chemosphere **50:**775-780.

Xu, X., W. Liu, and G. Kiely. 2011a. Modeling the change in soil organic carbon of grassland in response to climate change: effects of measured versus modelled carbon pools for initializing the Rothamsted Carbon model. Agriculture, Ecosystems & Environment **140:**372-381.

Xu, X., W. Liu, C. Zhang, and G. Kiely. 2011b. Estimation of soil organic carbon stock and its spatial distribution in the Republic of Ireland. Soil Use and Management **27:**156-162.

Yimer, F., S. Ledin, and A. Abdelkadir. 2007. Changes in soil organic carbon and total nitrogen contents in three adjacent land use types in the Bale Mountains, south-eastern highlands of Ethiopia. Forest Ecology and Management **242:**337-342.