# Soil Acidity Induced Land Use/Management Change, and its Impact on Soil Chemical and Biological Properties in the Central Highlands of Ethiopia

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## Abstract

*Land use/management changes have become more common in the highlands of Ethiopia due to the prevalence of soil acidity, population growth and their demand for diverse products that might have positive or negative consequences on soil resources. In an attempt to explore the effect of soil acidity induced land use/management changes on soil properties, remote sensing and evaluation of selected soil chemical and biological properties in the different land uses was carried out. Analysis of remote sensing data categorized four major land use/cover classes: natural forest, Eucalyptus plantations, cropland/settlements and grasslands. In 1975, natural forest, Eucalyptus plantations, croplands/settlements and grasslands occupied 3.5, 7.5, 28.8 and 61.5 % of the total land area, respectively. Over a period of 39 years (1975 to 2014) of analysis, Eucalyptus plantations and cropland/settlements increased by 335 and 62.5 %, respectively. Soil chemical and biological properties under three land use (grassland, cropland, Eucalyptus) and two management systems (limed land and fallow land) all existing adjacent to each other were compared. Results of soil chemical and biological analysis showed considerable differences between the grassland and other land uses and management systems considered. A reduction of 53, 45, 46 and 47% in soil organic carbon (SOC) was observed under cropland, Eucalyptus, limed and fallow lands, respectively. However, cropland, Eucalyptus and limed fields showed similar values for most of the soil chemical properties studied. Soil microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were also significantly higher under grassland, and lower under fallow land. Furthermore, r*esults clearly demonstrated that deterioration in soil chemical properties is more pronounced in 10-year-old *Eucalyptus* plantations than in 5-year-old *Eucalyptus*. *Soil organic carbon, the MBC to SOC ratio and MBN to total nitrogen could be considered as the three most important bio-chemical parameters to assess functional capacities of soils for soil acidity affected areas in the central highlands of Ethiopia.*

**Keywords:** *Low pH, land use change, MBC, MBN, Eucalyptus, central highlands*

# Introduction

Soil acidification is a natural process which can be enhanced by human activity or can be controlled by appropriate soil management practices. Generally, acid soils have various constraints for crop production and are readily degraded when subjected to erosion, leaching, or contamination. The recently conducted soil fertility status maps produced by the Ethiopian Soil Information System (EthioSIS) have reported that 43 % of the agricultural land is affected by soil acidity, out of which 28 % of it being strongly acidic. The strongly acidic soils account about 3.7 million hectares of the currently cultivated land in the country. Several agricultural practices have been recommended to overcome the problem of tropical acid soil infertility worldwide. However, one of the immediate solutions to this chronic problem is amelioration through application of ground calcium and/or magnesium carbonates, hydroxides, and oxides aiming at raising the soil pH, modifying its physical, chemical and biological properties (Edmeades and Ridley, 2003; Temesgen *et al*., 2016). In the past, this practice had not been in use among Ethiopian smallholder farmers owing to technological, institutional and socio-economic related constraints. Instead, among few strategies that were in practice and still in use to mitigate the negative effects of soil acidity includes: fallowing croplands, conversion of grassland/cropland to short rotation *Eucalyptus* plantations and expansion of farming to communal grazing lands. The so called ‘fallowing’, the resting state of agricultural field (Szott *et al*., 1999) is common in some high-spot soil acidity areas, and areas with low soil fertility. This is intended to allow the soil to rest and regain some of its fertility by growing vegetation, usually consisting of naturally growing weeds and grasses.

Another strategy in response to the prevailing low soil pH and associated problems in the highlands of Ethiopia is conversions of natural vegetations and agricultural lands to *Eucalyptus.* This type of land use changes has become more common in the highlands of Ethiopia due to population growth and their demand for diverse products that led to the degradation of soil resources (Temesgen *et al.*, 2014). Particularly, the growing demand for construction and fuel wood and the wide adaptation of *Eucalyptus* to the different agro-ecological zones of the country are resulting in increased plantation of *Eucalyptus.* Consequently, *Eucalyptus* is voraciously integrated into farming systems in spite of a perception that this practice adversely affects soil quality and crop productivity. When soils come under increasing pressure to maintain a range of ecosystem services, there is interest in how soils change over time in response to factors such as change in land use (Tye *et al*., 2013). Hence, timely detection of land use/management change and its potential effect on soil quality parameters is an essential prerequisite to take appropriate restorative measures, efficient land use planning and resource management. To date, however, there is insufficient information on the effect of soil acidity-induced land use change to eucalyptus on soil quality in the highland agro-ecosystems of Ethiopia. Hence, the objectives of this study were: 1) to show trends of LULC changes between 1974 -2014; 2) to assess and compare the changes in soil chemical and biological properties due to different land use changes; 3) appraise whether short-term fallowing would improve important soil properties such as SOC, MBC and MBN and; 4) investigate whether soil properties differ due to age of Eucalyptus and between soil depths.

# Materials and Methods

## Descriptions of the study area

The study was conducted in Wetabecha Minjaro peasant associations located in western central highlands of Oromia National Regional State, Ethiopia (Fig 1). It is situated at 9° 05′ 55″ N, 38° 36′ 21″ E, at an altitude of 2600 m.a.s.l. According to the local agro-climatic classifications, the study area belongs to moist highland agro-climatic zone with two rainy periods; the main rainy season occurs from June to mid-September, and the short rainy season extending from February to April. The area receives a total of about 1100 mm of rainfall annually. The mean maximum and mean minimum temperatures are 23.3°C and 8.7°C, respectively. The soils are classified as Nitisols with deep, red, well-drained tropical soils (IUSS, 2006). Most of the soils have a pH range of 4.5 to 5.5, contain low organic matter (<20 g $kg^{-1}$) and low nutrient availability. Agriculture is the main source of livelihood for the community, and subsistence type mixed barley-fallow-livestock best characterizes the farming system. Apart from croplands, the study landscape also comprises mosaic natural forests that belong to a tropical dry Afromontane Forest.

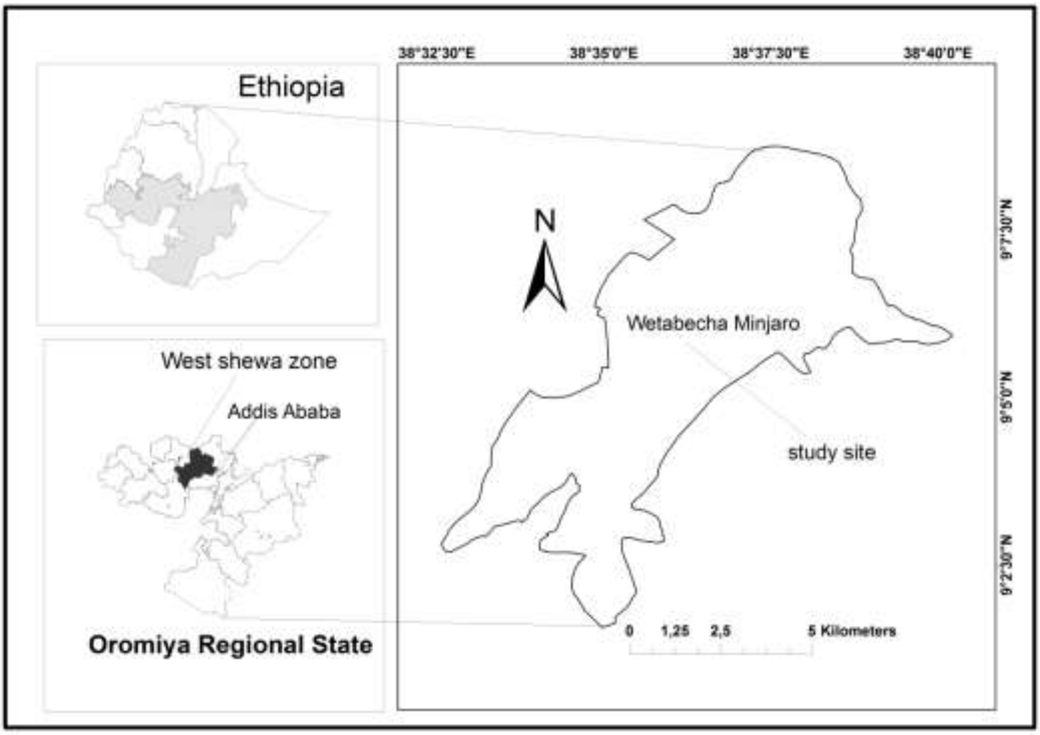


Fig.1. Location map of the study area

## Land use/cover (LULC) change analysis

The main data source for LULC classification and change analysis were a series of Landsat imagery data. These include Landsat MSS, Landsat Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+) and Landsat OLI scenes of the year 1975, 1986, 2000 and 2014, respectively. These datasets were obtained from the National Aeronautics and Space Administration (NASA) through their EOS Data Gateway Database. All the Landsat images were acquired in the same season (between October and January). All GIS data were projected to the Universal Transverse Mercator (UTM) projection system zone 37N and datum of World Geodetic System 84 (WGS84), ensuring consistency between datasets during analysis. Identifications and classifications of the land use/cover were supported by interpretation of aerial photographs and satellite images of the study area.

The satellite images were analyzed by utilizing data image processing techniques in ERDAS Imagine© 10.0 and ArcGIS© 10.0 software. A supervised signature extraction with a maximum likelihood was used in the analysis. Change analysis was conducted using post image comparison technique (Singh, 1989). Ground truthing was complemented with topographical maps of the study area as well as several field visits, interviews with individuals and elderly people of the study site. As rural settlements are scattered and close to cultivated lands, croplands and settlements were classified together. The classified images were compared in three periods, i.e., 1975-1986, 1986-2000, and 2000- 2014. The identified land use/cover data were used for soil sample collection.

## Soil sampling and analysis

A plot size of 10 m x 10 m (100 $m^2$) was demarcated in different land uses for soil sample collection. From demarcated area, composite soil samples were collected from eight randomly located sites where different land use and management systems (grassland, cropland, *Eucalyptus* plantation, limed land and fallow land) that exist adjacent to each other. Each of the soil samples consisted of ten sub-samples in a composite. Soil samples were collected from two depths; 0-10 cm and 10-20 cm for all land use types. A total of 80 soil samples (8 sites * 5 land use/management * 2 depths) were collected for laboratory analysis. Apart from these, soil samples were collected from 5- and 10-year-old *Eucalyptus* plantations and grassland that exist adjacent to each other. The collected samples were air dried and gently sieved through a 2 mm mesh to remove stones, roots, and were sealed in plastic bags before analysis. Soil chemical and biological parameters were analysed in duplicates. Soil biological analyses were done by wetting and keeping for one week of acclimatization period at room temperature. Soil organic carbon was determined by the Walkley-Black oxidation method (Walkley and Black, 1934). Total nitrogen (TN) was determined by Kjeldahl digestion method (Bremner and Mulvaney, 1982), and available phosphorous (AvP) by Olsen's extraction method (Olsen and Sommers, 1982). Exchangeable bases ($Na^+$, $K^+$, $Ca^{2+}$, and $Mg^{2+}$) were measured by atomic absorption spectrophotometer after extraction by ammonium acetate (Black *et al.,* 1965). The cation exchange capacity (CEC) was determined by extraction with ammonium acetate (Chapman, 1965). Exchangeable-titratable acidity was determined in 1 M KCl extracts titrated with 0.01 M NaOH. Microbial biomass carbon and microbial biomass nitrogen (MBN) were estimated by the classical chloroform fumigation extraction method (Brookes *et al*., 1985; Vance *et al.,* 1987). Twenty five grams of dry weight-equivalent soil samples were fumigated with $CHCl_3$ for 24 hours in a dark in vacuum desiccators in two duplicates. After removal of chloroform by three repeated evacuations, the soil samples were extracted by 0.5 M $K_2SO_4$ (using a soil: extractant ratio of 1:4). Similarly, the unfumigated controls were also subjected to 0.5 M $K_2SO_4$ extraction. After shaking for 30 minutes in automatic shaker, the extracts were filtered through Whatman filter paper ($N^o$.42). The filtrates were analysed for organic C and total N by using SKALAR TOC/TN automatic analyzer. The difference in the C content of the extracts from fumigated and unfumigated samples was converted to biomass-C by dividing the value obtained by a factor ($K_C$) of 0.45 (Vance *et al*., 1987). The results were expressed as µg $g^{-1}$ of oven-dried soil. The difference in the content of N of the extractants was also converted to biomass nitrogen by dividing the value obtained by a factor ($K_N$) of 0.54 (Brookes *et al*., 1985).

## Statistical analysis

Analysis of variance (ANOVA) was performed to evaluate the main effects of land use/management, depth, and their interactions using SAS (version 9.1). A linear mixed model analysis with repeated measurements, considering two between-subjects factors (site with eight levels and land use/management with five levels) in a main effects design, and one within-subjects factor (depth with two levels). Tukey´s HSD procedure was used for multiple comparisons of mean chemical and biological properties of the soil under different land use systems.

# Results and Discussions

### Land use land/cover analysis

Analysis of remote sensing data categorized four major land use/cover classes: natural forest, Eucalyptus plantations, cropland/settlements and grasslands. Mapping of the land use and land cover changes of the study area has been published (Temesgen et al., 2014).In 1975, natural forest, *Eucalyptus* plantations, croplands/ settlements and grasslands occupied 3.5, 7.5, 28.8 and 61.5 % of the total land area, respectively. Over a period of 39 years (1975 to 2014) of analysis, *Eucalyptus* plantations and cropland/settlements increased by 335 and 62.5 %, respectively (Fig. 2). The increase in the area of *Eucalyptus* and croplands/settlements was at the expense of grasslands, where a corresponding 74% decrease in the area of grassland was observed in the same period. Between 1975 and 1986, the increases in *Eucalyptus* plantation and cropland/settlements were due to rapid population increases in the study area, and their demand for diverse products (food, feed, fuel and farm implements). This situation forced farmers to convert natural vegetations such as grassland to cropland/settlements and *Eucalyptus*. Numerous studies in Ethiopia and elsewhere (Dessie and Kleman, 2007; Kamusoko, 2007; Ningal *et al*., 2008; Paré *et al*., 2008; Zhao *et al*., 2006) also reported expansion of croplands and *Eucalyptus* plantations at the expense of grasslands. Similarly, Mengistie et al. (2013) also reported the highest conversion of grasslands into other land uses in sub-humid highlands of Ethiopia.

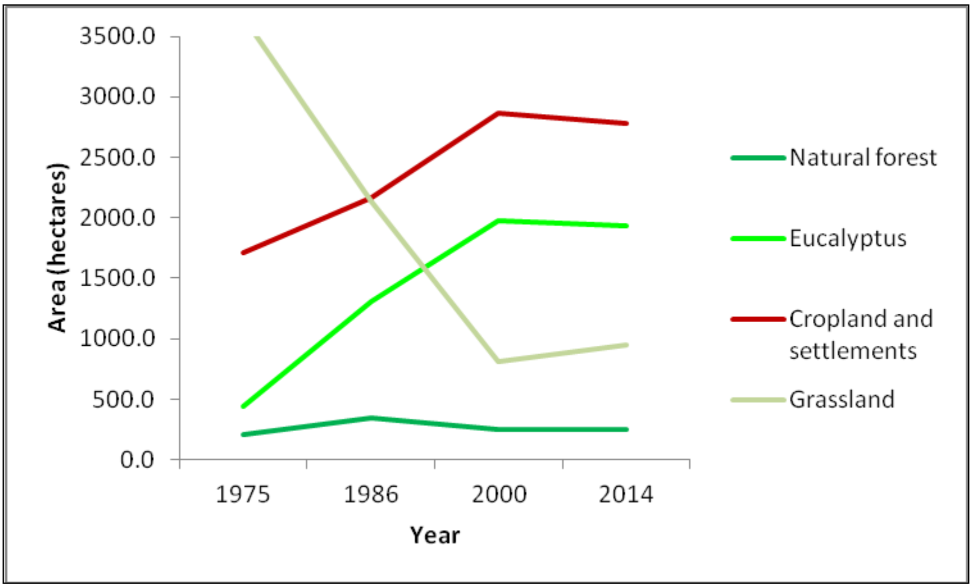


Fig.2. Summary of LULC changes between 1975 and 2014

Hierarchical evolution of Eucalyptus in the farming systems of the study area is presented in Fig. 3. In the past several decades, tropical meadow-type grassland and shrub lands were the dominant type of vegetation. Now, such types of vegetations are gradually replaced by croplands, settlements, and *Eucalyptus* plantations (Temesgen *et al.*, 2014). *Eucalyptus* plantations are widespread and 95% of the community grows *Eucalyptus* on private and communal land or around homesteads. As evidenced from a discussion with the community during soil sample collection, population growth and the growing demand for construction and fuel wood and depletion of soil fertility due to continuous cultivation without addition of external inputs are primarily resulted in increased plantation of *Eucalyptus* in the study area. As a result, the area of *Eucalyptus* is doubling every decade, and more and more smallholder farmers are growing it primarily on grassland or cropland. Even though the policy environment in Ethiopia discourages farmers from planting this exotic tree on productive land, many farm households still continued planting of *Eucalyptus*. Consequently, *Eucalyptus* is voraciously integrated into farming systems in spite of a perception that this practice adversely affects soil quality and crop productivity.

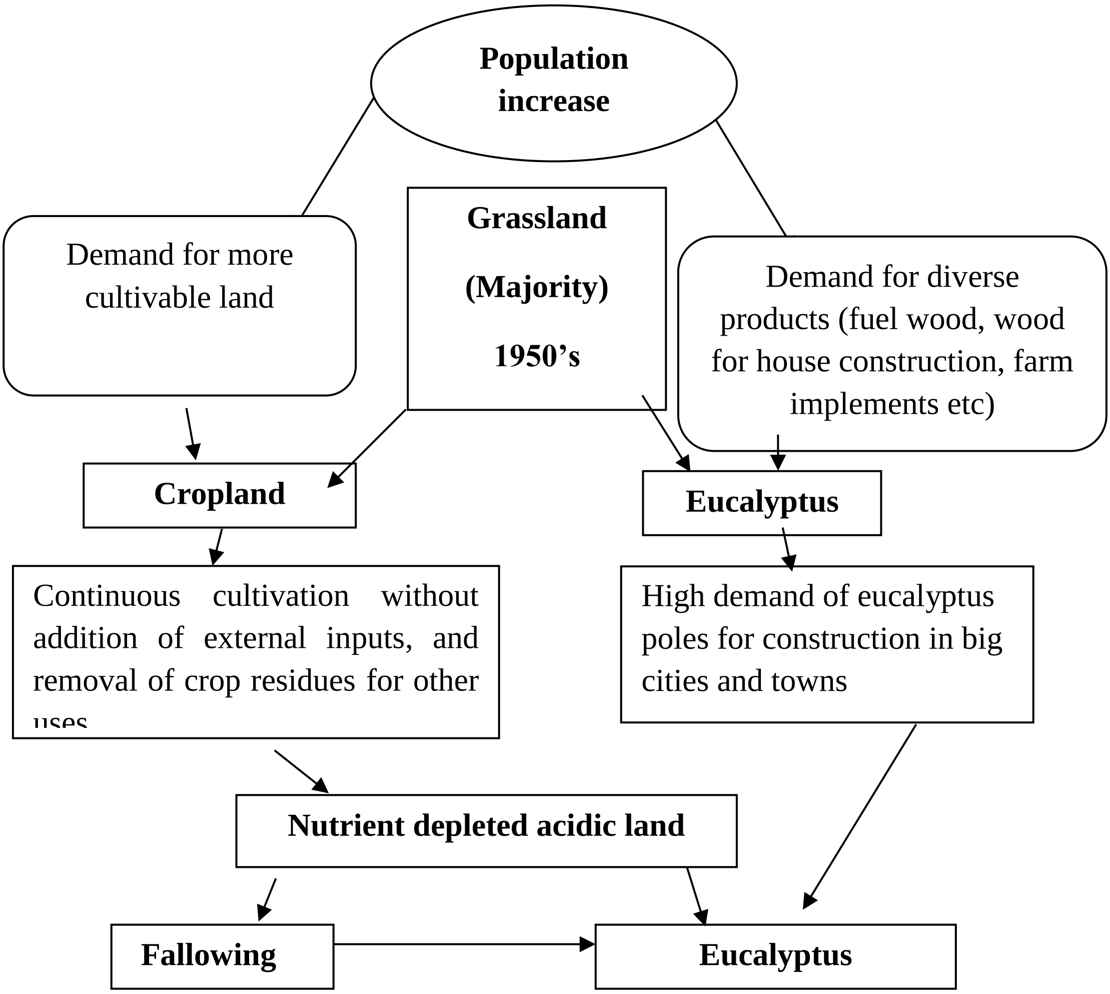


Fig.3. Hierarchical evolution of *Eucalyptus* in the farming systems of the study area (own analysis during soil sample collection)

## Effect of land use/management change on soil chemical properties

Mean values of soil chemical properties as affected by different land use/management are presented in Table 1. The study clearly demonstrated that applications of lime significantly raised soil pH, and drastically reduced exchangeable acidity. When lime is added to acid soils that contain high aluminum and $H^+$ concentrations, it dissociates into $Ca^{+2}$ and $OH^-$ ions. The hydroxyl ions will react with hydrogen and aluminum ions forming water and aluminum hydroxide, respectively, and thereby increase soil pH in the soil solution. Numerous authors have reported decreases of Al in the soil solution as well as in the exchange complex upon liming (Álvarez and Fernández, 2009; Prado *et al*., 2007).

Higher amounts of SOC (4.3%) observed in grassland relative to the cropland, *Eucalyptus land*, limed land and fallow were contributed to the high amount of CEC in grassland. Grassland in our study area includes tropical type grasses and herbaceous vegetations which resulted in a higher litter input compared to the other land uses and management systems. Therefore, greater return of plant litter to soils and high root biomass of grasses could be the reason for the higher SOC in grassland. Tripathi and Singh (2009) also showed cultivation of soil previously supporting natural vegetation could lead to considerable losses of soil organic matter and microbial biomass. The lower values of SOC in other land use and management systems could be due to less physical protection, because tillage periodically breaks up macro-aggregates and exposes previously protected organic matter. The lowest mean values of soil chemical parameters, except for $K^+$, under fallow land might be associated with the current fallow management practices in the study area. Fallow fields are considered as grazing grounds for different species of livestock even though the primary purpose of fallowing by individual farmers is to restore soil fertility. Such practice leaves the land bare and exposes it to surface run-off during rainy season. In addition, crop residues are removed for domestic use, either as a source of fuel or animal feed. Many studies (e.g. Cai and Qin, 2006; Hati *et al*., 2007; Lemke *et al*., 2010) have shown that increases in SOC levels is directly related to the amount of organic residues added to soils. Therefore, the lowest soil fertility status (low pH, SOC, available P, $Mg^{2+}$, $Ca^{2+}$, MBC and MBN) in fallow lands was due to removal of crop residues and the washing away of nutrients by intense rainfall during fallow period. This clearly demonstrates that highly weathered acid soils in the study area would not recover rapidly after short-term fallow periods. Similar to this finding, short-term fallow (four years) in Senegal did not increase SOC or nutrient content (Masse *et al.,* 2004). On the other hand, even though, it is generally believed that plantations of *Eucalyptus* bring about a decrease in soil fertility, the absence of significant variation between *Eucalyptus* and cropland/limed lands in most of the soil chemical parameters is not clear, and needs further investigation. Danju *et al*. (2012) reported restoration of soil fertility following plantation of *Eucalyptus grandis* in south-western China. In their study, they found that soil organic matter content, SOC/ TN ratio, and MBC and MBN concentrations showed an initial phase of decline and then increased significantly over time in the upper soil layers of *Eucalyptus grandis* plantations aged from 1 to 4 or 5 years. Similarly, Tilashwork (2009) also reported that soils under cropland and *Eucalyptus* did not vary significantly in texture, bulk density, organic matter, pH, exchangeable K and available water content in the highland of north western Ethiopia.

Table 1. Mean values of soil chemical properties affected by different land uses and management systems (n=16) at two sampling depths (n=40).

| | | SOC | TN | AvP | $K^+$ | $Na^+$ | $Ca^{2+}$ | $Mg^{2+}$ | CEC | EXa |
|---|---|---|---|---|---|---|---|---|---|---|
| LUM† | pH ($H_2O$) | -----------%--------- | | ---- mg $kg^{-1}$---- | ---------------------------------(cmol (+) $kg^{-1}$)------------------------------------- | | | | | |
| Grassland | 4.9a | 4.4a | 0.4a | 5.1 | 0.8b | 0.2 | 12.6a | 2.6a | 23.2 | 1.2b |
| Crop land | 4.6b | 2.3b | 0.2b | 5.6 | 0.9ab | 0.2 | 8.9b | 2.0b | 17.5 | 1.2b |
| *Eucalyptus* | 4.5b | 2.5b | 0.2b | 6.0 | 0.8b | 0.2 | 8.6b | 2.3b | 18.0 | 2.3a |
| Limed land | 4.7ab | 2.4b | 0.2b | 4.9 | 0.7b | 0.3 | 9.6ab | 1.9b | 18.6 | 0.9b |
| Fallow land | 4.3c | 2.3b | 0.2b | 4.4 | 1.0a | 0.1 | 0.18c | 1.2c | 18.9 | 1.5b |
| *S.e* | 0.06 | 0.13 | 0.01 | 0.73 | 0.05 | 0.03 | 0.96 | 0.23 | 0.82 | 0.26 |
| *Depth(D)* | | | | | | | | | | |
| 0 -10 cm | 4.6 ± 0.02 | 2.8 | 0.26 | 5.6a ± 0.33 | 0.9 | 0.22 | 8.0 | 1.9b ± 0.11 | 19.1 ± 0.41 | 1.3b ± 0.11 |
| 10 -20 cm | 4.6 ± 0.35 | 2.7 | 0.25 | 4.8b ± 0.35 | 0.8 | 0.19 | 7.9 | 2.1a ± 0.11 | 19.4 ± 0.42 | 1.5.a ± 0.13 |
| *ANOVA* | | | | | | | | | | |
| LUM | *** | *** | *** | ns | ** | ns | *** | ** | *** | * |
| D | ns | ns | ns | *** | ns | ns | ns | * | ns | * |
| LUM*D | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |

†LUM= land use/ management,, D= soil sampling depth, SOC= soil organic carbon, TN= total nitrogen, AvP= available phosphorus, CEC= cation exchange capacity, EXa= exchangeable acidity. Mean values with different letters within the same column indicate significant differences (Tukey's HSD procedure). The analysis of variances for the LUM, D and LUM*D are reported, p <0.001***, p <0.01** and p <0.05, S.e= standard error, ns= not significant.

## Effect of land use/management change on soil biological properties

Even though, various physical and chemical soil properties can be used to characterize soil quality, soil biological properties are more sensitive to changes than other indicators and could describe the soil quality in a broader picture (Bastida *et al.*, 2008). The diversity of microorganisms and the related biochemical processes are also the most important components of soil quality, especially for the highly weathered acid soils, in which plant productivity is closely related to biological cycling (He *et al.*, 2003). The effect of land use/management change on soil biological properties is presented in Table 2.

Table 2: Mean values of microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), MBC/MBN, MBC/SOC and MBN/TN as affected by different land uses and management systems (n=16) at two sampling depths (n=40).

| LULC† | MBC | MBN | MBC/MBN | MBC/SOC | MBN/TN |
|---|---|---|---|---|---|
| | ------------μg g$^{-1}$ soil----------- | | | Computed as mean of the two depths (%) | |
| **Grassland** | 763.7a† | 87.8a | 9.0ab | 2.56a | 2.89a |
| **Cropland** | 342.6b | 71.28a | 5.7c | 1.03cd | 2.30b |
| ***Eucalyptus*** | 345.0b | 37.9bc | 10.2a | 1.44bc | 1.69c |
| **Limed land** | 335.7b | 47.2b | 7.4b | 1.54b | 2.31b |
| **Fallow land** | 190.8c | 23.1c | 8.8ab | 0.80d | 1.06d |
| ***S.e*** | 35.25 | 4.16 | 0.40 | 0.14 | 0.16 |
| ***Depth (D)*** | | | | | |
| **0 -10 cm** | 485.4a ± 21.48 | 67.2a ± 2.99 | 8.00ns | 1.62a±0.09 | 2.31a ±0.10 |
| **10 -20 cm** | 305.8b ± 15.45 | 39.7b ± 2.40 | 8.42ns | 1.32b ±0.09 | 1.78b ±0.10 |
| **ANOVA** | *** | *** | *** | *** | *** |
| **LULC** | | | | | |
| **D** | *** | *** | ns | * | ** |
| **LULC*D** | ns | ns | ns | ns | ns |

†Means within a column with different letters between different land uses and management systems indicate significant differences ((Tukey's HSD procedure). The analysis of variance for each land use and management is reported, p <0.001***, S.e= standard error, ns= not significant

Results revealed that the highest values of MBC (763.7 μg g$^{-1}$) and MBN (87.8 μg g$^{-1}$) were recorded under grassland soils as compared to cropland, *Eucalyptus*, limed land and fallow land. Soils under fallows had the lowest MBC (190.8 μg g$^{-1}$) and MBN (23.1 μg g$^{-1}$). Values of MBC recorded under cropland, *Eucalyptus* plantations and limed land did not show significant differences. However, the MBN in grassland and cropland was comparable, and significantly superior to the other land uses. The lowest values of MBN were observed in *Eucalyptus* and fallow land. Depth wise, MBC and MBN values were significantly higher in 0-10 cm relative to 10- 20 cm. In this study, changes in the ratios of MBC/SOC and MBN/TN due to land use changes were quite considerable. Accordingly, the values of MBC/SOC were in the following order: grassland >limed land >*Eucalyptus* > cropland >fallow land. Whereas, MBN/TN followed the order: grassland >limed land >cropland >*Eucalyptus* >fallow land. As expected, the mean values of MBC/SOC and MBN/ TN were significantly higher in 0-10 cm as compared to 10-20 cm soil profile. Higher mean values of both MBC and MBN in 0-10 cm depth as compared to 10-20 cm might be attributed to a decline in carbon availability and more occurrence of microbial biomass in the surface of 10 cm soil profile. The study demonstrated that more C mineralization happens in the first 0-10 cm than in 10-20 cm, indicating rapid activities of microbes that mineralize C within the surface of the soil profile. The decrease in the C mineralization in 10- 20 cm might be due to lower SOC content at 10-20 cm depth and relatively smaller number of microbes. These results are in line with the findings of Taylor (2002), who found reduced microbial and fungal activities in deeper *versus* surface soil layers.

The most important soil biological properties such as MBC/SOC and MBN/TN showed lower values in fallow land and croplands relative to grasslands or limed land. Similar to this result, cultivation of soils in the central highlands of Mexico with maize reduced MBC, and Reyes-Reyes *et al*. (2007) reported that converting soil under natural vegetation to arable soil was not only detrimental for soil quality, but also unsustainable when organic matter input is limited. A high MBC/SOC indicates an increased pool of available carbon in soil (Klose *et al*., 2004). Therefore, this work suggested that the MBC/SOC and MBN/TN could be useful tools to assess biological soil quality changes due to the conversion of grasslands to other land uses and management systems in highly weathered acidic soils of the central highlands of Ethiopia.

## Effect of Eucalyptus age on soil chemical and biological properties

The effect of Eucalyptus age on soil chemical and biological properties is presented in Table 3 and 4, respectively. According to the results of a linear mixed model, the mean values of pH, SOC, and TN in adjacent grassland were significantly ($p<0.5$) higher than plantations of 5- and 10-year-old *Eucalyptus* (Tables 3). However, the two age groups of *Eucalyptus* did not differ from each other in the above parameters. Land use conversions from grassland to *Eucalyptus* resulted in higher soil acidity, and lower SOC and TN. The increased acidity under *Eucalyptus* plantations could be associated with increased cation uptake by trees and consequent changes in the proportions of adsorbed cations to the soil exchange complex (Temesgen et al., 2016). Relative to SOC of grassland, the SOC of 5- and 10-years-old plantations decreased by 48% and 44% respectively. Similarly, TN was decreased by 50% and 42% in 5- and 10-years-old *Eucalyptus* plantations respectively. Lower SOC and TN in *Eucalyptus* plantations agree with reports from Balagopalan and Jose (1995), Animon et al. (1999) and Behera and Sahani (2003).

Table 3: Effect of Eucalyptus age on selected soil chemical properties

| Depth | Land use type | pH ($H_2O$) | EXa (cmol(+)/kg | SOC (%) | TN (%) | AvP (mg/kg) |
|---|---|---|---|---|---|---|
| 0 -10 cm | Grassland | 4.9a† | 0.56b | 4.6a | 0.41 a | 5.8ns |
| | 5-year-old *Eucalyptus* | 4.3b | 3.23a | 2.4b | 0.20b | 3.9ns |
| | 10-year- old *Eucalyptus* | 4.4b | 2.23a | 2.3b | 0.23b | 6.0ns |
| 10 -20 cm | Grassland | 5.0a | 1.0b | 3.8a | 0.36a | 5.0ns |
| | 5-year-old *Eucalyptus* | 4.3b | 3.6a | 2.1b | 0.18b | 3.4ns |
| | 10-year- old *Eucalyptus* | 4.5b | 2.2ab | 2.4b | 0.22b | 5.0ns |

†Mean values within a column with similar depth that share the same letters are not significantly different between land use type. EXa = exchangeable acidity; SOC=soil organic carbon; TN=total nitrogen; AvP=available phosphorus

Soil microbial biomass greatly depends on soil organic matter as substrate; a decrease in SOM causes a reduction in soil microbial biomass (Chen *et al*., 2005). Hence, the higher MBC and MBN in grassland is mainly attributed to greater availability of organic matter. The lower microbial biomass under *Eucalyptus* plantations could possibly be due to the toxic effects of harmful allelochemical compounds released from *Eucalyptus* leaf litter (Rice, 1984). Harmful effects of *Eucalyptus* leaf litter on microbes were also reported by Dellacassa *et al*. (1989) and Sankaran (1993). In this study, MBC/SOC and MBN/TN did not show remarkable differences among land uses. Generally, lower levels of MBN/TN in 10-year-old *Eucalyptus* indicate that the nitrogen supplying ability of soils is gradually decreasing as the age of the plantations progresses. Low ratios of microbial biomass and nitrogen in *Eucalyptus* plantations were also reported by Yu *et al*. (2008).

Table 4: Soil biological parameters as affected by age of Eucalyptus

| Land use | MBC ($\mu g\ g^{-1}$ soil) | MBN ($\mu g\ g^{-1}$ soil) | MBC: SOC | MBN: TN |
|---|---|---|---|---|
| | | | Computed as mean of the two depths (%) | |
| Grassland | 669.3a† | 81.5a | $1.7^{ns}$ | $2.0^{ns}$ |
| 5-year-old *Eucalyptus* | 365.4b | 30.5b | $1.7^{ns}$ | $1.6^{ns}$ |
| 10-year-old *Eucalyptus* | 280.2b | 32.5b | $1.2^{ns}$ | $1.5^{ns}$ |

†Means within a column that share the same letters are not significantly different within land use type. MBC=microbial biomass carbon; MBN=microbial biomass nitrogen; MBC: SOC= ratio of MBC to organic carbon; MBN: TN= ratio of microbial biomass nitrogen to total nitrogen; ns= non-significant

# Conclusions

Remote Sensing and GIS data analysis clearly showed a dramatic decrease in the area of grassland from 1975 to 2014, accompanied by an increase in the area of croplands and settlements in the same period. Rapid population growth and their demand for diverse products and soil fertility deterioration over time are the major drivers to change part of a land to other forms of land use/management. Generally, conversions of grasslands to either cropland or *Eucalyptus* plantations or fallowing deteriorate the functional capacities of soils in the central highlands of Ethiopia. Even though, it is generally believed that plantations of *Eucalyptus* bring about a decrease in soil fertility, the absence of significant variation between *Eucalyptus* and cropland/limed lands in most of the soil chemical parameters is not clear, and needs further investigations. However, land use conversions from grassland to *Eucalyptus* resulted in higher soil acidity levels. The lowest soil fertility status (low pH, SOC, available P, $Mg^{2+}$, $Ca^{2+}$, MBC and MBN) in fallow lands clearly demonstrates that highly weathered acid soils in the study area would not recover rapidly after short-term fallow periods. Hence, improving soils conditions in the current land use system in sustainable way requires improving and maintaining soil productivity. This includes crop residues retention in crop fields after harvesting; avoiding bare fallows and judicious application of lime along other management practices would be sustainable options for the current soil acidity problem in the study area.

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