ORIGINAL ARTICLES

Comparison of soil quality parameters under different land use and management systems in the highlands of Ethiopia

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ABSTRACT

In response to the prevailing low soil pH and associated problems in the highlands of Ethiopia, conversions of natural vegetations and agricultural lands to other land use and management systems have been in practice since several decades. A study was conducted to compare several soil physical, 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. Results showed that soil quality indicators were higher under grassland than under the other land uses and management systems considered. As compared to grassland 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 lands 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 significantly lower under fallow land. Soil depth only affected available phosphorus, Mg^{2+}, exchangeable acidity, ratios of MBC to SOC, and MBN to total nitrogen (TN). Therefore, our results suggest that SOC, MBC: SOC and MBN:TN could be considered to assess functional capacities of soils under soil acidity conditions in the highlands of Ethiopia.

Keywords: Ethiopian highlands, Eucalyptus, Fallowing, Land use, Low pH

INTRODUCTION

In the Ethiopian highlands, the rapidly growing population with heavy reliance on subsistence type of agriculture has forced farmers to an unwise use of land resources leading to a subsequent deterioration of functional capacity of soils. Particularly the areas with altitudes >1800 m.a.s.l., here after referred to as the highlands of Ethiopia, were once majorly covered with tropical type meadow vegetation. In the last 50 years, however, land use changes have been more rapid due to population growth and demand of the local people for diverse products with its negative consequence on soil resources. 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). For example, due to the prevailing soil acidity problem, the highland ecology is known to have undergone a series of changes in land use/cover types. Land use change (e.g. grassland to cropland, infertile cropland to eucalyptus plantations) and change in management (fallowing croplands and liming of croplands) are being practiced as alternative strategies to mitigate the negative effects of soil acidity. Fallowing (Szott *et al.,* 1999) is commonly practiced due to its cheaper practice to restore soil fertility. However, due to population pressure in the highlands and their demand for diverse products, fallow periods have become as short as 18 months in some areas.

The need for understanding and assessing soil quality is getting increasingly important because of growing public interest in determining the effect of management practices on the sustainability of the soil resource base (Rongjiang *et al.,* 2013). Soil quality assessment was envisioned as a tool to help balance challenges associated with (1) increasing world demand for food, feed, and fiber, (2) increasing public demand for environmental protection, and (3) decreasing supplies of nonrenewable energy and mineral resources (Pesek, 1994; Doran *et al.,* 1996). The capacity of soil to function can be evaluated by measuring some selected physical, chemical and biological properties, also known as soil quality indicators. In this context, several soil quality assessment have been conducted in different countries under various cropping conditions including: organic and conventional farming (Fliessbach *et al*., 2007), tillage and residue management (Sharma *et al.,* 2005; Imaz *et al.*, 2010), crop rotation (Mubarak *et al.*, 2005; Aziz *et al*., 2011), soil quality around mining areas (Shukla *et al.,* 2004), manure application and burning Lee *et al.,* (2006). However, concepts of soil quality under tropical conditions are still insufficient and missing because these concepts were mainly developed for temperate climates and cannot be applied to tropical conditions Sánchez *et al.* (2007). The most effective soil quality indicators will probably vary according to region, climate, and cropping systems (Parr *et al*., 1992). Therefore, there are many factors that affect soil quality indicators in tropical regions, including but not limited to, soil and vegetation type, socio-economic conditions of the users, current and past land use practices. Many studies (e.g. Lepsch *et al.*, 1994; Shukla *et al.,* 2006; Yimer *et al.,* 2007, 2008) indicate that conversion of native vegetation into cultivation in tropical regions causes important changes in soil properties, including loss of organic matter, increase in soil bulk density and decreases in exchangeable cations, pH and base saturation. Yimer *et al*. (2008) reported that land use change mainly through converting the natural vegetation into cropland and grassland in the highlands of Ethiopia influenced many natural phenomena and ecological processes, leading to a remarkable change in the soil properties. Such changes directly affect soil physical, chemical and biological processes such as soil water retention and availability, nutrient cycling, gas influx, plant root growth and soil conservation (Ashagrie *et al.,* 2005; Emadi *et al.,* 2008). As a result, apart from many development bottlenecks that currently facing the highlands of Ethiopia, soil degradation in the form of soil acidification, soil salinization and nutrient transport through erosion, deteriorates the functional capacity of soils. Teklu *et al.* (2006) reported that soil quality degradation and reduced agricultural productivity as the main causes of wide spread poverty in the highlands of Ethiopia.

Recently, land use change has become an area of particular concern in the highlands of Ethiopia due to the rapid land conversion practices and its environmental consequences. Therefore, timely detection of land use 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 our knowledge, however, there is no or insufficient knowledge on soil acidity-induced land use changes and management systems in the highland agro-ecosystems of Ethiopia. Therefore, the objectives of this study were: 1) to assess and compare the changes in soil biological, chemical and physical properties under different land uses (grassland, cropland and eucalyptus) and management systems (limed land and fallow land); 2) appraise whether short-term fallowing would help improve important soil quality parameters such as SOC, MBC and MBN and; 3) investigate whether the soil quality parameters vary with soil depth.

MATERIAL AND METHODS

Description of the study site

The study area,Wetabecha Minjaro peasant associations, commonly known as Bedi, is located in western central highlands of Oromiya regional State, Ethiopia. It is situated at (9° 05′ 55″ N, 38° 36′ 21″ E), at an altitude of 2600 m.a.s.l (Fig. 1).

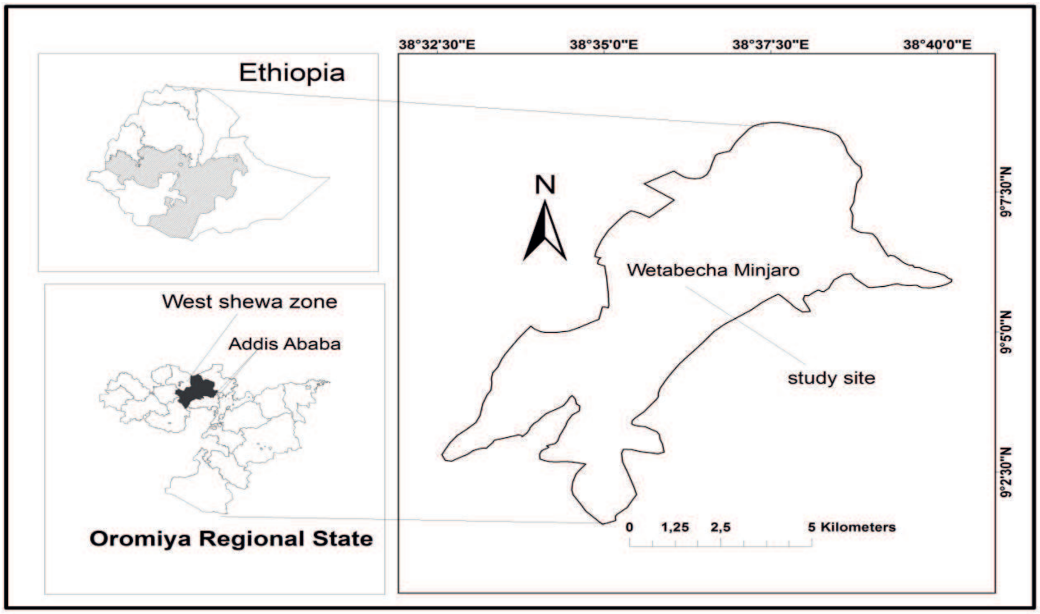


Figure 1. Location map of the study area

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 which occurs from June to mid September and the short rainy season extending from February to April. The area receives about 1100 mm of rainfall annually. The mean monthly maximum and minimum temperatures are 23.3°C and 8.7°C, respectively (Figure 2).

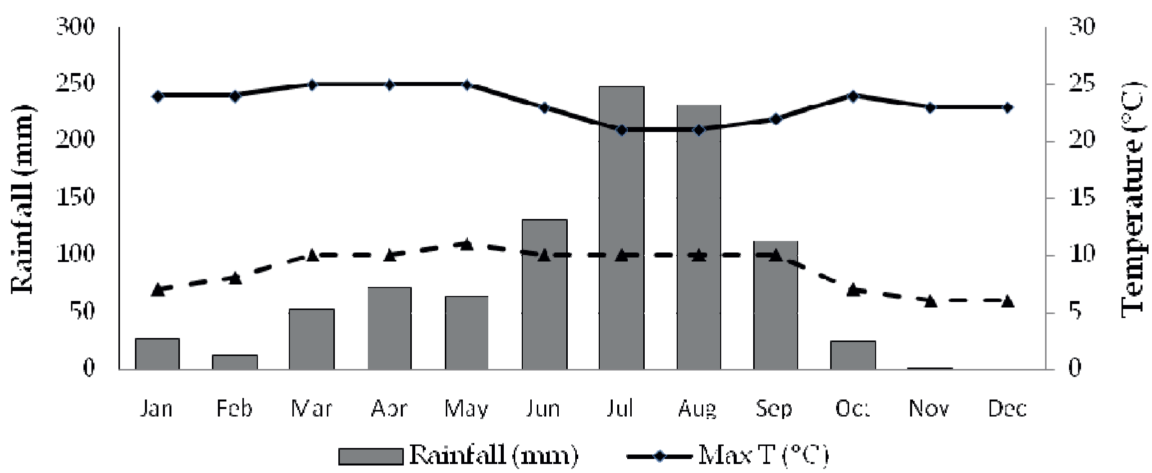


Figure 2. Monthly maximum and minimum temperature and mean monthly precipitation for the study site, mean of 10 years (1998- 2007) taken from the nearest meteorology station, Holetta Agri. Research Center.

The soils are classified as Nitisols with deep, red, well- drained tropical soils (IUSS, 2006)that are characterized by thick solum with high contents of weathered minerals. In terms of topography, all land uses of the study site are located within similar topography and altitude. Hence, there was no variation in terms of soil types and vegetation cover types of the area. However, in the past several decades, tropical meadow type grassland vegetation and shrub lands were the dominant type of vegetation. Now, such types of vegetations are gradually replaced by croplands and eucalyptus plantations (Temesgen *et al.*, 2014). The grassland mainly composed of grasses and very few legumes such as, *Schizachyrium* sp. *Paspalum notatum*, *Axonopus sp.*, *Desmodium* spcies. Agriculture is the main source of livelihood for the community and subsistence type mixed crop-livestock systems characterize the farming system. Barley is the only major cereal crop grown in the region. Communal/private eucalyptus plantations are widespread, and literally native forest species is non-existent that satisfies the high demand for construction and biomass energy.

Experimental design and sampling

A land use/cover survey (Temesgen *et al.,* 2014) carried out in 2012 in relation to this work identified three major land uses and two management practices, namely; grassland (open grazing lands dominated by natural tropical grasses), cropland (barley monoculture without liming), eucalyptus plantations (6-7 years old); fallow land (18 months of resting period) and limed land (lands reclaimed by liming to counteract the negative effect of soil acidity). Descriptions of land use and management practices of the area are given in Table 1. Identifications and classifications of the three land uses were supported by interpretation of aerial photographs and satellite images of the study area (Temesgen *et al.,* 2014). However, the two management practices were identified by collecting information from land owners and government development agents. The sites had similar altitudes, slopes and soil types.

Table 1. Descriptions of land use management systems in the study area

Land use/management	Brief descriptions
Cropland	Areas that were under barley cultivation at the time of soil sampling
Grassland	Huge areas of land with no cropping practice, trees or settlements; totally dominated by natural grasses and used for grazing
Fallow land	Abandoned previously croplands from cultivation for a period of 18 months to restore soil fertility
Limed land	Lime applied fields to counteract soil acidity and its associated problems
Eucalyptus plantations	Areas occupied by *eucalyptus globulus* plantations (6 -7 years of age)

During July to September, 2012, eight sites where selected with the following criteria: 1) grassland, cropland, eucalyptus plantation, fallow land, and limed land that were located in adjacent areas; 2) previous land use must grassland based on the individual interviews and by comparing satellite images between 1986 and 2014; 3) for soil sample collection, the area of each land use and management practice should be greater or equal to half a hectare. Soil samples from limed lands were collected after 3 years of liming based on exchangeable acidity (EXa) of the area (Kamprath, 1984). The exchangeable acidity of the area was 1.32 meq/100 grams of soil, and the corresponding lime applied was 1.65 tha^{-1}. Samples were collected from two depths; 0-10 cm and 10-20 cm for all land use types. Each of the soil samples consisted of ten sub-samples in a composite, which were collected from a 10 x 10 m demarcated plots. A total of 80 soil samples (8 sites * 5 land use/management * 2 depths) were collected for laboratory analysis. Samples was gently sieved through a 2 mm mesh to remove stones, roots, and were sealed in plastic bags before analysis. Both 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 (Vance *et al.,* 1987.

Soil physical and chemical analysis

Soil bulk density (BD) of the top layer soil was estimated using a 5 cm diameter and 5 cm height metal cylinder (Blake, 1965). Field capacity (FC) was determined by saturating soil samples with water and allowing them to drain for 24 hours. After oven drying at 105°C, moisture loss was expressed as percentages. Permanent wilting point (PWP) was estimated from soil samples equilibrated at a pressure of 15 bars on a pressure plate (Cassel and Nielsen, 1986). Hence, plant available water (PAW) was determined by the difference between field capacity and permanent wilting point in percentage. Soil particle size distribution analysis was performed using hydrometric method (Bouyoucos, 1962). The USDA particle size classes viz. sand (2.0–0.05 mm), silt (0.05–0.002 mm) and clay (<0.002 mm), were used when classifying textural classes. Soil pH was determined by potentiometric methods at a 1:2.5 soil to water ratio. Soil organic carbon was determined by the Walkley-Black oxidation method (Walkley and Black, 1934). Total nitrogen (TN) by Kjeldahl digestion method (Bremner and Mulvaney, 1982), and available phosphorous (AvP) was determined using 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.

Biological properties

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°.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 9.0). A linear mixed model analysis with repeated measurements, considering two between-subjects factors (site with eight levels and land use with five levels) in a main effects design, and one within-subjects factor (depth with two levels). The mathematical formulation of the model was given by:

$$Y_{ij;k} = \mu + \alpha_i + \beta_j + \gamma_k + \beta\gamma_{jk} + \varepsilon_{ij;k}$$

with i=1,…,8 for the sites, j=1,…,5 for the land use/management and k=1,2 for the two depths, and being:

$Y_{ij;k} =$ observed value of the dependent variable for the land use j at depth k in the site i.

$\mu =$ general mean effect; $\alpha_i =$ main effect of the site I; $\beta_j =$ main effect of the land use/management j; $\gamma_k =$ main effect of the depth k; $\beta\gamma_{jk} =$ interaction effect of the land use j with the depth k; $\varepsilon_{ij;k} =$ random error in the dependent variable for the land use j at depth k in the site i.

The assumptions for the model were:

- $\varepsilon_{ij;k} \sim N(0, \sigma_k^2)$, with σ_k^2= random variance for errors at depth k.

- $Cov(\varepsilon_{ij;k}, \varepsilon_{i'j';k'}) = \begin{cases} \omega & \text{if } i = i', j = j' \text{ and } k \neq k' \\ 0 & \text{if } i \neq i' \text{ or } j \neq j' \end{cases}$

, with ω=covariance between errors at different depths. Therefore, the model included three variance parameters, which were estimated using the restricted maximum likelihood method (REML). Finally, Tukey´s HSD procedure was used for multiple comparisons of mean physical, chemical and biological properties of the soil under different land use systems.

RESULTS

Soil physical properties

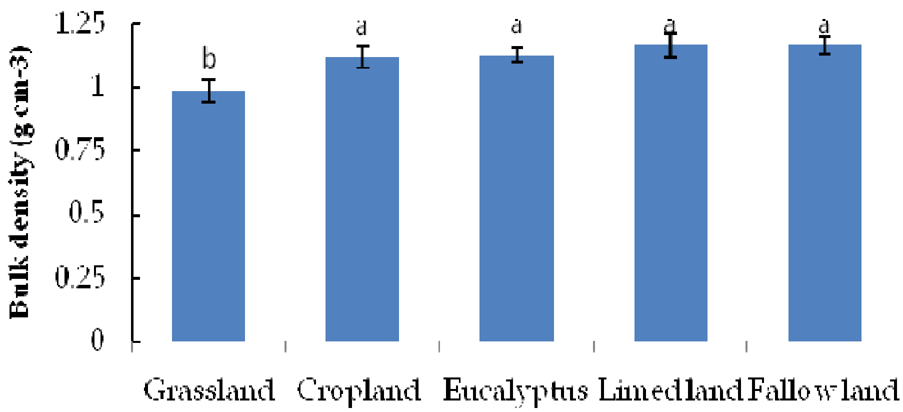
Mean values of percent sand, silt and clay for each of the five land use and management under two sampling depths are summarized in Table 2. Results revealed that the soil was majorly composed of silt and clay, clay being the most representative fraction. It represents about 46% in the top 0-10 cm and 48% in the 10-20 cm soil profile. Relative to the other four land uses, soils under fallow land had lower sand content. Percent sand under the other four land uses (grassland, cropland, eucalyptus and limed lands) did not differ from each other. Grassland had lower clay content relative to fallow lands, eucalyptus, limed lands and croplands.

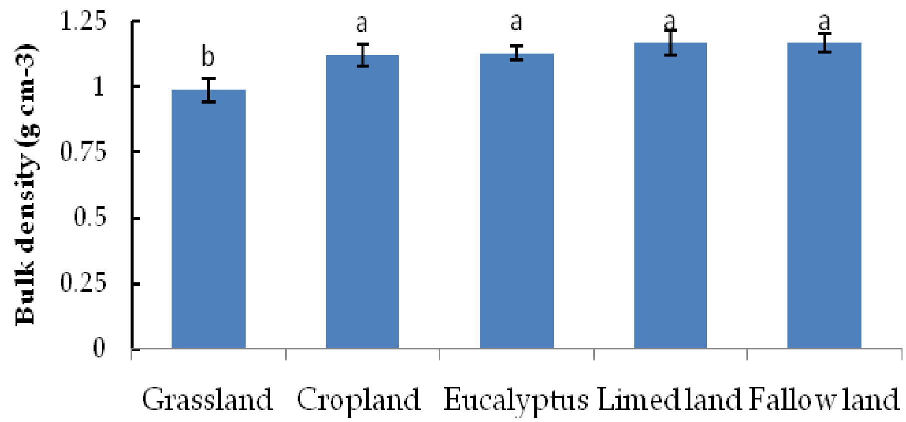
Soil samples from 0-10 cm had higher silt content as compared 10-20 cm. However, clay content was significantly higher ($p<0.05$) in 10-20 cm soil profile. Sand content was not significantly affected by depth of soil sampling. Values of BD ranged from 0.99 to 1.17 g cm^{-3} (Fig. 3). Bulk density increased with increase in soil depth.. Bulk density recorded in grassland was significantly lower as compared to the other land uses and management. However, grassland recorded significantly higher values of FC and PWP. Permanent wilting point recorded in 0-20 cm soil profile ranged from 14.7-19.5%; the highest being in grassland. The other land use and management systems were not significantly different from each other.

Table 2. Mean values of sand, silt and clay content (%) for land use and management systems at two depths.

LUM*	Particle size distribution (%) Sand	Silt	Clay	n
Grassland	14.69a	43.75a	41.56b	16
Cropland	13.59a	39.22a	47.19a	16
Eucalyptus	10.94[a]	38.12b	50.94a	16
Limed land	13.90[a]	39.38[a]	46.72a	16
Fallow land	8.59b	41.41[a]	50.00a	16
S.e	0.94	1.18	1.16	
Depth				
0 -10 cm	11.81ns	41.75a ± 0.62	46.44b ± 0.51	40
10 -20 cm	12.88ns	39.00b ± 0.69	48.12a ± 0.76	40
ANOVA				
LUM	***	*	***	
Depth	*Ns*	**	*	
*LUM*depth*	*Ns*	*Ns*	*ns*	

*LUM= land use/management, different letters within a column represent significant differences between different land use and management systems (Tukey's HSD procedure). The analysis of variance for each factor and their interaction is reported, p <0.001***, p <0.01** and p <0.05, n= number of samples, S.e= standard error, ns= not significant





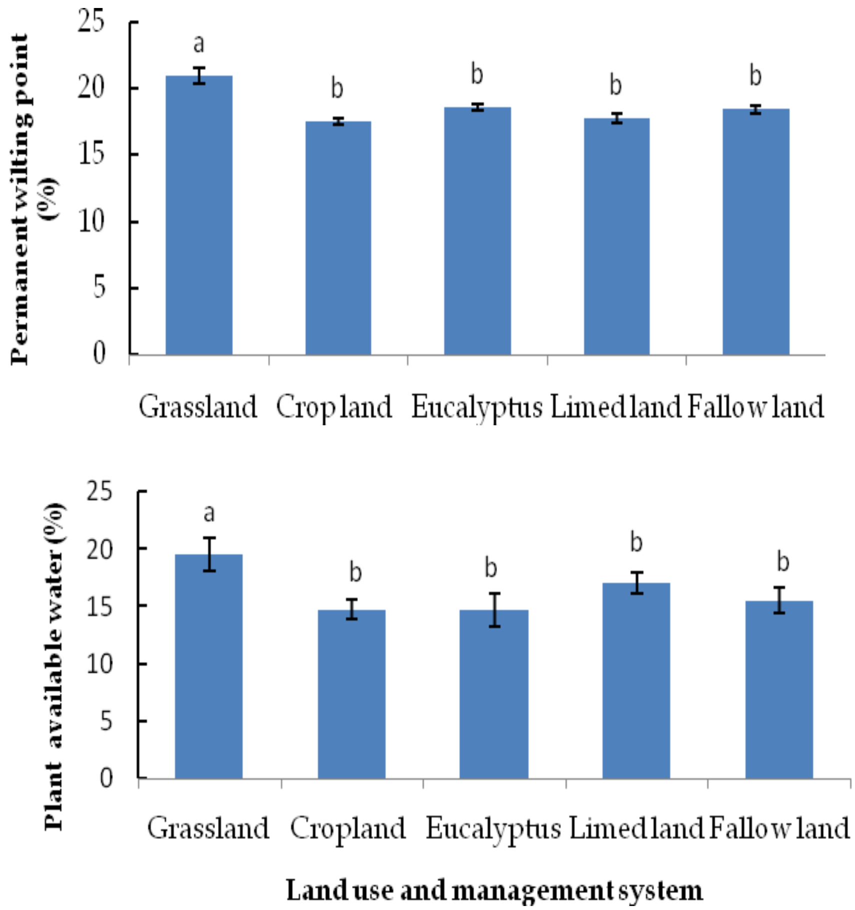


Figure 3. Effects of land use and management systems on soil bulk density, field capacity, permanent wilting point and plant available water (n=8). Different letters represent significant differences between different land use and management systems (Tukey's HSD procedure).

Soil chemical properties

Mean values of soil chemical properties as affected by different land uses and management systems at two sampling depths are presented in Table 3. Soil pH ranged from 4.3 to 4.9 indicating strongly acidic nature of the soils.

The soils under cropland, eucalyptus, limed and fallow lands contained 48, 43, 45 and 48% less SOC than grassland soils. On average a decrease of 50% in TN concentration was also observed by land conversions from grassland to other land use types. However, land use change did not affect the concentrations of Na^{+} in the soil. Statistically, cropland, eucalyptus and limed lands were similar for most of the soil chemical properties. However, EXa was significantly higher under eucalyptus plantations as compared to the other land uses and management systems. Similarly, concentrations of Ca^{2+} and Mg^{2+} were higher in grassland as compared to cropland, eucalyptus, limed land and fallow land.

The mean values of Ca^{2+} concentration in limed land, cropland, eucalyptus plantation and fallow land were comparable, though slightly higher values of Ca^{2+} were observed in limed land. Mean values of K^{+} from fallow land were higher than the other land uses and management systems. Among soil chemical properties, depth of sampling only affected AvP, EXa and Mg^{2+} Available phosphorus was considerably higher in the surface soil (0-10cm). Contrary to this, EXa and Mg^{2+} concentrations were found to be higher in 10-20 cm soil profile. Analysis of variance revealed no significant interaction between land use and depth of sampling for soil chemical properties.

Table 3. Mean values of soil chemical properties affected by different land uses and management systems (n=16) at two sampling depths (n=40).

LUM*	pH (H_2O)	SOC ------%----	TN	AvP - mg kg^{-1}-	K^+	Na^+	Ca^{2+}	Mg^{2+} --(cmol+ kg^{-1})-	CEC	EXa
Grassland	4.9a	4.4a	0.4a	5.1	0.8b	0.2ns	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										
0 -10 cm	4.6 ± 0.02^{ns}	2.8^{ns}	0.26^{ns}	5.6a ± 0.33	0.9^{ns}	0.22^{ns}	8.0^{ns}	1.9b ± 0.11	19.1 ± 0.41	1.3b ± 0.11
10 -20 cm	4.6 ± 0.35^{ns}	2.7^{ns}	0.25^{ns}	4.8b ± 0.35	0.8^{ns}	0.19^{ns}	7.9^{ns}	2.1a ± 0.11	19.4 ± 0.42	1.5.a ± 0.13
ANOVA										
LUM	***	***	***	Ns	**	ns	***	**	***	*
Depth	Ns	Ns	Ns	***	ns	ns	ns	*	ns	*
LUM*depth	Ns	Ns	Ns	Ns	ns	ns	ns	ns	ns	ns

*LUM= land use/ management, 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 variance for each land use is reported, p <0.001***, p <0.01** and p <0.05, S.e= standard error, ns= not significant

Soil biological properties

Microbial biomass carbon, MBN, MBC/MBN, MBC/SOC and MBN/TN were also affected by land use and management systems (Table 4). 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}). The mean 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 *Euclayptus* 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.

Table 4. 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).

LUM*	MBC ------------µg g^{-1} soil	MBN ---------------	MBC/MBN	MBC/SOC ------------%	MBN/TN -------------
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					
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					
LUM	***	***	***	***	***
Depth	***	***	ns	*	**
*LUM*depth*	Ns	ns	ns	ns	ns

*LUM= land use/ management.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

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.

DISCUSSION

A basic assumption in this comparative study was that initially the soils were similar in each ecosystem. Change in land use and management markedly affected several soil physical, chemical and biological properties. Soil textural class is a permanent characteristic of a soil that gives a general picture of soil's physical properties. However, in this study the change in particle size distribution due to land use change might be related to frequent tiling of cropland, fallow land and limed lands, where there is a chance of soil profile mixing as compared to grassland. In Transmexican Volcanic Belt, Covaleda *et al.* (2011) also reported that land use changes affect the particle size distribution. The lower bulk density in grassland indicates increased pore space, allowing for increased aeration necessary for biological activity. Generally, soil quality was higher in grassland than the other land uses and management. The high amount of SOC (4.3%) observed relative to other land uses or management systems contributed to the higher CEC in grassland. In the highlands of Ethiopia, deforestation and subsequent unsustainable agricultural management, as well as use of dung and crop residues for energy, have resulted in soil organic matter and nutrient depletion, hydrological instability, reduced primary productivity, and low biological diversity (Solomon *et al.,* 2002; Mulugeta *et al.,* 2005).

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. In grassland soils, much of the litter input is from root biomass (Tate *et al.,* 2000). Therefore, greater return of plant litter to soils and high root biomass of grasses could be the reason for the higher SOC in grassland. For example, in managed grasslands, between 60% and 90% of the ingested plant biomass is returned to soil in the form of manure (Haynes & Williams, 1993; Wells & Dougherty, 1997). Thus, grazed grasslands contain little plant litter (thatch), but a significant amount of SOC and TN in the soil (Bardgett *et al.,* 1996). The lower values of SOC in other land use systems could be due to less physical protection, because tillage periodically breaks up macro-aggregates and exposes previously protected organic matter (Islam & Weil, 2000). Tripathi & Singh (2009) also showed cultivation of soil previously supporting natural vegetation could lead to considerable losses of soil organic matter and microbial biomass.

Soil physical, chemical and biological parameters showed that the lowest soil quality was observed in fallow land, and it might be attributed to the current 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. In addition, crop residues are removed for domestic use, either as a source of fuel or animal feed. Such practice leaves the land bare and exposes it to surface run-off during rainy season. Many studies (e.g. Cai & Qin, 2006; Hati *et al.,* 2007; Lemke *et al.,* 2010) have shown that increases in SOC levels was directly related to the amount of organic residues added to soils. Therefore, the lowest soil fertility status (low values of pH, SOC, AvP, Mg^{2+}, Ca^{2+}, MBC and MBN) in fallow land was due to removal of crop residues and the washing away of nutrients by intense rainfall during fallow period.

The study clearly demonstrated that applications of lime significantly raised soil pH, and drastically reduced exchangeable aluminum. 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 aluminum hydroxide and water, 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 (Prado *et al*., 2007; Álvarez & Fernández, 2009). However, highly weathered acid soils in the study area would not recover rapidly after short-term fallow periods of 18 months. 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 physical and chemical parameters is not clear, and needs further investigation. However, Danju *et al.* (2012) reported restoration of soil fertility following plantation of *Eucalyptus grandis* in south-western China. In their study, they found that SOC content, C to N ratio, and MBC and MBN concentrations showed an initial phase of decline and then increased significantly over time in the upper soil layers of *E. 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 AWC in the highland of north western Ethiopia.

Soil microbial biomass and its related parameters such as MBC/SOC and MBN/TN have been used in comparing different land use types and are considered as early indicators of soil quality attributes, particularly when comparing lands under different agricultural uses (Chen *et al.,* 2010; Kaschuk *et al.,* 2010). In this study, differences in MBC, SOC, MBC/SOC, MBN and TN for the five land use and management systems were observed. The most important biological soil properties such as MBC/SOC and MBN/TN showed lower values in fallow lands and croplands relative to grasslands or limed lands. 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. The ratios of MBC to SOC has been suggested as a sensitive indicator of soil organic matter changes (Anderson & Domsch, 1989; Sparling, 1992), partly because the ratio will normalize some of the variability caused by temporal fluctuations in microbial biomass (Rice, *et al*., 1996). A low MBC/SOC indicates a reduced pool of available carbon in soil (Klose *et al*., 2004). Therefore, this work suggested that the ratio of MBC to SOC and MBN to TN could be useful tools to assess biological soil quality differences due to the conversion of grasslands to other land use and management systems in highly weathered acidic soils of the central highlands of Ethiopia. However, we cannot ascertain the universality of these results across a wide range of acidic soils due to variation in climate, soil types and land use and management systems.

CONCLUSIONS

As evidenced from soil physical, chemical and biological properties, conversions of grasslands to either cropland or eucalyptus plantations or fallowing in the central highlands of Ethiopia deteriorate the functional capacities of soils. Particularly, the lower values of biological attributes observed in these land uses and management system could be an early indication of soil quality deterioration. Soil organic carbon, the ratio of MBC to SOC and MBN to TN 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. Therefore, integration of these parameters with soil chemical properties is considered to be more useful than only chemical/physical properties in describing soil quality of the area. The traditional way of restoring soil fertility by fallowing land after a cropping period of 18 months would jeopardize further the functional capacities of soils to irrevocable levels in the long-term. These results, therefore, seriously dispute the current short-term fallowing practice by small-scale farmers in the study area. 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 with phosphate fertilizers and/manure would be sustainable options for the current soil acidity problem that has resulted in land use change.

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REFERENCES

Alvarez E, Viadé A, Fernández ML. 2009. Effect of liming with different sized limestone on the forms of aluminium in a Galician soil (NW Spain). *Geoderma* 152: 1–8.

Anderson TH, Domsch KH. 1989. Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil Biology & Biochemistry* 21: 471-479.

Ashagrie Y, Zech W, Guggenberger G. 2005. Transformation of a *Podocarpus falcatus* dominated natural forest into a monoculture *Eucalyptus globulus* plantation at Munesa, Ethiopia: Soil C, N and S dynamics in primary particle and aggregate-size fractions. *Agriculture, Ecosystems & Environment* 106: 89-98.

Aziz I, Ashraf M, Mahmood T, Islam KR. 2011. Crop rotation impact on soil quality. *Pakistan Journal of Botany* 43: 949-960.

Bardgett RD, Hobbs PJ, Frostegard A. 1996. Changes in soil fungal:bacterial biomass ratios following reductions in the intensity of management of an upland grassland. *Biology and Fertilty of Soils* 22: 261-264.

Bouyoucos GJ. 1962. Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal* 54: 464-465.

Black, C.A., D.D. Evans, J.L. White, L.E. Ensminger and F.E. Clerk, 1965. In *Method of Soil Analysis*. American Society of Agronomy Inc., Madison, WI., USA.

Bremner JM, Mulvaney CS. 1982. Total Nitrogen. In *Methods of Soil Analysis, Part II. Miller AL, Keeney RH (eds)*. ASA and SSSA: Madison WI; 595-624.

Brookes PC, Landman G, Jenkinson DS. 1985. Chloroform fumigation and release of soil nitrogen, a rapid extraction method to measure microbial nitrogen in soil. *Soil Biology & Biochemistry* 17:837-842.

Cai ZC, Qin SW. 2006. Dynamics of crop yields and soil organic carbon in a long-term fertilization experiment in the Huang-Hui-Hai plain of China. *Geoderma* 136: 708-715.

Cassel DK, Nielsen DR. 1986. Field capacity and available water capacity. In *Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods-Agronomy Monograph no. 9,* 2nd edn, Klute A (ed.). 901-926.ASA and SSSA: Madison, WI.

Chapman HD. 1965. Cation Exchange Capacity. In *Methods of Soil Analysis-Agronomy Monograph no. 9,* 2nd edn, Black, C.A. (ed.). 891-901. ASA and SSSA: Madison, WI.

Covaleda S, Gallardo, JF, Garcia-Oliva, F, Kirchmann H, Prat C, Bravo M, Etchevers JD. 2011. Land use effects on distribution of soil organic carbon within particle-size fractions of volcanic soils in the Transmexican Volcanic Belt. *Soil use and management* 27: 186-194.

Danju Z, Jian Z, Wanqin Y, Wu F. 2012. Effects of afforestation with *Eucalyptus grandis* on soil physicochemical and microbiological properties. *Soil Research* 50: 167-176.

Doran JW, Jones AJ. 1996. Methods for assessing soil quality. *Soil Science Society of America Special Publication, vol. 49.* ASA and SSSA: Madison, WI.

Emadi M, Baghernejad M, Fathi H, Saffari M. 2008. Effect of Land Use Change on Selected Soil Physical and Chemical Properties in North Highlands of Iran. *Journal of Applied Sciences* 8: 496-502.

Fliessbach A, Oberholzer HR, Gunst L, Mãder P. 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. *Agriculture, Ecosystems and Environment* 118: 273-284.

Hati KM, Swarup A, Dwivedi AK, Misra AK, Bandyopadhyay KK. 2007. Changes in soil physical properties and organic carbon status at the top soil horizon of a vertisol of central India after 28 years of continuous cropping, fertilization and manuring. *Agriculture Ecosystems and Environment* 119: 127-134.

Haynes RJ, Williams PH. 1993. Nutrient cycling and soil fertility in the grazed pasture ecosystem. *Advances in Agronomy* 49: 119-199.

Imaz MJ, Virto I, Bescansa P, Enrique A, Fernandez-Ugalde O, Karlen DL. 2010. Soil quality indicator response to tillage and residue management on semi-arid Mediterranean cropland. *Soil & Tillage Research* 107: 17-25.

Islam KR,Weil RR. 2000. Soil quality indicator properties in mid-Atlantic soils as influenced by conservation management. *Journal of Soil Science and Plant Analysis* 29: 2269 -2284.

IUSS Working Group WRB. 2006. World reference base for soil resources 2006. *World Soil Resources Reports No. 103*. FAO, Rome.

Kaschuk G, Alberton O, Hungria M. 2010. Three decades of soil microbial biomass studies in Brazilian ecosystems: lessons learned about soil quality and indications for improving sustainability. *Soil Biology & Biochemistry* 42: 1-13.

Klose S, Wernecke KD, Makeschin F. 2004. Soil microbial biomass and enzyme activities in forest soils exposed to atmospheric depositions from a lignite power plant. *Soil Biology & Biochemistry* 36: 1913-1923.

Lee CH, Wu MY, Asio VB, Chen ZS. 2006. Using a soil quality index to assess the effects of applying swine manure compost on soil quality under a crop rotationsystem in Taiwan. *Soil Science* 171: 210-222.

Lemke RL, VandenBygaart AJ, Campbell CA, Lafond GP, Grant B. 2010. Crop residue removal and fertilizer N: Effects on soil organic carbon in a long-term crop rotation experiment on a Udic Boroll. *Agriculture, Ecosystems & Environment* 135: 42-51.

Lepsch IF, Menk JRF, Oliveria JB. 1994. Carbon storage and other properties of soils under agriculture and native vegetation in São Paulo State, Brazil. *Soil use and management* 10: 34 -42

Masse D, Manlay RJ, Diatta M, Pontanier R, Chotte JL. 2004. Soil properties and plant production after shor-term fallows in Senegal. *Soil Use and Management* 20: 92-95.

Mubarak AR, Elshami OME, Azhari AA. 2005. Long- and short-term effects of cultivation on properties of a Vertisol under sugarcane plantation. *Soil & Tillage Research* 84: 1-6.

Mulugeta L, Karltun E, Olsson M. 2005. Soil organic matter dynamics after deforestation along a farm field chronosequence in southern highlands of Ethiopia. *Agriculture, Ecosystems and Environment* 109: 9-19.

Olsen SR, Sommers LE. 1982. Phosphorus. In *Methods of Soil Analysis.* Part II: Chemical and Microbiological properties. *Miller AL, Keeney RH (eds)*. 403-427. ASA and SSSA: Madison, WI.

Olson J, Salome M, David JC, Mbonile M, Mugisha S. 2012. A Research Framework to Identifying the Root Causes of Land Use Change Leading to Land Degradation and Changing Biodiversity. *LUCID Project Working Paper 48*. Available online: http://www.lucideastafrica.org/publications/ Olson_LUCID_WP48.pdf (accessed on 16 March 2014).

Parr JF, Papendick RI, Hornick SB, Young RE. 1992. Soil quality: Attributes and relationship to alternative and sustainable agriculture. *American Journal of* Alternative Agriculture 7: 5-16.

Pesek J. 1994. Historical perspective. Sustainable Agriculture Systems. In *Hatfield, JL., Karlen, DL. (eds.)*. CRC Press, Boca Raton, FL.

Prado RM, Natale W, Rozane DE. 2007. Soil-liming effects on the development and nutritional status of the carambola tree and its fruit-yielding capacity. *Communications in Soil Science and Plant Analysis* 38: 493-511

Reyes-Reyes BG, Alcantara-Hernandez R, Rodriguez V, Olalde-Portugal V, Dendooven L. 2007. Microbial biomass in a semi arid soil of the central highlands of Mexico cultivated with maize or under natural vegetation. *European Journal of Soil Biology* 43: 180-188.

Rice CW, Moorman T, Beare M. 1996. Role of microbial biomass C and N in soil quality. Chapter 12 In: J.W. Doran (eds.). Handbook of Methods for Assessing Soil Quality.

Rongjiang Y, Jingsong Y, Peng G, Jianbing Z, Wenhui J. 2013. Determining minimum data set for soil quality assessment of typical salt-affected farmland in the coastal reclamation area. *Soil & Tillage Research* 128: 137-148.

Sanchez PA, Palma CA, Buol SW. 2007. Fertility capability soil classification: a tool to help assess soil quality in the tropics. *Geoderma* 114: 57-185.

Sharma KL, Mandal UK, Srinivas K, Vittal KPR, Mandal B, Grace JK, Ramesh V. 2005. Long-term soil management effects on crop yields and soil quality in a dryland Alfisol. *Soil & Tillage Research* 83: 246-259.

Shukla MK, Lal, R, Ebinger M. 2004. Soil quality indicators for reclaimed mine soils in southeastern Ohio. *Soil Science* 169: 195-205.

Shukla, MK, Lal R, Ebinger M. 2006. Determining soil quality indicators by factor analysis. *Soil & Tillage Research* 87: 194-204.

Solomon D, Fritzszhe F, Lehmann J, Tekalign M, Zech W. 2002. Soil organic matter dynamics in the sub-humid agro-ecosystems of the Ethiopian Highlands: Evidence from 13_C abundance and particle size fractionation. *Soil Science Society of America Journal* 66: 969-978.

Sparling GP. 1992. Ratio of microbial biomass to soil organic carbon as a sensitive indicator of changes in soil organic matter. *Australian Journal of Soil Research* 30: 195-207.

Tate KR, Scott NR, Ross DJ, Parshotam A, Claydon JJ. 2000. Plant effects on soil carbon storage and turnover in a montane beech (Nothofagus) forest and adjacent tussock grassland in New Zeland. *Australian Journal of soil research* 38: 685-698.

Teklu E, Fisseha I, Karl S. 2006.Tillage effects on sediment enrichment, soil quality, and crop productivity in Ethiopian Highlands. *Australian Journal of Soil Research* 44:753-758.

Temesgen D, Cruz F, Kindu M, Turrión MB, Gonzalo J. 2014. Land-use/land-cover (LULC) change and socioeconomic conditions of local community in the central highlands of Ethiopia. *International Journal of Sustainable Development and World Ecology* DOI: 10.1080/13504509.2014.961181.

Tilashwork C. 2009. The effect of eucalyptus on crop productivity, soil properties in the Koga watershed, western Amhara, Ethiopia, M.Sc. Thesis submitted to the Faculty of the Graduate School of Cornell University, USA.

Tripathi N, Singh RS. 2009. Influence of different land uses on soil nitrogen transformations after conversion from an Indian dry tropical forest. *Catena* 77: 216-223.

Tye AM, Robinson DA, Lark RM. 2013. Gradual and anthropogenic soil change for fertility and carbon on marginal sandy soils. *Geoderma* 207-208: 35–48.

Vance ED, Brookes PC, Jenkinson DS. 1987. An extraction method for measuring soil microbial, biomass C. *Soil Biology & Biochemistry* 19: 703-707.

Walkley A, Black CA. 1934. An examination of the Degtjareff method for determining soil organic matter, and proposed modification of the chromic acid titration method. *Soil Science* 37: 29-38.

Wells KL, Dougherty CT. 1997. Soil management for intensive grazing. *Soil Science News Views* 18: 1-6.

Yimer F, Ledin S, Abdelkadir A. 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 & Management* 242: 337-342.

Yimer F, Ledin S, Abdelkadir A. 2008. Concentrations of exchangeable bases and cation exchange capacity in soils of cropland, grazing and forest in Bale Mountains, Ethiopia. *Forest Ecology & Management* 256: 1298-1302.