Variation in soil properties under different land use types managed by smallholder farmers in central Ethiopia

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ABSTRACT

Land use change causes a remarkable change in soil properties. The nature of change depends on multiple factors such as soil type, type and intensity of land use, climate, and the like. It is essential to study and understand how these factors interact and affect soil properties. In this study, we investigated the variation in soil physicochemical properties across five common land use practices, i.e. enset system, farmland, and grazing-land (closed and open), and Eucalyptus woodlots practiced on originally same soil type and comparable topographic and climatic settings. A total of 105 soil samples from three depths of 0–15 cm, 15–30 cm, and 30–45 cm were collected and analyzed for selected soil physicochemical properties. The results showed significant differences between the land uses in soil physical and chemical properties. Enset system had higher pH, available phosphorus (P), exchangeable potassium (K⁺), soil organic carbon (SOC), and total nitrogen (TN) and their stocks than other land use types. Further, the widely accepted notion of the alleged effects of Eucalyptus tree on soil nutrient composition was not demonstrated in this study except its lower pH of (5.61) and soil moisture contents of (26.14%) than other land use types over 15–20 years old. SOC stocks showed a decreasing trend of enset system (127.36 Mg ha⁻¹) > closed grazing land (108.07 Mg ha⁻¹) > eucalyptus woodlot (92.55 Mg ha⁻¹) > open grazing-land (88.57 Mg ha⁻¹) > cereal farm (76.65 Mg ha⁻¹) at 0–45 cm soil depth, implying the potential of enset system for climate changes mitigation. TN was also measured in the same trend. Overall, some land use systems (e.g. enset agroforestry) improve the soil biophysical and chemical properties, while others such as cereal production degrade the soil. The low input continuous cultivation of cereal farm land coupled with its poor soil conservation measures in the area could be the major factors for the depletion of soil nutrient in cereal farming. Hence, future soil management strategies should be focused on mitigating the continuous loss of soil nutrients from the dominantly practiced cereal cropping system through the retention of crop residues, practice of crop rotation and scaling-up agro-forestry practice.

1. Introduction

Soil degradation is a major agricultural and environmental problem impacting agricultural productivity and food security in Ethiopia (Agegnehu et al., 2013; Haileslassie et al., 2006; Tesfahunegn, 2013). Specifically, soil fertility in smallholder farms remains a major issue in developing countries like Ethiopia where more than 90% of their population depends on agriculture for food and livelihood (Agidew and Singh, 2018). However, high rate of soil erosion, over cultivation, suboptimal use of fertilizers and inappropriate land use and soil management practices among others have contributed significantly to the decline of the soil quality through deteriorating soil physical, chemical and biological properties. Most agricultural soils in highland of Ethiopia experiencing persistent loss of soil fertility due to high rate of soil erosion, chemical degradation (loss of nutrients through crop removal, erosion, leaching, etc.), physical deterioration (surface sealing, crust ing), and biological degradation (decline of soil humus content) and consequently leading to their decline in agricultural productivity (Lemenih et al., 2005; Negasa et al., 2017).

Most of the smallholder farmers in the highland of Ethiopia practice a mixed crop-livestock-tree farming system where they allocate portion of their holdings to crops, grazing lands and tree cultivations. Mixed farming system has evolved as a result of regional differences in climate, population density, diseases, economic opportunities and cultural practices (Agidew and...
Singh, 2018). Such practices serve two purposes: reduce risk and supply diverse products needed to sustain the households. Financial limitation to buy sufficient external inputs, distance from home and shortage of organic fertilizers enforces smallholder farmers to prioritize application of organic and inorganic fertilizers to important portion of their farm fields, which lead to formation of heterogeneous soil fertility between plots and within plots of land (Duguma et al., 2009; Haileslassie et al., 2006; Tittonell et al., 2005). The complex farming system practiced in densely populated southern highlands of Ethiopia displays a good example of such fertility gradient within and between plots (Duguma et al., 2010; Negasa et al., 2016).

Farmers in southern Ethiopia grow the staple food crop Enset ventricosum (Welw.). Cheesman together with multipurpose trees close to their homestead and fertilizes it with manure, while out farms grown with annual crops such as maize (Zea mays L.), and wheat (Triticum aestivum L.), teff (Eragrostis tef (Zucc.) Trotter), and barely (Hordeum vulgare L.) and are fertilized with inorganic fertilizer (Haileslassie et al., 2006; Mellisse, 2017). Enset is a perennial herbaceous species of flowering plant in the banana family, Musaceae, and which is used as a staple food for over 20 million people via its starch-rich corm and pseudostem (Borrell et al., 2020).

Besides, management practices applied to the fields such as plowing frequency, level of crop residue removal and the like varies between these plots all of which are likely to influence the physicochemical and biological properties of soils (Adugna & Abegaz, 2016; Duguma et al., 2009; Ketema and Yimer, 2014; Negasa et al., 2016).

In the highland of Ethiopia including in the study area many smallholder farmers practice a diverse land use systems by partitioning their holding into different land use systems, such as enset system, farmland, and grazing land (both closed and open) and woodlots. These different land use systems and their management practices obviously influence soil properties of each system, which is worth investigating.

The effects of land use on soil properties could be vary depending on several factors such as slope, soil types, soil depth, land use and their management (Duguma et al., 2010; Kebebew et al., 2022; Melak Tamene et al., 2020; Negasa et al., 2016). For instance, the latter authors had reported a significant variation in soil properties among different land use, which could be caused due to difference in level of cultivation and south central Ethiopia. Therefore, land use change can alter the soil chemical and physical properties either positively or negatively. Understanding the impacts of land use changes on soil properties is vital in determining the types of land and soil management practices that could be implemented by smallholder farmers for improving the soil health and improve agricultural productivity and to enhance household resilience to mitigate climate changes. Several studies have investigated land use effects on soil properties and but results of many earlier studies are inconsistent with some who reported significant effects of land use on soil properties (Duguma et al., 2009; Negasa et al., 2016) and in contrast other studies indicated non-significant effect of land use on soil chemical properties (Alemayehu and Sheleme, 2013; Getachew et al., 2013; Wolde et al., 2014). For instance, (Amede; Haileslassie et al., 2006) reported the significant positive effects of enset land use and closed grazing land on soil chemical properties compared to cereal farm land and open grazing land. In contrast other studies (e.g. Alemayehu and Sheleme, 2013 Wolde et al., 2014) found no significant difference in soil chemical properties among them.

On top of that, the effects of integrating exotic tree like Eucalyptus in farming system are still controversial. Some studies (e.g. Getachew et al., 2013; Shepherd et al., 2000) found alleged effects of Eucalyptus through reducing soil pH, decline in basic cation and drying soil moisture while other studies (e.g. Asfaw and Agren, 2007; Duguma et al., 2010) reported improvement on soil properties.

Such variations in soil properties among land use could be emerged from effects of biophysical and socio-economic setting of smallholder farmers, and their experience in managing land and soil, which are quite different. Therefore, it is important to assess the variation in soil physical and chemical properties due to difference in land use types and their management.

In the current study area of Meskan District, farm households are using their holdings by partitioning into different land use however, there are few studies that considered the effects of these land use on soil properties. Thus, there is a need to know what differences exist in soil properties due to difference in land uses. The main objectives of this study were, therefore, to: (1) evaluate the impacts of different land use systems, including enset system, eucalypts woodlot, grazing (open and closed), and cereal farmland on physicochemical properties of the soils; (2) identify land and soil management practices favorable for nutrient accumulation and responsible for nutrient depletion under current land use and management practices in southern Ethiopia; and (3) examine biophysical and socio-economic factors that influence soil fertility management in the study area.
2. Materials and methods

2.1. Study area

The study was conducted in Meskan District of Gurage Zone, southern Ethiopia, located between 38°15'0.7"– 38°33'50.9" E and 8°1' 58.8"–8°16' 29.6" N (Figure 1). The altitude of the study site ranges between 2000 and 2200 m.a.s.l. The topography of the study site is characterized by flat to undulating with slope ranging from 0 to 5%. The dominant soil types of the study area include utric Cambisols, chromic Luvisols, chromic Vertisols, eutric Fluvisols, Leptosols and pellic Vertisols (FAO, 2015). Traditionally, soils of the study area are classified into three major soil types: black, brown and red soil, which account for about 53%, 25%, and 22%, respectively (Haile et al., 2016).

The rainfall distribution is bimodal with long (July to August) and short (March to September) rainy season (Figure 2). The area receives the mean annual rainfall of 1167 mm and average monthly maximum and minimum temperatures were 27.3°C and 10°C, respectively (Figure 2).

The indigenous trees that are commonly found in the study area are Acacia abyssinica, Croton machrostachys, Cordia africana, and economically important exotic trees, mainly Eucalyptus species. The study area is characterized by a subsistence mixed crop-livestock farming system. Maize, teff, and wheat are the commonly grown annual crops and enset from perennial crops. The annual cereal system covered 52.68% of the farmland, while the enset system, grazing land, and Eucalyptus woodlots covered 26.49%, 12.68% and 8.17%, respectively (Haile et al., 2016).

2.2.3. Soil sampling design and soil sample collection

Mekicho Kebele, the lowest administrative unit in Ethiopia, which is shown in Figure 1, was selected based on the presence of different land use systems. Seven households who possess different land use such as enset field, farmland, grazing land and Eucalyptus woodlots were selected purposely from three nearby villages for soil sampling. The five adjacent land use systems were esnet system (Figure 5), grazing systems (Figure 4) (both open and closed), annual cereal system, and eucalyptus woodlot (Figure 3).

Soil samples were taken from each land use system at a depth of 0–15 cm, 15–30 cm, and 30–45 cm from adjacent land use types having similar soil type (clay loam) and climate (mid altitude) and slope (0–5%) to avoid confounding factors (Table 1). For bulk soil density determination, soil samples were collected from same pits at the three soil depths (0–15 cm, 15–30 cm and 30–45 cm) from opposite sides of the pits using soil core sampler of 5 cm height by 3 cm diameter. From the five different land use types of each farm household, soil samples were taken at three levels of depths. Totally 105 disturbed and undisturbed soil samples were taken for soil chemical and physical analysis, respectively.
2.3 Soil laboratory analysis

The physical and chemical properties of soils were determined using standard soil lab analytical procedures in Holetta soil and plant testing laboratory. Soil samples were air-dried and ground to pass through a 2 mm sieve for analysis of soil texture, soil pH, available phosphorus, exchangeable bases (Ca$^{2+}$, Mg$^{2+}$, K$^+$, and Na$^+$), and cation exchange capacity (CEC), for organic carbon and total nitrogen analysis soil samples were ground to pass through 0.5 mm sieve. Soil pH was determined at 1:2.5 (soil:water ratio), soil organic carbon (OC) by wet combustion method (Walkley and Black,
and total nitrogen by Kjeldahl digestion, distillation and titration method (Anderson & Ingram, 1993). Soil available phosphorus was determined using Olsen method (Olsen et al., 1954). Soil Cation Exchange Capacity (CEC) was determined using ammonium acetate saturation method at pH 7.0 (Anderson & Ingram, 1993) and exchangeable potassium (K⁺) was determined by ammonium acetate extraction method using the flame photometer (Anderson & Ingram, 1993). The particle size analysis was made using hydrometer method and the soil textural classification was determined using USDA textural triangle. Soil bulk density was determined through volumetric method after the soil was oven dried at 105 °C for 24 h as described by Yerima and Van Ranst (2005a, b) Soil-moisture content was determined by gravimetric methods after the soil was oven-dried at 105 °C for 30 h (Anderson & Ingram, 1993). The carbon and nitrogen stocks ha⁻¹ was calculated using the following formula by substituting N content at C content in the formula for nitrogen stock.

\[
\text{Carbonstock} (\text{MgCha}^{-1}) = \text{Cconcentration(%) } \\
\times \text{BD(gcm}^{-1}) \\
\times \text{soildepth(cm)} \times 100
\]

In addition, semi-structured interviews, visual observations and informal discussions were held with farmers in and around the study area to capture additional information such as their perception on the effects of soil fertility gradients, effects of eucalyptus on soil and crop yield and identify the types of soil and water conservation practices.

2.4. Statistical analysis

The results of the physical and chemical properties, and carbon and N stocks were subjected to GLM test with two-way analysis of variance using SPSS version 16 to test the effects of land use, soil depth and their interaction on soil chemical and physical properties using the following model.

\[
P_{ijk} = \mu + Y_i + R_{j(i)} + T_k + TY_{(ik)} + e_{ijk}
\]
Where $P_{ijk}$ is total observation, $\mu =$ grand mean, $Y_i$ = effect of the land use, $R_{E(i)}$ is the effect of the $i^{th}$ replication or household, $T_g$ is the effect of the soil depth, $T_{Y(ik)}$ is the interaction of land use and soil depth and $e_{ij}$ is the random error.

The means for treatments that showed significant differences by F-test were separated by Tukey’s honestly significant difference test (Tukey-HSD test) and a significance level was declared with $P < 0.05$. Prior to statistical analysis we performed Levene’s test to check for the homogeneity of variances (homogenous in all cases). To meet the assumptions of normal distribution and homogeneity of variances, data on available $P$ was log transformed before statistical analysis was undertaken and reported after back transformed.

3. Results

3.1 Impacts of land uses on soil physical properties

Land use had significant effects on soil physical properties mainly textural fraction, soil moisture and bulk density (Table 2; Annex). Clay fraction differed significantly among land use types but the sand and silt fraction did not vary between the different land use systems (Table 2; Annex). Significantly higher clay proportions of 41.96 ± 1.25% and 40.9 ± 1.96 were observed in farmland and closed grazing land, respectively while the lowest clay proportion of 35 ± 1.85% was recorded from enset field (Table 2). Although the clay fraction varied between land use types, the soil textural class in the study area is classified as clay loam as per USDA classification. Land use types had a significant effect on gravimetric soil moisture content (Table 2; Annex). Similar to clay fraction, cereal farmland and closed grazing land had significantly higher gravimetric soil moisture contents of 32.41 ± 1.19% and 34.79 ± 1.19%, respectively, while the adjacent soils under woodlots had low a moisture content of 26.14 ± 1.19 % (Table 2). Cereal farmland had significantly higher bulk density of 1.22 ± 0.02 g cm$^{-3}$ than other land use system (Table 2).

3.2 Impact of land use types on soil chemical properties

Table 1. Description of the studied land use types in the central highlands of Ethiopia

| Description | Land use types |
|-------------|----------------|
| Enset system | Enset system is field located close to home and used for growing enset plant and often fertilized with manure and other household waste for more than 50 years. Enset is a perennial herbaceous species of flowering plant in the banana family, Musaceae and one of the staple crops which has been feeding about 20 million peoples in southern Ethiopia. It also hosts diverse multipurpose tree, shrub as well as crops and grass. |
| Closed grazing land | Closed grazing land is privately owned pasture land located far from home. Served as pasture land for more than 50 years. It is used as closed grazing land in wet season (June-November) and open grazing land in dry season. It is located down the slopes; hence it is subjected to waterlogging during wet season. |
| Open grazing land | Open grazing land is privately owned pastureland, located close to home and used as open grazing land for more than 25 years. It is established on the degradedfarm land and often few park land trees are retained where the cattle use as shade during the day time. |
| Eucalyptus Woodlots | Woodlot is small-scale plantation of Eucalyptus camaldulensis. It is established on the degraded cropped land where farmers abandoned because of their poor soil fertility some 15–17 years ago. |
| Cereal farmland | Cereal farmland is a low input cereal cropping system, located far from home and dominantly used for growing annual cereal crops such as wheat, teff, and maize. The field has been used for cereal farming for more than 50 years and fertilized with inorganic fertilizers (DAP and Urea). It is intensively and frequently plowed, and crop residues are often removed for feed and fuel. |

Table 2. Soil physical properties across different land use types at 0 – 45 cm soil depth in central Ethiopia

| Soil property | Enset System | Closed grazing land | Open grazing land | Eucalyptus Woodlots | Cereal farmland |
|---------------|--------------|---------------------|------------------|---------------------|-----------------|
| Clay (%)      | 35 ± 1.85b   | 40.9 ± 1.96a        | 35.7 ± 1.95ab    | 35.7 ± 1.95ab       | 41.96 ± 1.25a   |
| Silt (%)      | 35 ± 2a      | 35.3 ± 2.2a         | 37.88 ± 2.2a     | 38.5 ± 2a           | 30.64 ± 2a      |
| Sand (%)      | 30 ± 2a      | 23.57 ± 2.2a        | 26.44 ± 2.2a     | 25.674 ± 2a         | 27.39 ± 2a      |
| Textural class | Clay loam    | Clay loam           | Clay loam        | Clay loam          | Clay loam      |
| MC (%)        | 31.1 ± 1.19ab| 34.79 ± 1.19a       | 29.9 ± 1.19c     | 26.14 ± 1.19c       | 32.41 ± 1.19 ab|
| BD (g cm$^{-3}$) | 1.15 ± 0.09ab| 1.14 ± 0.09a        | 1.19±0.09ab      | 1.15 ± 0.09ab       | 1.23 ± 0.09a    |

*Values followed by the same letters in a row are not significantly different at $P < 0.05$; MC and BD refer to moisture content and bulk density, respectively.
exchangeable K⁺ has shown significant (P < 0.05) difference among land use types (Table 3). The soil exchangeable K of enset field was about five times higher than the closed grazing land, and it was 2.8, 2.4 and 1.9 times higher than the farmland, eucalyptus woodlots and open grazing land, respectively (Table 3). The soil OC and total N stocks showed a decreasing trend with increasing soil depths regardless of the land use types (Table 4). The upper soil depth had higher SOC and total N for the five land use types. The enset system had the highest SOC stock of 42.45 ± 20.00 Mg C ha⁻¹ followed by the closed grazing land (36.02 ± 2.8 Mg C ha⁻¹). Eucalyptus woodlots and open grazing land had the SOC stocks of 30.85 ± 1.8, and 29.52 ± 2 Mg C ha⁻¹, respectively, while the cereal land had the lowest soil carbon stock of 25.55 ± 1.3 Mg C ha⁻¹ (Table 4). The total N stock also showed a similar trend, which was higher in enset farm and closed grazing land, but it was the lowest in the cereal farmland (Table 4).

Enset field had the highest soil OC stock of 127.36 Mg ha⁻¹, followed by the closed grazing land (108.07 Mg ha⁻¹). Open grazing land and woodlots had soil OC stocks of 92.55 and 88.57 Mg ha⁻¹, respectively, while soil under the cereal farmland had the lowest carbon stock of 76.65 Mg ha⁻¹ within 0–45 cm. Similarly, enset system had the highest TN stock of 10.6 Mg ha⁻¹, followed by the TN stock of 9.47 Mg ha⁻¹ in the closed grazing land, while open grazing land and woodlots had the TN stocks of 8.04 and 7.56 Mg ha⁻¹ and the soil under cereal farmland had the lowest carbon stock of 6.73 Mg ha⁻¹.

### 4. Discussion

#### 4.1 Soil physical properties

The variation in land use had significant effects on soil texture where higher clay fraction was recorded in closed grazing land and farmland than other land uses. Similar studies conducted elsewhere in Ethiopia indicated the significant effect of land use on textural fraction of clay, sand and silt (Awdenegest et al., 2013; Haileslassie et al., 2006; Negasa et al., 2016; Yimer et al., 2008). Other researchers also reported higher clay fraction on cereal farm land compared to other land uses (Adugna & Abegaz, 2016; Negasa et al., 2016). The possible cause for higher clay fraction in cereal farmland and closed grazing land could be attributed to systematic land use allocation and micro-site variability within sampling sites where enset is planted on the non-waterlogged upper slope-belt whereas closed grazing land and farmland in waterlogged down slopes. The lower slopes are usually known for their higher clay content than upper slopes due to the transportation of fine particles down to the slope through the process of

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### Table 3. Soil chemical properties across different land use types at 0 – 45 cm soil depth in central Ethiopia

| Soil property | Enset system | Closed grazing land | Open grazing land | Eucalyptus Woodlots | Cereal farmland |
|---------------|--------------|---------------------|-------------------|---------------------|-----------------|
| OC (%)       | 2.48 ± 0.67a | 2.23 ± 0.98ab       | 1.67 ± 0.63c      | 1.79 ± 0.44bc       | 1.39 ± 0.3c     |
| TN (%)       | 0.21 ± 0.06a | 0.20 ± 0.08ab       | 0.14 ± 0.06c      | 0.16 ± 0.04bc       | 0.12 ± 0.03c    |
| Av. P (mg kg⁻¹) | 187.52 ± 15.8a | 18.12 ± 1.5b   | 62.49 ± 10.2b     | 52.55 ± 5.5b        | 44.87 ± 5.6b    |
| pH           | 6.38 ± 0.46a | 5.81 ± 0.64ab      | 6.12 ± 0.57ab     | 5.61 ± 0.57b        | 6.82 ± 0.64ab   |
| K⁺ (cmole kg⁻¹) | 1.63 ± 0.46a | 0.32 ± 0.02b       | 0.85 ± 0.26ab     | 0.68 ± 0.03ab       | 0.36 ± 0.04bc   |
| CEC (cmole kg⁻¹) | 29.45 ± 1.03a | 29.64 ± 0.85a     | 28.93 ± 1.09a     | 29.03 ± 0.7a        | 29.09 ± 0.88a   |

*Values followed by the same letters in a row are not significantly different at P < 0.05; where OC – organic carbon; TN – total nitrogen, Av P – available phosphorus; K⁺ – exchangeable potassium; and CEC – cation exchange capacity.

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### Table 4. Effects of land use types on soil organic carbon (SOC) and total nitrogen (TN) stocks in central Ethiopia

| Soil Property | Soil depth (cm) | Enset system | Closed grazing land | Open grazing land | Eucalyptus Woodlots | Cereal farm land |
|---------------|----------------|--------------|---------------------|-------------------|---------------------|-----------------|
| SOC (Mg/ha)   | 0–15           | 49.41 ± 2.0  | 49.25 ± 5.58        | 36.47 ± 7.8       | 37.17 ± 4           | 27.59 ± 2.24    |
|               | 15–30          | 43.11 ± 4.91 | 32.67 ± 2.5         | 28.06 ± 2.35      | 29.15 ± 2.16       | 25.34 ± 3.38    |
|               | 30–45          | 34.86 ± 4.17 | 26.15 ± 1.99        | 24.05 ± 2.13      | 26.23 ± 1.46       | 23.72 ± 6.97    |
| Mean          |                | 42.45 ± 2.5a | 36.02 ± 2.8ab       | 29.52 ± 2bc       | 30.85 ± 1.8bc      | 25.55 ± 1.3c    |
| Total         |                | 127.36 ± 7.54a | 108.07 ± 8.7ab     | 88.57 ± 7.9bc     | 92.55 ± 5.54bc     | 76.65 ± 3.8c    |
| TN (Mg/ha)    | 0–15           | 4.11 ± 0.4   | 4.31 ± 0.5          | 3.18 ± 0.68       | 3.23 ± 0.32        | 2.49 ± 0.026    |
|               | 15–30          | 3.55 ± 0.68  | 2.76 ± 0.3          | 2.32 ± 0.22       | 2.47 ± 0.2         | 2.12 ± 0.18     |
|               | 30–45          | 2.94 ± 0.36  | 2.4 ± 0.47          | 2.06 ± 0.16       | 2.34 ± 0.14        | 2.13 ± 0.18     |
| Mean          |                | 3.53 ± 0.21a | 3.16 ± 0.12ab       | 2.52 ± 0.25bc     | 2.68 ± 0.16bc      | 2.25 ± 0.32c    |
| Total         |                | 10.6 ± 0.69a | 9.47 ± 0.72ab       | 7.56 ± 0.69bc     | 8.04 ± 0.45bc      | 6.73 ± 0.36c    |

*Values followed by the same letters in a row are not significantly different at P < 0.05; where SOC – Soil carbon stock; TN – Total nitrogen stocks.
deposition and eluviation (Negasa et al., 2016). This finding goes well with the finding of Negasa et al. (2016) who showed an increasing trend of clay textural fractions in the order of upper (53.67%) < middle (58%) < lower (66.5%) slope in cereal farmland in southern Ethiopia.

In addition, the frequent and long year intensive tillage in farmland may rise clay fraction through enhancing weathering process as it shears and pulverizes the soil and changes moisture, aeration, and temperature regime (Awdenegest et al., 2013; Yimer et al., 2008). In contrary to this study, insignificant effect of land use on soil textural fraction was reported in Kenya (Shepherd et al., 2000). The significantly lower soil moisture content observed in the soils of woodlots may be due the voracious moisture uptakes of eucalyptus tree given its deep rooted and fast-growing nature (Sanginga & Swift, 1992). Other studies conducted in other parts of Ethiopia reported lower soil moisture content under eucalyptus plantation compared to other land uses types (Chanie et al., 2013; Getachew et al., 2013; Kebebew et al., 2022).

For instance, the later authors reported lower available moisture contents under Eucalyptus plantation compared to enset field in south central Ethiopia. Almost all farmers in the study area perceived that eucalyptus tree species can deplete major soil nutrients, such as N, P and K, and moisture content due to the rapid growing nature and consequent high uptake of water and nutrients.

The results found in this study are in agreement with the finding of Negasa et al. (2016) who reported higher soil bulk density of 1.26 and 1.22 g cm⁻³ in open grazing land and cereal farmland, respectively as compared to the bulk density of 1.08 g cm⁻³ in agroforestry system in the southern Ethiopia. The observed relatively higher bulk density in cereal farmland could be associated with frequent and intensive cultivation for long years. In the study area, farmers plow their field, particularly for growing small grains such as teff (Eragrostis tef (Zucc.) up to 5–8 times, and this caused compaction of the soil. Other studies have reported higher bulk density in mono-cropping land than other than agro-forestry system (Khormali et al., 2009; Kim et al., 2015).

4.2 Soil chemical properties

Evidence has shown that land use differences significantly affect soil pH as soil in Enset system had higher soil pH (6.48) than soil in Eucalyptus woodlots pH (5.56). The observed higher soil pH in enset field, which receives organic fertilizer as input might be due to the soil’s increasing recovery of natural buffering capacity in response to increased organic matter in the soil. On the other hand, the higher pH might be resulted from the presence of high concentrations of exchangeable bases such as Ca²⁺, Mg²⁺, and K⁺ following continuous application of household wastes including cow dung, wood ash, and crop residues. Various studies have reported higher concentrations of Ca²⁺, Mg²⁺, and K⁺ under homestead and/enset system compared to other land use types in Ethiopia (Duguma et al., 2010; Haileslassie et al., 2006; Kiflu & Beyene, 2013).

On the other hand, the observed low soil pH under woodlots soil might indicate that eucalyptus takes up copious amount of basic cation such as Ca²⁺ and Mg²⁺ and sequestered in its biomass. Studies from Ethiopia Zewdie (2008) and Nigeria Ololwolafe and Ololwolafe (2007) reported lower soil exchangeable bases of Ca²⁺ and Mg²⁺ under plantation of Eucalyptus globulus and Eucalyptus camaldulensis, respectively than other land use types. Other studies in Ethiopia (Getachew et al., 2013; Yitaferu et al., 2013), Kenya (Shepherd et al., 2000), and Nigeria (Ololwolafe, 2007) have reported lower soil pH of 5.4–5.9 in soils under eucalyptus tree than other land uses.

The present study showed the potential of enset land use on soil amelioration particularly, soil chemical properties such as TN, OC, available P, and exchangeable K. Other studies reported improved soil OC, TN, available P, and exchangeable K in fields close to homestead than far from home (Duguma et al., 2010; Haileslassie et al., 2006; Tittonell et al., 2005). Farmers in the study area perceived a decreasing trend of soil fertility gradient with increasing distance from homestead. For examples, about 83.3% of the interviewed farmers perceived better soil fertility in fields close to home than those situated far from home. Financial limitation to buy sufficient external inputs and distance from home to transport manure, and low availability of organic fertilizers mainly manure enforces farmers to prioritize application of organic and inorganic fertilizers to important portion of their farm fields, which lead to formation of heterogeneous soil fertility between plots and within plots of land (Duguma et al., 2009; Haileslassie et al., 2006; Tittonell et al., 2005). Farmers in southern Ethiopia including in the study area grow the perennial food crop Enset ventricosum (Welw.) Cheesman close to the homestead and fertilize it with organic fertilizers but they grow annual field crops in out farm further away from the homestead and fertilize it with suboptimal rate of inorganic fertilizers (Haile et al., 2016; Haileslassie et al., 2006; Mellisse, 2017). In field close to home where enset is grown farmers apply large amount of organic inputs such as household wastes, livestock manure and urine, wood and/or dung.
ash, crop residues including pruned lateral branches of enset plant, which could lead to increased soil nutrient and carbon content over a long period of time. For instance, the majority of the interviewed farmers often applied organic inputs such as manure, crop residue or green manure and household waste including ash and cattle urine mainly in homestead or enset field.

The improved soil fertility in the enset system might also be associated with the co-existence of multipurpose trees, shrubs, herbs, and grasses that could enhance internal organic inputs (Duguma & Hager, 2011; Haile et al., 2016). Other studies (e.g. Amede & Diro, 2005; Negash & Starr, 2015; Kim et al., 2015) reported the role of integrating woody component in enset system for soil amelioration, soil erosion control and soil carbon sequestration. Enset system can improve soil quality not only through the addition of organic inputs but also can interact positively with soil fertility due to the presence of perennial components, funnel shaped leaves and sponge root has minimized loss of soil nutrients and carbon content (Amede & Diro, 2005; Duguma & Hager, 2011). This result is different from the finding of Kiflu and Beyene (2013) who reported lower soil organic carbon and total nitrogen in enset field than farmland and grazing land in southern Ethiopia.

The current study has shown a less expected finding of extremely high available P of 187.52 mg kg⁻¹ under enset system which seems much higher than reported in the literatures. The possible reasons for observed extremely high available P in enset field could be due to the long-term application of household wastes in the form of wood and dung ash. Haileslassie et al. (2006) also reported higher concentration of 992 mg kg⁻¹ of available P in enset system in the central Ethiopia. In contrast, several studies in Ethiopia (e.g. Awenegest et al., 2013; Gelaw et al., 2015; Getachew et al., 2013; Lemenih et al., 2005) have shown no significant effects of land use and soil management on available P which could be attributed to the difference in soil management.

Next to the enset field, the closed grazing land could be the second alternative land use system for storing soil nutrient and carbon stocks. The observed high SOC and TN in closed grazing land could be attributed to the protection of soil nutrient from wind and soil erosion due to the permanent grass cover, which agrees with the finding of Gurmessaa et al. (2016) who reported higher OC and TN contents and their stocks in closed pasture land than other land use types in southern Ethiopia. Moreover, the improvement in soil OC and TN under closed grazing land could be due to the high organic input added into the system and high turnover rate of fine grass root biomass especially in the surface layer (Rhodes et al., 2000). In contrast, the observed low available P and exchangeable K in soil under closed grazing land could be due to reduced pH and absence of grazing inputs such as urine and dung due to the enclosure of closed grazing land during wet season and collection of dung during dry seasons by the farmers for fuel. Another possible explanation for the observed low available P could be associated with waterlogged conditions of the sites. For instance, we found high clay contents of 40.9% in adjacent closed grazing land and 41.96% in cereal farmland, respectively (Table 2). For instance, two adjacent soils under cereal crops land showed similar amount of low available P concentrations of 15.2 and 18.01 mg kg⁻¹, which is different from the finding of Gurmessaa et al. (2016) who found higher available P in the closed grazing land than other land use types in Ethiopia. This is attributed to the addition of inorganic fertilizers, mainly diammonium phosphate (DAP) by land users in the study sites.

The current study has also shown a less expected finding of higher OC and TN in woodlots than the adjacent farmland. For instance, among seven cases considered in this study there was one case where woodlots had higher OC and TN contents of 2.75% and 0.25%, respectively than other land use types, which is different from the findings of other studies (Beweket & Stroosnijder, 2003; Girmay & Singh, 2012; Zewdie, 2008) who reported the negative impacts of eucalyptus tree on the soil chemical properties. The results of this study reaffirm the findings of other studies (Duguma et al., 2010; Yitaferu et al., 2013) who reported better soil nutrient status under eucalyptus plantation in Ethiopia. Duguma et al. (2010) also reported higher organic carbon and total nitrogen content under eucalyptus woodlots than the existing adjacent cereal land when established on degraded cropped land where farmers abandoned because of their poor soil quality in central Ethiopia. Moreover, Jiregna et al. (2007) reported 25–46% more soil N, P, K, and OC content in the soil under Eucalyptus stand than soils far from it in eastern Ethiopia. In the present study, in contrast to the popular notion of negative effects of Eucalyptus tree species on soil chemical properties, the species enhanced soil OC and TN which could be associated with its high litter inputs, slow litter decomposition rate, absence of litter raking and presence of diverse understory vegetation in woodlots (Duguma et al., 2010; Lemma et al., 2006). However, woodlots over the age of 15–20 years old showed significantly lower pH (5.61) and gravimetric soil moisture content (26.14%) than other land use types.

Except bulk density and clay content, cereal farmland had significantly lower soil chemical properties, especially TN and OC, and their stocks. The lower soil OC
(1.39%) and TN (0.12%) content in the farmland could be associated with multiple factors, such as intensive tillage, lack of optimal fertilizer use, erosion, long year of cultivation, and complete removal of crop residues. For instance, Haileslassie et al. (2006) reported the loss of N, P, and K associated with nutrient mining. Other studies also reported the exposure of physically protected micro-aggregate organic carbon to biological degradation agents due to the breakage of soil aggregate because of intensive and frequent tillage (Islam & Weil, 2000; Six et al., 2004) and loss of nutrients due to water and wind soil erosion (Delgado et al., 2013; Islam & Weil, 2000).

Other biophysical conditions such as land fragmentation (increased distance of cereal field from home; Tittonell et al., 2005) and lack of fallowing and crop rotation due to land scarcity and suboptimal use of inorganic fertilizers due to the escalating prices of chemical fertilizers and the competitive use of crop residues for livestock feed and animal dung for fuel wood could have negative impacts on soil quality (Agegnehu et al., 2013; Tsige et al., 2011; Vaje, 2007). Similar studies also reported lower organic carbon and total nitrogen and their stocks in frequently and intensively plowed cereal cropping land than adjacent soil of other land uses in Ethiopia (Adugna & Abegaz, 2016; Awenegest et al., 2013; Berhanu T et al., 2015; Tesfahunegn, 2013). Poor tradition of soil and water conservation practices by farmers in the study area has exacerbated the soil degradation in cereal farmland. For example, among the interviewed farm households only 55.56% practiced one or two soil conservation practices such as terracing, soil and stone bund on their farm. The major reason poor adoption of soil and water conservation practices could be lack of appropriate soil and water conservation technologies and land constraints as the existing soil and water conservation practices takes their land. Therefore, introduction of site specific and appropriate soil and waters conservation practices preferably integrated soil and water conservation practices is essential for minimizing soil erosion and improving crop production.

In this study, the carbon sequestration potential of all land use types was higher except the cereal farm, which implies the capacity of smallholder farmers in managing land use to fight against climate change. The measured carbon stock under agroforestry land at a depth of 0–15 cm was comparable with that of 43–26 Mg ha\(^{-1}\) reported in agricultural landscapes by Girmay and Singh (2012) at the depth of 0–20 cm in northern Ethiopia. However, the measured carbon and nitrogen stock were lower than that of SOC and TN stocks of 221 ± 13.7 and 18 ± 2.2 Mg ha\(^{-1}\) measured in forest lands and 166.8 ± 13.7 and 16.4 ± 1.26 Mg ha\(^{-1}\) in traditional agro-forestry land use and 149.5 ± 9.46 and 15 ± 1.2 Mg ha\(^{-1}\) measured in agricultural land (Sing et al., 2010) in the Central Rift Valley of Ethiopia. Enset based agro-forestry system of the study area had lower SOC stock of 92.5 Mg ha\(^{-1}\) for the 0–30 cm soil depth than SOC stock of 122.15 Mg ha\(^{-1}\) reported by Negash and Starr (2015) for enset based agro-forestry systems for the 0–30 cm layer in southern Ethiopia. This could be due to the simplicity of enset system in the study area compared to complex and multi-strata nature of enset based agro-forestry system in their sites. The results of this study are in line with the findings of other studies (Gurmessa et al., 2016; Yimer et al., 2008) who reported higher carbon and total nitrogen stocks under closed grazing land than other land uses in southern Ethiopia. However, the results of this study are different from the findings of (Wolde et al. (2014) in Ethiopia and Mureithi et al. (2014) in Kenya who have reported no significant difference in carbon and total nitrogen stocks between closed and open grazing lands.

In general, integrating perennial food crops such as enset with multipurpose trees close to the homestead and fertilizing them with manure, compost and household waste as well as protecting grazing lands from free grazing through enclosure has not only improved soil nutrient status but also enhance soil carbon stocks and mitigate climate changes at watershed level (Haileslassie et al., 2006) and at farm level (Negash & Starr, 2015). Overall, some land use systems (e.g. enset agroforestry) improve the soil biophysical and chemical properties, while others such as cereal production degrade the soil.

5. Conclusions

The results of this study showed that land use types significantly influenced the physical and chemical properties of soils under different land-use types. Soils under enset system had significantly high pH, available P, exchangeable K, OC, TN and their stocks. OC and TN showed the same trend while available P and exchangeable K showed the opposite trend. Despite the popular notion of environmentally alleged effects of eucalyptus tree on soil properties we only found minimal negative effects on soil properties (e.g. low pH and moisture content) from woodlots established some 15–20 years ago on degraded crop lands where farmers abandoned because of soil degradation. The improvement of soil OC and TN under woodlots indicates that planting of fast-growing eucalyptus tree species on degraded crop lands will enhance their soil quality while improving the livelihoods of rural communities and could reduce the pressure on remnant native forests for various wood products.
The OC and TN stocks often served as a proxy for soil quality indicators which followed a decreasing trend of enset farm > closed grazing land > eucalyptus woodlots > open grazing land > cereal farmland at 0–45 cm soil depth. Other soil nutrients such as available P and K+, with the exception of available P in the closed grazing land were also measured in the same trend. The overall results of the study clearly indicated that among the five land use types considered in this study enset and closed grazing land-use types will have higher potential for improving soil quality and mitigating climate change while the dominantly practiced cereal cropping is responsible for the continuous loss of soil organic carbon and nutrients in the study area. The continuous low input cultivation of cereal farm land and poor soil conservation measures could be the major caused for the observed poor soil properties in cereal farm land. Hence, future soil management strategies should focus on improving soil nutrient management through the retention of crop residues, practice of crop rotation and promotion of agro-forestry system to reduce the continuous loss of soil nutrients from the dominantly cereal cropping system. Based on the results of this study it can be concluded enset based agro-forestry can play a remarkable role in climate change adaptation and mitigation through storing carbon in soil and biomass while diversifying household income and ensuring food security therefore it should be scaled-up in other similar area. However, the potential of smallholder land use for biomass carbon storage should be studied in the future to claim for carbon trading.

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Annex Statistical analysis

### Analysis of Variance (ANOVA) for soil bulk density.

| Source                  | Df  | Mean Square | F      | Sign. |
|-------------------------|-----|-------------|--------|-------|
| Corrected Model         | 14.00 | 0.05         | 3.90   | 0.00  |
| Intercept               | 1.00  | 132.93      | 10,403.93 | 0.00 |
| LUT                     | 4.00  | 0.03         | 2.57   | 0.04  |
| Soil depth              | 2.00  | 0.19         | 14.65  | 0.00  |
| LUT * Soil depth        | 8.00  | 0.03         | 2.19   | 0.06  |
| Error                   | 84.00 | 0.01         |        |       |
| Total                   | 99.00 |              |        |       |
| Corrected Total         | 98.00 |              |        |       |

### Analysis of Variance (ANOVA) for clay content.

| Source                  | Df  | Mean Square | F      | Sign. |
|-------------------------|-----|-------------|--------|-------|
| Corrected Model         | 14.00 | 78.24        | 1.80   | 0.06  |
| Intercept               | 1.00  | 95,094.38   | 2193.24 | 0.00 |
| LUT                     | 4.00  | 174.91      | 4.03   | 0.01  |
| Soil depth              | 2.00  | 102.92      | 2.37   | 0.10  |
| LUT * Soil depth        | 8.00  | 22.57       | 0.52   | 0.84  |
| Error                   | 54.00 | 43.36       |        |       |
| Total                   | 69.00 |              |        |       |
| Corrected Total         | 68.00 |              |        |       |

### Analysis of Variance (ANOVA) for silt content

| Source                  | Df  | Mean Square | F      | sign |
|-------------------------|-----|-------------|--------|------|
| Corrected Model         | 14.00 | 72.08        | 1.34   | 0.22 |
| Intercept               | 1.00  | 84,485.84   | 1571.17 | 0.00 |
| LUT                     | 4.00  | 130.32      | 2.42   | 0.06 |
| Soil depth              | 2.00  | 69.72       | 1.30   | 0.28 |
| LUT * Soil depth        | 8.00  | 40.78       | 0.76   | 0.64 |
| Error                   | 53.00 | 53.77       |        |      |
| Total                   | 68.00 |              |        |      |
| Corrected Total         | 67.00 |              |        |      |

### Analysis of Variance (ANOVA) for sand content

| Source                  | Df  | Mean Square | F      |
|-------------------------|-----|-------------|--------|
| Corrected Model         | 14.00 | 45.07        | 1.58   |
| Intercept               | 1.00  | 46,555.52   | 1626.95 | 0.00 |
| LUT                     | 4.00  | 60.63       | 2.12   |
| Soil depth              | 2.00  | 0.56        | 0.02   |
| LUT * soil depth        | 8.00  | 42.80       | 1.50   |
| Error                   | 53.00 | 28.62       |        |
| Total                   | 68.00 |              |        |
| Corrected Total         | 67.00 |              |        |

### Two-Way Analysis of Variance (ANOVA) for exchangeable K

| Source variation       | Df | Mean Square | F     | Sign. |
|------------------------|----|-------------|-------|-------|
| Corrected Model        | 14.00| 1.30        | 1.39  | 0.19  |
| Intercept              | 1.00 | 45.50       | 48.64 | 0.00  |
| LUT                    | 4.00 | 3.25        | 3.47  | 0.01  |
| Soil depth             | 2.00 | 0.80        | 0.86  | 0.43  |
| LUT * Soil depth       | 8.00 | 0.37        | 0.40  | 0.92  |
| Error                  | 53.00| 0.94        |       |       |
| Total                  | 68.00|             |       |       |
| Corrected Total        | 67.00|             |       |       |

### Analysis of Variance (ANOVA) for CEC level

| Source variation       | Df | Mean Square | F     | Sign. |
|------------------------|----|-------------|-------|-------|
| Corrected Model        | 14.00| 14.57       | 1.26  | 0.26  |
| Intercept              | 1.00 | 59,927.86   | 5175.47 | 0.00  |
| LUT                    | 4.00 | 7.02        | 0.61  | 0.66  |
| Soil depth             | 2.00 | 16.33       | 1.41  | 0.25  |
| LUT * Soil depth       | 8.00 | 17.79       | 1.54  | 0.17  |
| Error                  | 55.00| 11.58       |       |       |
| Total                  | 70.00|             |       |       |
| Corrected Total        | 69.00|             |       |       |

### Analysis of Variance (ANOVA) for organic carbon content

| Source variation       | Df | Mean Square | F     | Sign. |
|------------------------|----|-------------|-------|-------|
| Corrected Model        | 14.00| 2.697       | 12.156 | 0.000 |
| Intercept              | 1.00 | 362.447     | 1633.831 | 0.000 |
| LUT                    | 4.00 | 3.711       | 16.730 | 0.000 |
| Soil depth             | 2.00 | 9.404       | 42.391 | 0.000 |
| LUT * Soil depth       | 8.00 | 0.753       | 3.392  | 0.002 |
| Error                  | 84.00| 0.222       |       |       |
| Total                  | 99.00|             |       |       |
| Corrected Total        | 98.00|             |       |       |

### Analysis of Variance (ANOVA) for total nitrogen content

| Source variation       | Df | Mean Square | F     | Sign. |
|------------------------|----|-------------|-------|-------|
| Corrected Model        | 14.00| 0.019       | 12.254 | 0.000 |
| Intercept              | 1.00 | 2.675       | 1750.397 | 0.000 |
| LUT                    | 4.00 | 0.024       | 15.592 | 0.000 |
| Soil depth             | 2.00 | 0.069       | 45.095 | 0.000 |
| LUT * Soil depth       | 8.00 | 0.005       | 3.537  | 0.001 |
| Error                  | 84.00| 0.002       |       |       |
| Total                  | 99.00|             |       |       |
| Corrected Total        | 98.00|             |       |       |
### Analysis of Variance (ANOVA) for available P content

| Source             | Df  | Mean Square | F    | Sign |
|--------------------|-----|-------------|------|------|
| Corrected Model    | 14.00 | 31,344.53  | 2.91 | 0.00 |
| Intercept          | 1.00  | 519,661.95 | 48.23 | 0.00 |
| LUT                | 4.00  | 86,788.57  | 8.05 | 0.00 |
| Soil depth         | 2.00  | 23,900.86  | 2.22 | 0.12 |
| LUT * Soil depth   | 8.00  | 4487.61    | 0.42 | 0.91 |
| Error              | 84.00 | 10,774.56  |      |      |
| Total              | 99.00 |            |      |      |
| Corrected Total    | 98.00 |            |      |      |

### Analysis of Variance (ANOVA) for organic carbon stocks

| Source             | Df  | Mean Square | F    | Sign |
|--------------------|-----|-------------|------|------|
| Corrected Model    | 14.00 | 523.735    | 6.519 | 0.000 |
| Intercept          | 1.00  | 107,411.61 | 1336.879 | 0.000 |
| LUT                | 4.00  | 833.943    | 10.379 | 0.000 |
| Soil depth         | 2.00  | 1693.306   | 21.075 | 0.000 |
| LUT * Soil depth   | 8.00  | 101.607    | 1.265 | 0.273 |
| Error              | 84.00 | 80.345     |      |      |
| Total              | 99.00 |            |      |      |
| Corrected Total    | 98.00 |            |      |      |

### Analysis of variance(ANOVA) for total nitrogen stocks for entire soil profile

| Source             | Df  | Mean Square | F    | Sign |
|--------------------|-----|-------------|------|------|
| Corrected Model    | 14.00 | 4338.965   | 4.871 | 0.000 |
| Intercept          | 1.00  | 945,944.645 | 1061.879 | 0.000 |
| LUT                | 4.00  | 7922.220   | 8.893 | 0.000 |
| Soil depth         | 2.00  | 12,600.119 | 14.144 | 0.000 |
| LUT * Soil depth   | 8.00  | 729.803    | 0.819 | 0.588 |
| Error              | 84.00 | 890.821    |      |      |
| Total              | 99.00 |            |      |      |
| Corrected Total    | 98.00 |            |      |      |

### Analysis of Variance (ANOVA) for total nitrogen stocks

| Source             | Df  | Mean Square | F    | Sign |
|--------------------|-----|-------------|------|------|
| Corrected Model    | 14.00 | 3.556      | 6.245 | 0.000 |
| Intercept          | 1.00  | 794.961    | 1396.023 | 0.000 |
| LUT                | 4.00  | 5.032      | 8.836 | 0.000 |
| Soil depth         | 2.00  | 12.630     | 22.179 | 0.000 |
| LUT * Soil depth   | 8.00  | 0.730      | 1.282 | 0.264 |
| Error              | 84.00 | 0.569      |      |      |
| Total              | 99.00 |            |      |      |
| Corrected Total    | 98.00 |            |      |      |