Effects of Different Land Use Types Managed By Smallholder Farmers on Soil Properties in Central Ethiopia

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Abstract

Background Aim: 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. This study 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.

Methods: A total of 105 disturbed and undisturbed soil samples [5 treatments (land use types) *7 replications (household) * 3 soil depth layers: 0–15cm, 15–30 cm, 30–45cm] were collected for selected soil chemical and physical analyses. Standard soil analytical procedures were followed in carrying out soil analysis. To meet the assumptions of normal distribution and homogeneity of variances, soil data on available phosphors were log-transformed before statistical analysis was undertaken and reported after back transformation. Two way analysis of variable were used to investigate the effects of land use and soil depth and their interaction on soil properties and when the analysis showed a significant difference (p <0.05) among land use and soil depth men separation were made using Turkey’s pairwise comparisons.

Results: There were significant differences in physical and chemical properties of soil across land use and soil depth categories. Enset system had significantly higher pH, available phosphorus (P), exchangeable potassium (K+), soil organic carbon (SOC), and total nitrogen (TN) and their stocks than other land use types. Enset fields had higher SOC (78.4%) and soil TN (75%), and SOC and TN stocks of (66%) and (58%), respectively than cereal farmland. This study had also revealed a less expected finding of higher soil organic carbon and total nitrogen under Eucalyptus wood than farm land. Soil carbon and total nitrogen stocks showed a decreasing trend of enset system> closed grazing-land > eucalyptus woodlot > open grazing-land > farmland 0-45cm.

Conclusion: 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. Hence appropriate land and soil management intervention should be promptly adapted to mitigating the continuous loss of nutrient from the dominantly practiced cereal farm land through maintaining crop residues, manure, crop rotation and scaling up agro-forestry system.

1. Introduction

In developing countries like Ethiopia, smallholder farmers produce more than 90% of the total agricultural produce (Agidew and Singh, 2018). Most of the smallholder farmers practice a mixed crop-livestock-tree farming system where they allocate portion of their holdings to crops, grazing lands and tree cultivations. Such practices serve two purposes: reduce risk and supply diverse products needed to sustain the households. Financial limitation to buy sufficient external inputs enforces them 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 (Tittonel et al., 2005; Haileslassie et al., 2006; Duguma et al., 2009). The complex farming system practiced in densely populated southern highlands of Ethiopia displays a good example of such fertility gradient within and between plots.

Farmers in southern Ethiopia grow the stable 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 and wheat, teff, and barely are fertilized with inorganic fertilizer (Haileslassie et al., 2006; Mellisse, 2017). 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 (Duguma et al., 2009; Ketema and Yimer, 2014; Negasa et al., 2016; Adugna and Abegaz, 2016).

Soil degradation is a major agricultural and environmental problems impacting agricultural productivity and food security in Ethiopia (Haileslassie et al., 2006; Nyssen et al., 2008; Tesfahunegn, 2013; Agegnehu et al., 2013). 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. Land use change can alter the soil chemical and physical properties either positively or negatively. Several studies have investigated land use effects on soil properties and results of many earlier studies are inconsistent with some who reported significant effect of land use on soil properties (Duguma et al., 2009; Kim et al., 2015; Negasa et al., 2016). In contrast other studies indicated non-significant effect of land use on soil chemical properties (Getachew et al., 2013; Alemayehu and Sheleme, 2013 Wolde Mekuria et al., 2014). Such variations may emerge 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, farm households practice a complex farming system by allocating their small holdings into different land use systems, such as enset system, out farmland, grazing land, and woodlots. These different land use systems and their management practices obviously influence soil properties of each system, which is worth investigating. 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 socioeconomic 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 (Fig. 1). The altitude of the study site ranges between 2000–2200 m.a.s.l. The topography of the study site is characterized by flat to undulating with slope ranging from 0–5%. 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., 2017).

The rainfall distribution is bimodal with long (July to August) and short (March to September) rainy season (Fig. 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 (Fig. 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 subsistent 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., 2017).

2.2. Soil sampling and analysis

Within the Miskan woreda, three kebeles (the smallest administrative unit in Ethiopia) represented by the presence of different land use systems were purposely selected and a total of seven farm households were considered. In this study, the five land use systems were considered as treatments and seven farm households as replications. The five land use systems were enset system, grazing systems (open and closed), annual cereal system, and eucalyptus woodlot (Fig. 3). Soil samples were taken from each land use system at a depth of 0-15cm, 15-30cm, and 30-45cm from adjacent land use types having similar soil type (i.e. soil textural class is clay loam) and climate (altitude) and slope (0–5%) to avoid confounding factors. For bulk soil destiny 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 core sampler of 5 cm height by 3 cm diameter. From the five land use types of each farm household, soil samples were taken at three level of depths, totally 105 samples were taken for soil chemical and physical analysis. Representative soil samples were taken from each land use type of the different farm households and were analyzed at the Holetta soil and plant testing laboratory. The samples were mixed manually and subsamples were grounded to pass through a 2 mm sieve. Soil pH in water was determined at 1:2.5 (soil: water ratio), soil organic carbon (OC) by wet combustion method (Walkley and Black, 134), and total nitrogen by Kjeldahl digestion, distillation and titration method (Anderson and Ingram, 1993). Soil available phosphorus was determined using Olsen method (Olsen, 1954). Soil exchangeable potassium (K⁺) was determined by ammonium acetate extraction method using the flame photometer (Anderson and 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 (Hillel, 2004). Soil-moisture content was determined by gravimetric methods after the soil was oven dried at 105°C for 30 h (Anderson and 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.
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. 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 effect on soil physical properties mainly textural fraction, soil moisture and bulk density (Table 2). Clay fraction was the only particle size fraction (%) that significantly ($p < 0.005$) affected by land use but not affected by soil depth and by interaction effects (Table 2) but the sand and silt fraction did not vary between the different land use systems, soil depth and by their interaction (Table 2). Significantly higher clay proportions of $41.47 \pm 1.25\%$ and $40.9 \pm 1.96$ were observed in farmland and closed grazing land, respectively while the lowest clay proportion of $32.9 \pm 1.85\%$ was recorded from enset field (Table 3). 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 and soil had a significant ($p = 0.009$) effect on gravimetric soil moisture content (Table 2). Similar to clay fraction, cereal farmland and closed grazing land had significantly higher gravimetric soil moisture contents of $32.41 \pm 1.19\%$ and $34.79 \pm 1.19\%$, respectively, while the adjacent soils under woodlots had low moisture content of $26.14 \pm 1.19\%$ (Table 3). Surface soil holds significantly higher gravimetric soil $28.63 \pm 0.9$ (Table 3).

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

| Land use       | Description                                                                                                                                 |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| **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 degraded farm 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
Mean ± SE result of soil moisture (MC%) and bulk density (BD gm/cm³) among land uses and corresponding ANOVA

| Property          | soil depth | Enset          | Closed GL     | Open GL       | Woodlots      | Cereal farm   | Overall mean  |
|-------------------|------------|----------------|---------------|---------------|---------------|---------------|---------------|
| Clay              | 0–15       | 32.75 ± 3.2    | 41.34 ± 3.2   | 34.5 ± 3.2    | 33 ± 3.2      | 37.25 ± 3.2   | 35.97 ± 1.4a  |
|                   | 15–30      | 31 ± 3.2       | 40.5 ± 3.2    | 33.88 ± 3.6   | 36.5 ± 3.2    | 42.15 ± 3.2   | 37 ± 1.5a     |
|                   | 30–45      | 34 ± 3.2       | 40.94 ± 3.6   | 36.35 ± 3.2   | 38.25 ± 3.2   | 44.15 ± 3.2   | 38.7 ± 1.5a   |
| Overall mean      |            | 32.9 ± 1.85a   | 40.9 ± 1.96b  | 34.9 ± 1.95ab | 35.9 ± 1.95ab | 41.47 ± 1.25b |
| Silt              | 0–15       | 35.5 ± 3.68    | 37.25 ± 3.68  | 38 ± 3.69     | 42.6 ± 3.68   | 30.8 ± 3.68   | 36.5 ± 1.6b   |
|                   | 15–30      | 35.5 ± 3.68    | 36.5 ± 3.68   | 40 ± 4.1      | 37.5 ± 3.68   | 30.85 ± 3.68  | 36 ± 1.7b     |
|                   | 30–45      | 35.75 ± 3.6    | 32.19 ± 4     | 38.7 ± 3.69   | 35 ± 3.69     | 32.6 ± 3.68   | 43.9 ± 1.7b   |
| Overall           | 35.58 ± 2  | 35.3 ± 2.2     | 39.9 ± 2.2    | 38.5 ± 2      | 31.4 ± 2      |
| Sand              | 0–15       | 35.5 ± 3.7     | 37.25 ± 3.7   | 38 ± 3.7     | 42.6 ± 3.7    | 30.85 ± 3.7   | 36.8 ± 1.6c   |
|                   | 15–30      | 35.5 ± 3.7     | 36.5 ± 3.7    | 40 ± 4       | 37.5 ± 3.7    | 30.85 ± 3.7   | 36 ± 1.7c     |
|                   | 30–45      | 35.75 ± 3.7    | 32.29 ± 4     | 38.7 ± 3.7   | 35 ± 3.7     | 32.8 ± 3.7    | 34.8 ± 1.7c   |
| Overall           | 35.58 ± 2  | 35.3 ± 2.2     | 38.9 ± 2.2    | 38.4 ± 2     | 31.4 ± 2     |
| Textural classes  |            | Clay loam      | Clay loam     | Clay loam    | Clay loam    | Clays loam    |
| Moisture          | 0–15       | 31.42 ± 1.96   | 33.40 ± 3.36  | 26.04 ± 2.13 | 22.51 ± 1.64 | 29.24 ± 2.59 | 28.63 ± 0.9a  |
|                   | 15–30      | 30.32 ± 0.91   | 32.24 ± 2.08  | 31.72 ± 2.52 | 27.72 ± 1.51 | 33.41 ± 2.52 | 31.31 ± 0.9ab |
|                   | 30–45      | 31.59 ± 1.26   | 35.32 ± 3.00  | 32.02 ± 2.08 | 28.18 ± 1.58 | 34.57 ± 2.08 | 32.63 ± 0.9b  |
| Overall           | 31.1 ± 1.19bc | 34.79 ± 1.19b  | 29.9 ± 1.19c  | 26.14 ± 1.19a | 32.41 ± 1.19bc |
| Bulk density      | 0–15       | 1.07 ± 0.04    | 1.23 ± 0.05   | 1.18 ± 0.04   | 1.15 ± 0.05   | 1.01 ± 0.02   | 1.13 ± 0.02a  |
|                   | 15–30      | 1.15 ± 0.06    | 1.13 ± 0.05   | 1.13 ± 0.02   | 1.11 ± 0.03   | 1.13 ± 0.03   | 1.13 ± 0.02a  |
|                   | 30–45      | 1.23 ± 0.06    | 1.35 ± 0.04   | 1.22 ± 0.04   | 1.24 ± 0.05   | 1.28 ± 0.05   | 1.24 ± 0.02b  |
| Overall           | 1.15 ± 0.09a | 1.15 ± 0.09a   | 1.16 ± 0.09a  | 1.15 ± 0.09a  | 1.23 ± 0.09a |

Values followed by the same letters in a row are not significantly different at P < 0.05; or 0.01* significantly different at p < 0.05; ** significantly different at (p = 0.01) ns denotes not significantly different.
Table 3
Mean ± S.E. of soil chemical properties across different land uses in 0-15cm, 15-30cm and 30-45cm soil depth in Butajira area

| Property | soil depth | Enset | Closed GL | Open GL | Woodlots | Cereal | Overall mean |
|----------|------------|-------|-----------|---------|----------|--------|--------------|
| OC (%)   | 0–15       | 3.09 ± 0.017 | 3.25 ± 0.017 | 2.3 ± 0.17c | 2.14 ± 0.20 | 1.50 ± 0.12 | 2.46 ± 0.08a |
|          | 15–30      | 2.46 ± 0.017 | 1.99 ± 0.017 | 1.63 ± 0.14 | 1.75 ± 0.12 | 1.49 ± 0.14 | 1.86 ± 0.08b |
|          | 30–45      | 1.90 ± 0.017 | 1.38 ± 0.017 | 1.23 ± 0.10 | 1.47 ± 0.04 | 1.18 ± 0.10 | 1.43 ± 0.08c |
| Overall  | mean       | 2.48 ± 0.1 a | 2.21 ± 0.1 a | 1.73 ± 0.1b | 1.79 ± 0.1b | 1.39 ± 0.1b |
| TN (%)   | 0–15       | 0.26 ± 0.014 | 0.29 ± 0.014 | 0.20 ± 0.014 | 0.19 ± 0.014 | 0.13 ± 0.014 | 0.21 ± 0.006a |
|          | 15–30      | 0.20 ± 0.014 | 0.17 ± 0.014 | 0.13 ± 0.014 | 0.15 ± 0.014 | 0.12 ± 0.014 | 0.16 ± 0.006b |
|          | 30–45      | 0.18 ± 0.014 | 0.12 ± 0.014 | 0.11 ± 0.014 | 0.13 ± 0.014 | 0.11 ± 0.014 | 0.13 ± 0.006c |
| Overall  | mean       | 0.21 ± 0.008a | 0.19 ± 0.008a | 0.15 ± 0.008bc | 0.16 ± 0.008b | 0.12 ± 0.008c |
| P(ppm)   | 0–15       | 238 ± 34 | 267.68 ± 34 | 26.2 ± 34 | 213.63 ± 19.8a | 58.9 ± 34 | 87.9 ± 34 | 100.34 ± 15.3a |
|          | 15–30      | 267.68 ± 34 | 26.2 ± 34 | 213.63 ± 19.8a | 49.43 ± 15.3a |
|          | 30–45      | 135.2 ± 34 | 20.13 ± 34 | 61.4 ± 19.8b | 62.55 ± 19.8b |
| Overall  | mean       | 213.63 ± 19.8a | 24.36 ± 19.8b | 61.4 ± 19.8b | 24.36 ± 19.8b | 67.5 ± 0.1a |
| pH       | 0–15       | 6.93 ± 0.23 | 6.58 ± 0.23 | 6.87 ± 0.23 | 6.4 ± 0.23 | 6.72 ± 0.23 | 6.68 ± 0.1a |
|          | 15–30      | 6.8 ± 0.23 | 6.58 ± 0.23 | 6.87 ± 0.23 | 6.4 ± 0.23 | 6.72 ± 0.23 | 6.68 ± 0.1a |
|          | 30–45      | 6.67 ± 0.23 | 6.74 ± 0.23 | 6.85 ± 0.23 | 6.56 ± 0.23 | 6.9 ± 0.23 | 6.75 ± 0.1a |
| Overall  | mean       | 6.81 ± 0.13b | 6.55 ± 0.13b | 6.79 ± 0.13b | 6.39 ± 0.13b | 6.69 ± 0.13b |
| K*(meq/100g soil) | 0–15 | 1.9 ± 0.37 | 0.31 ± 0.37 | 1.4 ± 0.37 | 0.81 ± 0.37 | 0.64 ± 0.37 | 1.02 ± 0.17b |
|          | 15–30      | 1.5 ± 0.47 | 0.32 ± 0.37 | 0.52 ± 0.37 | 0.72 ± 0.37 | 0.55 ± 0.37 | 0.73 ± 0.17b |
|          | 30–45      | 0.42 ± 0.23 | 0.35 ± 0.42 | 0.57 ± 0.48 | 0.67 ± 0.42 | 0.55 ± 0.37 | 0.51 ± 0.19b |
| Overall  | mean       | 1.28 ± 0.23a | 0.32 ± 0.2a | 0.84 ± 0.24a | 0.73 ± 0.2a | 0.59 ± 0.22a |

Values followed by the same letters in a row are not significantly different at P < 0.05; or 0.001* significantly different at p < 0.05; ** significantly different at p = 0.001 ns denotes not significantly different.

On contrast, bulk density (g/cm3) significantly affected by soil depth but land use did not significantly affect it (Table 2). Soil bulk density was significantly higher (1.25 ± 0.02g cm-3) at 30-45cm (Table 3). Though, land use did not affect soil bulk density in terms of absolute values cereal land use had the higher bulk density of 1.23 ± 0.09a(Table 3).

3.2. Impact of land use types on soil chemical properties

Similar to soil physical properties, land use had a significant effect on soil chemical properties (Table 4). Soil organic carbon (%) and total nitrogen (%) showed significant difference among land use types (p = 0.000), soil depths (p = 000) and by interaction effect (p = 0.001) (Table 4). Enset fields had significantly higher soil organic carbon and total nitrogen than other land-use types, while the adjacent the cereal farmland had the lowest content of soil OC and total N (Table 5). Significantly higher organic carbon of 2.48 ± 0.17 and total nitrogen of 0.21 ± 0.08) and were measured in enset field(Table 5). Soil organic carbon and total nitrogen were significantly affected across soil depth. Significantly higher organic carbon of 2.46 ± 0.08% and total nitrogen of 0.21 ± 0.06% were measured from surface (0-15cm) respectively (Table 5).
Table 4
Mean ± S.E. of soil carbon and total nitrogen stocks (Mg/ha-1) across different land uses for depths of 0–15 cm, 15–30 cm and 30–45 cm

| Property | Depth(cm) | Enset     | Closed GL | Open GL | Woodlots | Cereal | Overall mean |
|----------|-----------|-----------|-----------|---------|----------|--------|--------------|
| C(Mg/ha) | 0–15      | 49.5±3.2  | 46.9±4.2  | 41±3.1  | 37.2±3.2 | 27.6±3.2 | 40.9±1.4a   |
|          | 15–30     | 43.1±0.32 | 30.9±2.8  | 27.6±3.2 | 29.2±3.2 | 25.4±3.2 | 31.7±1.4a   |
|          | 30–45     | 35.8±3.12 | 27.7±0.50 | 21.7±1.8 | 30.5±3.2 | 23.7±3.2 | 28.8±1.4a   |
|          | Overall   | 42.5±1.9a | 36.6±1.9b | 30±1.9b  | 30.9±1.9b | 25.6±1.9b |              |
|          | 0–15      | 4.1±.15   | 2.5±0.26  | 3.6±0.45 | 3.2±0.32 | 4.0±0.39 | 2.5±0.1a    |
| TN(Mg/ha)| 15–30     | 3.6±0.41  | 2.1±0.18  | 2.3±0.45 | 2.5±0.20 | 2.7±0.23 | 1.8±0.1b    |
|          | 30–45     | 2.9±0.36  | 2.1±0.18  | 1.9±0.15 | 2.3±0.14 | 2.4±0.32 | 1.5±0.1c    |
|          | Overall   | 2.4±0.97a | 2.2±0.97a | 1.8±0.97b| 1.8±0.97b| 1.4±0.97b|              |

Values followed by the same letters in a row are not significantly different at P < .05 or p = 0.001 values followed by different letter are significantly different at p < 0.05; * significantly different at p = 0.001 ns denotes not significantly different.

Available phosphorus (ppm) showed statistically significant difference among land use but it did not vary with soil depth and by the interaction effect (Table 4). Enset soil contained significantly higher available phosphorus of (213.63 ± 19.8 mg kg⁻¹) than other land uses while the adjacent soils under closed grazing land had the lowest available P (18.12 ± 1.5 mg kg⁻¹) (Table 5). Likewise, exchangeable K⁺ has shown significant (P < 0.05) difference among land use types (Table 4). 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 5).

The soil OC and total N stocks showed a decreasing trend with increasing soil depths regardless of the land use types (Table 5). The upper soil depth had higher SOC and total N for the five land use types. Enset field which received manure as input had higher soil OC and total N and their stocks (Table 5).

Table 5. Effects of land use types on soil organic carbon (SOC) and total nitrogen (TN) Stocks in central Ethiopia.

Table 4. Mean ± S.E. of soil carbon and total nitrogen stocks (Mg/ha-1) across different land uses for depths of 0–15 cm, 15–30 cm and 30–45 cm

| Property | Depth(cm) | Enset     | Closed GL | Open GL | Woodlots | Cereal | Overall mean |
|----------|-----------|-----------|-----------|---------|----------|--------|--------------|
| C(Mg/ha) | 0–15      | 49.5±3.2  | 46.9±4.2  | 41±3.1  | 37.2±3.2 | 27.6±3.2 | 40.9±1.4a   |
|          | 15–30     | 43.1±0.32 | 30.9±2.8  | 27.6±3.2 | 29.2±3.2 | 25.4±3.2 | 31.7±1.4a   |
|          | 30–45     | 35.8±3.12 | 27.7±0.50 | 21.7±1.8 | 30.5±3.2 | 23.7±3.2 | 28.8±1.4a   |
|          | Overall   | 42.5±1.9a | 36.6±1.9b | 30±1.9b  | 30.9±1.9b | 25.6±1.9b |              |
|          | 0–15      | 4.1±.15   | 2.5±0.26  | 3.6±0.45 | 3.2±0.32 | 4.0±0.39 | 2.5±0.1a    |
| TN(Mg/ha)| 15–30     | 3.6±0.41  | 2.1±0.18  | 2.3±0.45 | 2.5±0.20 | 2.7±0.23 | 1.8±0.1b    |
|          | 30–45     | 2.9±0.36  | 2.1±0.18  | 1.9±0.15 | 2.3±0.14 | 2.4±0.32 | 1.5±0.1c    |
|          | Overall   | 2.4±0.97a | 2.2±0.97a | 1.8±0.97b| 1.8±0.97b| 1.4±0.97b|              |

Values followed by the same letters in a row are not significantly different at P < .05 or p = 0.001 values followed by different letter are significantly different at p < 0.05; * significantly different at p = 0.001 ns denotes not significantly different.

Soil organic carbon stocks and total nitrogen (Mg/ha) were significantly affected by land use and soil depth but they did not affected by their interaction effects (Table 6). The enset system had the highest mean 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)(Table 7). 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 7). 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 7).

Table 6
The correlation matrix for soil properties in surface layer (0-45 cm) soil depth

|                  | OC(%) | TN(%) | K⁺ meq/100gsoil | P(ppm) | pH  | Clay(%) | Silt(%) | sand(%) | MC(%) | BD(g/.cm³) |
|------------------|-------|-------|-----------------|--------|-----|---------|---------|---------|-------|------------|
| Organic carbon(%)| 1     |       |                 |        |     |         |         |         |       |            |
| Total Nitrogen(%)| .984**| 1     |                 |        |     |         |         |         |       |            |
| K⁺ meq/100gsoil | .381**| .383**| 1               |        |     |         |         |         |       |            |
| Av. P (ppm)      | .411**| .415**| .609**          | 1      |     |         |         |         |       |            |
| pH               | -.192 | -.203*| .064            | .242*  | 1   |         |         |         |       |            |
| Clay             | -.177 | -.165 | .008            | -.249* | .010| 1       |         |         |       |            |
| Silt             | .119  | .090  | -.116           | -.036  | .037| -.688**| 1       |         |       |            |
| Sand             | .144  | .153  | -.078           | -.078  | -.289*| .005   | .037   | 1      |       |            |
| Moisture content(%)| .058 | .044  | -.049           | -.215* | -.258**| .284*  | -.197   | -.098  | 1      |            |
| Bulk density     | -.362**| -.338**| -.023           | .020   | .197* | .022   | -.101  | -.049  | .006  | 1          |

*. Correlation is significant at the 0.05 level (2-tailed **. Correlation is significant at the 0.01 level (2-tailed).

In the entire soil profile, 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)(Table 7). 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. (Table 7) 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 SOC (Table 7).

Surface soil that received higher inputs had the highest soil organic carbon stock of (40.90 ± 1.4 Mg C ha⁻¹) and TN stock of (2.5 ± 0.1 Mg ha⁻¹) respectively than subsurface soil (Table 7).

OC and TN at correlation coefficient of (0.983**) (Table 8) and OC and TN were positively and strongly correlated with available P at r (0.421**) and (0.425**), respectively while they were strongly and negatively correlated with BD at r (-0.356**) and (0.339**) (Table 8)

4. Discussion

4.1 Soil physical properties

The variation in land use had significant effect 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 (Haileslassie et al., 2006; Yimer and Abdulkadir, 2008; Awdenegest et al., 2013; Negasa et al., 2016). Other researchers also reported higher clay fraction on cereal farm land compared to other land uses (Negasa et al., 2016; Adugna and Abegaz, 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 slops(Fig. 5). 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 deposition and eluviation.
soil erosion control and soil carbon sequestration. Enset system can improve soil quality not only through the addition of organic

2005; Negas and Starr, 2015; Kim et al., 2015) reported the role of integrating woody component in enset system for soil amelioration,

grasses that could enhance internal organic inputs (Duguma and Hager, 2013). In contrast to this study, the insignificant effect of land use on soil textural fraction was reported in Kenya (Shepherd et al., 2000). The significantly lower soil moisture observed in the soils of woodlots may be due to the voracious moisture uptakes of eucalyptus tree given its deep rooted and fast-growing nature (Sanginga and Swift, 1992). Other studies conducted in other parts of Ethiopia reported lower soil moisture content under eucalyptus plantation compared to other land uses types (Getachew et al., 2013; Chanie et al., 2013). 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 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 hence increased compaction of the soil. Other studies have reported higher bulk density in mono-cropping land than other agro-forestry system (Khormail 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 (6.81) than soil in Eucalyptus woodlots pH (5.68). The observed higher soil pH in enset field, which received manure, household waste and ash as input may 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 Ca$^{2+}$, Mg$^{2+}$, and K$^{+}$ following continuous application of household wastes including cow dung, wood ash, and crop residues. Various studies have reported higher concentrations of Ca$^{2+}$, Mg$^{2+}$, and K$^{+}$ under homestead and/enset system compared to other land use types in Ethiopia (Haileslassie et al., 2006; Duguma et al., 2010; Kiflu and 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 Ca$^{2+}$and Mg$^{2+}$ and sequestered in its biomass. Studies from Ethiopia Zedie (2008) and Nigeria Olowolafe and Alexander (2007) reported lower soil exchangeable bases of Ca$^{2+}$ and Mg$^{2+}$ under plantation of Eucalyptus globulus and Eucalyptus camaldulenisiss, 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 (Olowolafe and Alexander, 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 (Tittonell et al., 2005; Haileslassie et al., 2006; Duguma et al., 2010). Farmers in the study area perceived an increasing 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. Farmers in southern Ethiopia including in the study area grow the perennial food crop Ensete ventricosum (Welw.) Cheesman) close to the homestead and fertilize it with organic fertilizers such as manure, household waste (ash and crop residues), but they grow annual field crops further away from the homestead and fertilize them with inorganic fertilizers, mainly N and P fertilizers (Haileslassie et al., 2006; Haile et al., 2017; Mellisse, 2017). In the study area, 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 (Fig. 4). 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 and Hager, 2011; Haile et al., 2017). Other studies (e.g., Amede and Diro, 2005; Negas and 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 its perennial nature, funnel shaped leaves and sponge root has minimized loss of soil nutrients and carbon content (Amede and Diro, 2005; Duguma and 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 213 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., Lemenih et al., 2005; Getachew et al., 2013; Awdenegest et al., 2013; Gelaw et al., 2015) have shown no significant effects of land use and management on available P which could be attributed to the difference in the application of organic fertilizer.

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 Gurmessa et al. (2016) who reported higher OC and TN contents and their stocks in closed pastureland than other land use types in southern Ethiopia. Moreover, the improvement in soil OC and TN under closed grazing may 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 because of 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 Gurmessa 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 (Table 5, Fig. 6). The finding of this study is different from the findings of other studies (Beweket and Stroosnijder, 2003; Zewdie, 2008; Girmay and Singh, 2012) who reported the negative impacts of eucalyptus tree on the chemical soil 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 smallholder 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 due to its high litter inputs, slow litter decomposition rate, absence of litter raking and presence of diverse understory vegetation in woodlots (Lemma et al., 2006; Duguma and Hager, 2010). However, woodlots over the age of 15–20 years old showed significantly lower pH (5.68) and gravimetric soil moisture content (26.14%) than other land use types. The observed high organic carbon, total nitrogen and available P in the surface layer as compared to subsurface layer indicates that large amount of external inorganic fertilizers temporarily remain in the top surface soil compared deeper soil layer. Similar results were reported by (Wakene Negass and Heluf Gebrekidan, 2004; Alemayehu Kiflu and Sheleme Beyene, 2013; Woldeamlak Bewket and Stroosnijder, 2003) who found higher available P in surface layers.

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 (Table 5) 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 and Weil, 2000; Six et al., 2004) and loss of nutrients due to water and wind soil erosion on bare cereal land (Islam and Weil, 2000; Delagado et al., 2013).
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 (Vaje, 2007; Tsigie et al., 2011; Agegnehu et al., 2013). 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 (Tesfahunegn, 2013; Awdenegest et al., 2013; Dong et al., 2015; Adugna and Abegaz, 2016). The traditional 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.

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 ± 1.2 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 may be attributed to the complexity 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 (Yimer and Abdulakdir, 2008; Gurmesha et al., 2016) 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 (Mekuria 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.

This result agrees with studies by Negasa et al.,2017; Duguma et al. (2010) and Yimer et. al (2007) who found a decreasing trend of OC and TN content and their stocks with increasing soil depths in Southern and Central Ethiopia. The higher TN on the top soil surface (0–15 cm) was directly related to addition of higher inputs in the form of manure, household waste, ash and inorganic fertilizers on the surface soil.

In general, integrating perennial food crops such as enset with multipurpose trees close to the homestead and fertilizing it 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 and Starr, 2015). However, the dominantly practiced cereal farming has been degrading the quality of soils.

Conclusions

The results of this study showed that land use types and soil depth were significantly influenced physicochemical properties of the soils. Soils under enset system and surface soil had significantly high pH, available P, exchangeable K, OC, TN and their stocks than other land use and depth categories. Moreover, closed grazing land had higher OC and TN except for available P and exchangeable K.

Despite the popular notion of environmentally alleged effects of eucalyptus tree on soil properties we only found specific 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. 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 continuously loss of soil nutrients from the dominantly nutrient depleting cereal cropping system.
Declarations

Ethics approval and consent to participate

No relevant

Consent for publication

Not relevant

Availability of data and material

Not relevant

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Authors' contributions

The first author designed the methodology, collect field data, analyzed and write the manuscripts while the 2nd authors was contributed in designing sampling methods and edited the first version of the manuscripts and the 3rd, 4th and 5th authors edited first were edited the final version of the manuscript.

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Figures
Figure 1

Location map of the study area. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 2

Climatic condition of the study area (Source: NMSA, 2015). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 3

Soil sampling points from the five different land use systems; WL = wood lot; EF: enset field; GL: grazing land; FL: annual crops field (farmland) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 4

Enset system receives large amount of organic inputs
Enset and closed grazing land are located close to home while closed grazing land and farm(cereal land far from it.

Woodlots had higher SOC and cereal land. The nutrient below the trees may be due to leaf litter inputs & presence of other herbaceous spp. E.g. Lalisa Alemayehu & found significantly higher TN under cereal farm. Addisu et al., 2007 also found 25-46% soil fertility (measured by NPK & tree than ways from it. Woodlots had low soil pH & MC than indicating the need for precaution minimize soil degradation.
Deposition of leaf litter can improve OC and TN under Eucalyptus woodlots