Research Article

Soil quality evaluation under *Khat* (*Catha edulis*), *Enset* (*Ensete ventricosum*) alone and *Enset-Khat* intercropping in Hanshika sub-watershed, South Ethiopia

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Abstract

Agricultural land use type affects the physical, chemical, and biological properties of soil. This study was designed to evaluate the impact of different agricultural land use types: *Khat* (*Catha edulis*), *Enset* (*Ensete ventricosum*), and *Enset-Khat* on the physical and chemical properties of soils in Hanshika subwatershed, Southern Ethiopia. Twenty seven (3 treatments* 3 replications * 3 sample plots**)** composite soil samples were collected from the top 0-30 cm depth. Undisturbed soil samples were also collected for bulk density determination. The result showed that bulk density (BD) varied significantly with land use types, and was smaller in soil under *Enset* (*Ensete ventricosum*) than the rest of land use types. The soil pH (H_2O), soil organic carbon, total N, available P, available K and cation exchange capacity were higher in soils under *Enset* (*Ensete ventricosum*) than in *Khat* (*Catha edulis*) mono-cropping land use type. Exch. K, Ca and Mg also varied with land use types while exch. Na did not show any trend of variation among the land use types. Cultivating *Enset* (*Ensete ventricosum*) alone or intercropping with *Khat* (*Catha edulis*) have improved most of the investigated soil qualities than *Khat* (*Catha edulis*) alone. Further studies might be required to fully understand and clarify the influence of these management practices on soil properties and soil qualities for valid generalization.

Keywords: Soil health, land conversion, land uses, intercropping, soil properties

1. Introduction

From the point of view of agriculture, it is a basic interest to evaluate soil quality (Carter et al. 2004). Maintaining soil quality provide economic benefits in the form of increased products and productivity (USDA-ERS, 1997). Soil quality (Karlen et al. 1997), which is the capacity of a soil to function, within natural or managed ecosystem boundaries, to sustain biological productivity, maintain or increase water and air quality, and promote human health. Soil quality started to be interpreted as a sensitive and dynamic way to document soil conditions, as resistance to stress imposed by land use changes (Karlen et al. 2001). From the view of soil quality, the dynamic soil nature describes the condition of a specific soil due to land use types and management practices which is measured by using various chemical, physical and biological indicators (Karlen et al. 2003). [1]

In natural processes of soil, reference values represent the inherent capacity of a soil to function by the soil forming factors in its native state and can be used to compare effects of land use types or different management practices on similar soils. Management of the inherent soil health can enhance sustainable production of high quality products with little or no external inputs (Mausbach and Seybold 1998).

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Agriculture is the backbone of the Ethiopian economy and special attention has been given by the government to transform the sector. It represents 42% of the GDP and 85% of the population gain their livelihood directly or indirectly from agriculture. About 64% of agricultural value addition comes from different crops. The most important constraint limiting crop yield in developing nations, and especially among resource-poor farmers, is the decline in soil quality (CSA 2015) primarily due to lack of land use planning, inappropriate cropping system with lower levels of fertilizer application, reduction in the length of fallow periods, complete removal of crop residues from fields and lack of adequate soil conservation practices (Elias 2002).

Ethiopia is one of the countries that experience the highest rates of nutrient depletion in Sub Sahara Africa (FAO 2010). UNDP-ERS (2002) reported that loss of 30 kg N/ha and 15-20 kg P/ha annually. A field level investigation in southern Ethiopia revealed even higher rate of nutrient depletion amounting -102 N and 26 kg K particularly in distant fields planted to cereals (Elias 2002).

The ever increasing soil degradation and nutrient loss from cultivated fields result in declining soil quality that urgently call for actions before reaching at an irreversible stage. The uncultivable lands of the country (hilly, stony and marshy lands) which constituted a significant proportion of the total land size, currently are converted into cultivated land due to high population pressure. Such practices are more widely observed in the southern Ethiopia particularly in Gedeo, Sidama, Gurage, Kambata and Walaita Zones where cultivated lands are converted into *Enset (Ensete ventricosum), Khat (Catha edulis)* and *Khat-Enset* intercropping. However, there is no detail research conducted on the impacts of such conversion practices on soil quality. Hence, this study was proposed to evaluate soil quality as impacted by different agricultural land use types: *Enset (Ensete ventricosum), Khat (Catha edulis)* and *Khat-Enset,* in Hanshika subwatershed, Southern Ethiopia.

2. Materials and methods

2.1 Description of the study area

The study area, Hanshika Subwatershed, is located at about 268 kms Southeast of Addis Ababa, in Wondo Genet District of the Sidama Regional State. Geographically, Wondo Genet District is located between 38^0 37’ to 38^0 42’ E longitude and 7^0 02’ to 7^0 07’ N latitude (Fig. 1). It is part of the L. Hawassa watershed situated in the eastern boundary of the southern rift valley.

2.2 Climate and agro-ecology

The climate of the area belongs to the Ethiopian rift valley and characterized by subtropical agro climatic zone. The minimum and maximum annual temperature of the area is 17^oC and 19^oC, respectively. The mean annual rainfall of the study area is 1214mm (EOSA 2007).

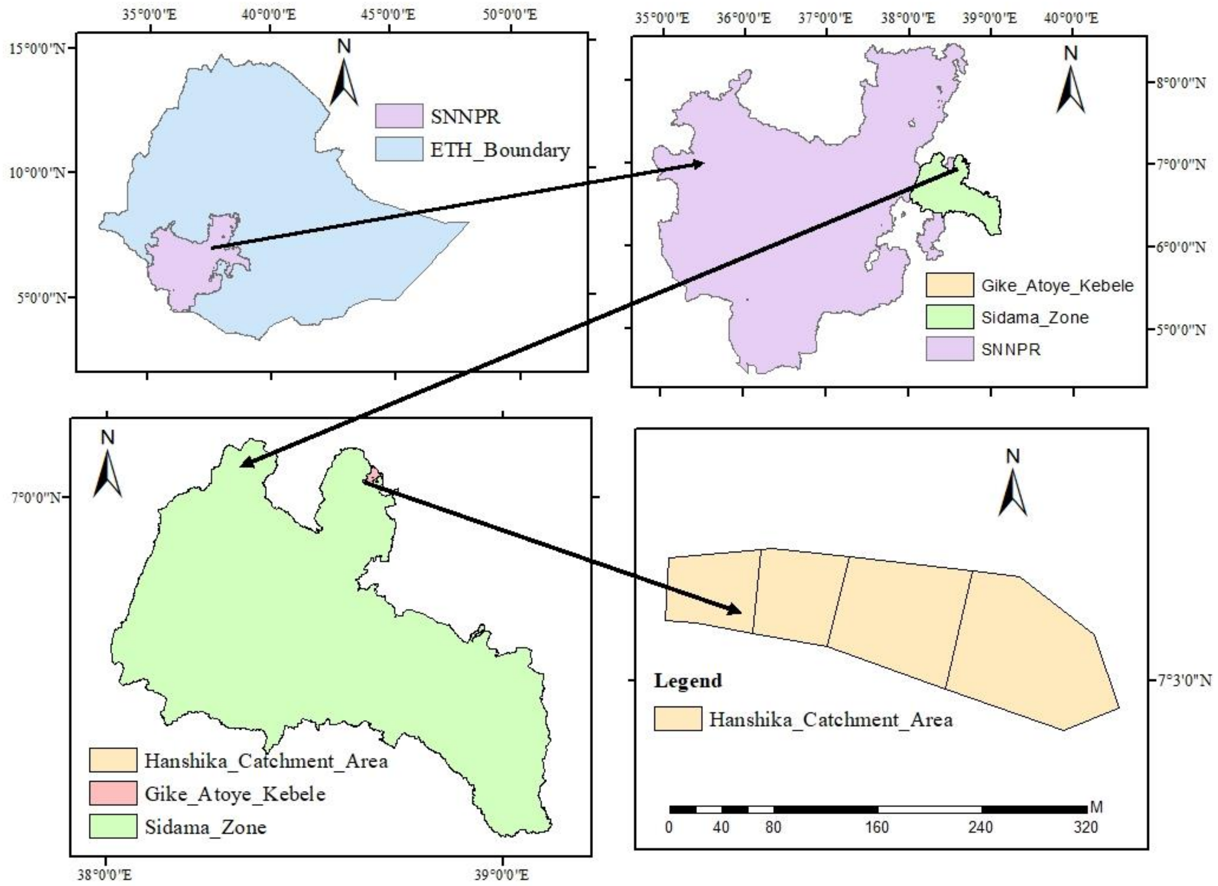

Figure 1. Location map of the study area

2.3 Geology, soil and vegetation

According to Makin et al. (1975) the main parent materials are volcanic deposits of ignimbrite, ash, lava and tuff. The geological bedrock of the area consists of mainly acidic rocks, sometimes inter bedded with lavas of basaltic composition, probably of terrain origin (Eriksson and Stern 1987). The soils around Wondo Genet District are classified as andosols with sandy loam - loam to silt loam textures (Fantaw 2017) and are naturally fertile soils except phosphate limitations (Makin et al. 1975).

Montane forest species such as Celtis africana, Cordia africana, Croton macrostachys, Albizia gumifera, Podocarpus gracilor, Milletia sp. And Phonix spp. are the most dominant tree species (Eriksson and Stern 1978). Currently, the landscape has been changed to different cultivated land use types for the production of both cereal and perennial crops such as sugar cane, *Khat (Catha edulis), Enset (Ensete ventricosum)*, Coffee and various fruit trees. The study area, Hanshika Subwatershed, is particularly characterized by *Khat (Catha edulis), Enset (Ensete ventricosum)* and *Enset-Khat* intercropping.

2.4 Site selection, soil sampling and analyses

Reconnaissance survey has been carried out to record the land use history, cropping sequences, and have some field observation in the study area followed by identification of representative soil sampling plots. Although data was not presented, topographic attributes such as altitude, landscape position, and slope percent were also recorded. Three replicates of dominant cultivation practices (here after *land use* *types*): *Khat (Catha edulis)*, *Enset (Ensete ventricosum)* and *Enset-Khat* intercropping, were selected and three sample plots were randomly assigned and replicated in each land use type.

Fifteen sub-samples, five from each plot, were collected from each land use type to pool one homogenized representative composite soil sample. A total of twenty seven (3 land use types *3 replications*3 sample plots* 1 soil depth: 0-30 cm) bulk soil samples were collected. The soil samples were air-dried, grounded and made to pass through a 2 mm diameter sieve. For soil bulk density determination, a total of twenty seven separate undisturbed soil samples were also collected from 0-30 cm soil depth with three cylindrical cores (10 cm height and 7.2 diameter) per depth. Finally, the prepared soil samples were brought to Wondo Genet College of Forestry and Natural Resorce and Batu Soil Laboratory Centers to analyse selected physical and chemical parameters. The soil physical parameters considered were particle size distribution, bulk density and total porosity while the soil chemical parameters include soil pH, organic carbon content, total nitrogen, available phosphorus, available potassium, cation exchange capacity and exchangeable bases (Na, K, Ca, and Mg).

Soil textural fractions were determined by hydrometer after dispersion in a mixer with hexametaphosphate. Soil bulk density was determined after drying the soil samples in an oven at 105^{o}C to constant weights method (Blake 1965). Total porosity was computed from the values of bulk density (BD) and particle density (PD) considering 2.65g/cm^3 as:

$$\text{Total porosity}\,(\%) = \left(1 - \frac{\text{BD}}{\text{PD}}\right) \times 100$$

The soil pH-H_2O was measured in water suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combination electrode (Reeuwijk Van 1993). The Walkley and Black (1934) wet digestion method was used to determine soil organic carbon content and percent soil OM was obtained by multiplying percent soil OC by a factor of 1.724 following the assumption that OM is composed of 58% carbon. Total nitrogen was measured titrimetrically following the Kjeldhal method as described by Jackson (1973). The carbon- nitrogen ratio of the prepared compost was determined from the quotient of soil organic carbon to total nitrogen (Martin 1991). Available phosphorus was determined colorimetrically using spectrophotometer after the extraction of the soil samples with 0.5M sodium bicarbonate ($NaHCO_3$) at pH 8.5 following the Olsen extraction method (Olsen *et al*. 1954). The exchangeable basic cations (Ca, Mg, K and Na) were extracted with 1N ammonium acetate at pH 7 (Chapman 1965). Exchangeable Ca and Mg were determined from this extract with atomic absorption spectrophotometer, while exchangeable K and Na were determined from the same extract with flame photometer. Cation exchange capacity (CEC) of the soil was determined from ammonium acetate saturated samples that was subsequently replaced by sodium from a percolated sodium chloride solution after removal of excess ammonium by repeated washing with alcohol (Chapman 1965). Percentage base saturation (PBS) was calculated by dividing the sum of the charge equivalents of the base-forming cations (Ca, Mg, Na and K) by the CEC of the soil and multiplying by 100.

2.5 Data analysis

The collected data was subjected to completely randomized design analysis of variance (ANOVA) (CRD) using the General Linear Model (GLM) of the Statistical Analysis System software (SAS Institute 2002). Mean separation was done using Duncan's Multiple Range Test (DMRT) at 5% probability level.

3. Results and discussion

3.1 Soil Physical Properties

3.1.1 Soil texture

Analyses of the soil textural fractions showed that there was no significant variation ($p > 0.05$) in all fractions across all land use types (Table 1). Even though there was no significant difference between them, relatively higher mean sand fraction was observed in soil under *Khat-Enset* intercropping (56%) followed by *Khat* (*Catha edulis*) (52%). The lowest sand percent (49%) was in soil under Enset *(Ensete ventricosum)*. The highest silt (21%) proportion was observed in soils of the *Enset (Ensete ventricosum)* whereas the lowest (13%) was in *Khat-Enset* intercropping of cultivated land use types. Across all land use types, the soil textural class is sandy clay loam (Table 1). The similar textural class across all land use types indicates the homogeneity of soil forming processes and similarity of parent materials (Foth, 1990) and not influenced considerably by land use types and soil management (Brejda et al. 2000).

Table 1. Mean (±SEM) of soil texture, soil bulk density and total porosity at Hanshika Subwatershed

Land use type (0-30 cm depth)	Soil texture (%)			Textural class	BD (g/cm^3)	TP (%)
	Sand	Silt	Clay			
Khat	52±0.33^{a}	18±0.23^{a}	30±0.06a	SCL	0.98±0.00^{a}	63.02±0.09^{c}
Enset	49±0.28^{a}	21±0.25^{a}	30±0.06a	SCL	0.86±0.01^{c}	67.54±0.06^{a}
Khat-Enset	56±0.30^{a}	13±0.20^{a}	31±0.07a	SCL	0.92±0.01^{b}	65.28±0.08^{b}
LSD (0.05)	6.45	0.82	NS		0.05	1.55

LSD = Least significant difference; NS = Not significant; SEM = Standard error of mean; BD = Bulk density; TP = Total porosity; SCL = Sandy clay loam; Means within a row for the same factor followed by the same letters in superscripts are not significantly different from each other at P = 0.05

3.1.2 Soil bulk density

The soil bulk density showed significant variation with land use types ($p \leq 0.05$). The highest mean soil bulk density was recorded under *Khat (Catha edulis)* (0.98 g/cm^3) while the lowest was under the *Enset* (*Ensete ventricosum*) (0.86 g/cm^3) land use type (Table 1).

The highest mean soil bulk density obtained in *Khat (Catha edulis)* land use type could be attributed to the lower level soil organic matter content and total porosity (Tables 1 and 2). Sintayehu (2006) also reported variation in soil bulk density with land use types due to differences in the land management and land use histories. The smaller bulk density in soils under *Enset* (*Ensete ventricosum*) land use type is an indicative of better soil physical quality as it is less compacted and does not limit root penetration (Landon 1991).

3.1.3 Total porosity

The soil total porosity results of the three land use types were significantly ($p \leq 0.01$) different. The largest mean value of soil total porosity was observed under the *Enset (Ensete ventricosum)* (67.54%) land use type while the lowest was under the *Khat (Catha edulis)* (63.02%) land use type (Table 1). The highest mean total porosity under the *Enset (Ensete ventricosum)* land use type might be due to the high organic carbon (4.98%) or organic matter (8.58%) contribution from the *Enset (Ensete ventricosum)* (Table 2). However, the total porosity of soils of the study area falls within the normal porosity range (30 and 70%) for most mineral soils and can be used as a very general indication of the degree of compaction in a soil in the same way as bulk density is used (Landon 1991).

3.2 Soil Chemical Properties

3.2.1 Soil pH (H_2O: 1:2.5)

The soil pH also varied significantly ($p \leq 0.05$) with land use types (Table 2). The highest soil pH was recorded in the soils under *Enset (Ensete ventricosum)* (pH 5.76) followed by the *Khat-Enset* (pH 5.75) land use types and both fall under medium ratings and preferred range for most crops (Landon, 1991). The lowest pH (pH 5.49) was observed in soil under *Khat (Catha edulis)* land use type. However, according to Tekalign (1991) rates for Ethiopian soils, the soil pH of the study area was medium (5.3-5.9) acidic across all land use types.

3.2.3 Soil organic carbon (OC, %)

The soil organic carbon showed significant ($p \leq 0.05$) differences with land use types (Table 2). The highest (4.77%) mean OC was observed in soil under *Enset* followed by the *Khat-Enset* (4.12%) land use type while the lowest (2.67%) mean value of OC was found in the *Khat*. The lower SOC content under *Khat* than in *Enset* and *Khat-Enset* intercropping could be due to the reduced amount of organic materials (green leaves) being returned to the soil system (Girmay et al. 2008).

Table 2. Mean (±SEM) of selected soil chemical properties at Hanshika Subwatershed

Land use type (0-30 cm depth)	pH-H_2O	OC (%)	Total N (%)	C:N	Av. P (mg/kg)	Av. K (mg/kg)
Khat	5.49 ± 0.02^b	2.67 ± 0.02^b	0.23 ± 0.01^c	11.6 ± 0.30^a	2.02 ± 0.03^b	154 ± 0.03^c
Enset	5.76 ± 0.01^a	4.77 ± 0.03^a	0.42 ± 0.00^a	11.4 ± 0.28^a	2.44 ± 0.02^a	333 ± 0.49^a
Khat-Enset	5.75 ± 0.30^a	4.12 ± 0.02^a	0.36 ± 0.01^b	11.4 ± 0.27^a	2.15 ± 0.03^b	298 ± 0.48^b
LSD (0.05)	0.25	1.40	0.05	0.09	0.24	10.47

LSD = Least significant difference; SEM = Standard error of mean; OC = Organic carbon; N = Nitrogen; C:N = Carbon to nitrogen ratio; Av. P = Available phosphorus; Av. K = Available potassium; Means within a row for the same factor followed by the same letters in superscripts are not significantly different from each other at P = 0.05

On the other hand, the soil organic matter content under *Enset* land use type was also higher than under *Khat (Catha edulis)* land use type due to addition of enset residues after harvest. According to the soil OC rating scale of Tekalign (1991), the soil OC values under *Khat* land use type fall within the medium (1.5-3.0) range and the soil carbon under *Enset* and *Khat-Enset* were high (> 3.0).

3.2.4 Total nitrogen (N, %) and C:N ratio

Total N and C:N ratios showed significant ($p \leq 0.05$) differences. The highest mean (0.42%) soil total N was observed under the *Enset* and the lowest (0.23%) in the soils under Khat land use type (Table 2). In all land use types considered in this study, total N decreased consistently from *Enset (Ensete ventricosum)* to *Khat-Enset* then to *Khat*. The variation seem parallel with the change in organic carbon content (Table 2). Moges and Holden (2008) reported that total nitrogen is associated with the relatively higher organic carbon which in turn resulted from plant and root biomass as well as residues being returned to the soil system. The C:N ratio did not significantly vary with land use types and found to be within the range of 8:1-15:1 which is commonly cited as an indicator of intermediate organic matter mineralization (Prasad and Power 1997). The narrow variations in C/N ratios across all land use types suggest less variability in the degree of humification of organic matter.

3.2.5 Available phosphorus (P, ppm)

The analysis of variance revealed that the available phosphorus showed significant ($p \leq 0.05$) difference with land use types (Table 2). The highest (2.44 mg/kg) mean available P was observed in soils under *Enset (Ensete ventricosum)* land use type compared with the rest land use types. Girma and Endalkachew (2013) reported low available phosphorus resulted from absence of biomass addition to the soils and P- fixation by Al and Fe (Eylachew 1999). However, according to the soil quality rating scales of Cottenie (1980) and Landon (1991), soils of the study area are generally deficient (< 4 ppm) of available P. Consequently, low available P in the soils became one of the major soil fertility limiting factors to crop production (Fantaw 2017).

3.2.6 Available potassium (K)

The available K showed significant ($p \leq 0.05$) variation with land use types. The highest (333 mg/kg) mean value of available K was observed in soil under *Enset (Ensete ventricosum)* while the lowest (154 mg/kg) was under *Khat (Catha edulis)* land use type (Table 2). The observed highest concentration of available potassium under the *Enset (Ensete ventricosum)* land use type was attributed to the application of organic wastes (Bohn et al., 2001). According to FAO (2006) ratings, the available K was medium (117.2-234.6 mg/kg) in soils under *Khat (Catha edulis)* to high (234.6-469.2 mg/kg) ratings both in soils under *Enset (Ensete ventricosum)* and *Khat-Enset* land use types.

3.2.7 Exchangeable sodium (Na, meq/100g) and potassium (K, meq/100g)

The exchangeable Na showed no significant ($p \leq 0.05$) variation with land use types but, the exchangeable K varied significantly with land use types (Table 3). The mean exchangeable K was the highest (8.97 meq/100gm) under *Enset (Ensete ventricosum),* while it was the lowest under *Khat (Catha edulis)* (4.87meq/100gm). According to the FAO (2006) ratings, the observed mean values of exchangeable K of the studied soils fall in the range of very high (> 1.2 meq/kg) across all land use types.

3.2.8 Exchangeable calcium (Ca, meq/100g) and magnesium (Mg, meq/100g)

Ca and Mg were the principal base cations in the exchange complex of studied soils which significantly varied with use types (Table 3). The highest (12.45meq/100gm) mean concentration of Ca was observed under *Enset (Ensete ventricosum)* and followed by *Khat-Enset* (10.90 meq/100gm) while the lowest exchangeable values of Ca (8.76 meq/100gm) were recorded in soils under *Khat (Catha edulis)* land use type. The highest exchangeable Ca in soil under *Enset (Ensete ventricosum)* and *Khat-Enset* could be due to the relatively higher OM content in these land use types. The concentration of Ca and Mg generally follow the pH trend, in agreement with the findings of Young and Hammer (2000). Exchangeable calcium in a soil has an important relation to soil pH and to the availability of several nutrient elements (Thompson and Troeh 1993).

Table 3. Mean (±SEM) exchangeable bases, CEC and base saturation at Hanshika Subwatershed

Land use type (0-30 cm depth)	Na	K	Ca	Mg	CEC	BS (%)
	------------------------------(meq/100g) ---------------------------------					
Khat	3.46±0.02	4.87 ± 0.28^{b}	8.76 ± 0.05^{b}	7.34 ± 0.09^{b}	46.58 ± 0.50^{c}	52.45 ± 0.34^{b}
Enset	3.66±0.01	8.97 ± 0.14^{a}	12.45 ± 0.04^{a}	10.42 ± 0.04^{a}	59.46 ± 0.13^{a}	59.70 ± 0.05^{a}
Khat-Enset	3.62±0.01	5.72 ± 0.12^{ab}	10.90 ± 0.08^{a}	8.50 ± 0.04^{b}	52.78 ± 0.27^{b}	54.45 ± 0.26^{b}
LSD (0.05)	NS	3.64	1.76	1.14	6.04	4.34

LSD = Least significant difference; NS = Not significant; SEM = Standard error of mean; CEC = Cation exchange capacity; BS = Base saturation; Means within a row for the same factor followed by the same letters in superscripts are not significantly different from each other at P = 0.05

According to the FAo (2006) ratings for exchangeable Ca and Mg, the mean concentration of Ca in soil under Enset (Ensete ventricosum) and Khat-Enset were rated as high (10.0-20.0

meq/100gm), and very high Mg concentration (> 8.0 meq/100 gm) indicating that the two concentrations were sufficiently available in the soils.

3.2.9 Cation exchange capacity (CEC, meq/100g)

The variation in CEC was significant ($p \leq 0.05$) with the land use types. Accordingly, the highest mean CEC value was observed in soils under *Enset (Ensete ventricosum)* (59.46 meq/gm) land use type while the lowest (46.58 meq/gm) was under *Khat (Catha edulis)* land use type (Table 3). This might be due to high OM contents recorded under the *Enset (Ensete ventricosum)* land use type (Table 2). Similar result was reported by Gao and Chang (1996) that the organic matter plays an important role in exchange process as it provides more negatively charged surfaces than clay particles do. According to the Landon's (1991) ratings, the investigated soils have a very high level (> 40 meq/100 gm) of CEC for agricultural crop productions. The very high CEC values may be attributed to the predominance of high surface area clay minerals such as allophane and imegolite (Wada, 1985; Southard and Southard, 1989) and organic matter (Voundi Nkana et al. 1998; Fantaw 2017). CEC of a soil is determined by the relative amount and/or of two main colloidal substances; humus and clay (Gao and Change 1996).

3.2.10 Percent base saturation (PBS)

The percent base saturation (PBS) varied with land use types ($p \leq 0.05$; Table 3). It was higher (59.7%) in soil under *Enset (Ensete ventricosum*) compared to the rest of land use types (Table 3), attributed to the exchange sites with less amounts of organic matter (carbon) and more base cations leading to higher base saturation (Fantaw, 2017). The investigated soil the different land use types had high PBS of greater than 50 percent values and were generally considered fertile according to Landon (1991) ratings.

4. Conclusion

Soil quality indicators are affected by several physicals, chemical, and biological parameters of the different land use types. Accordingly, statistically significant differences in soil quality indicators such as bulk density, total porosity, soil pH (H_2O), CEC, exchangeable bases (Ca, Mg, K and Na), PBS, OC, total N, available P and available potassium were mainly impacted by the management practices. Thus, the low soil quality results in the *Khat (Catha edulis)* cultivation should be corrected through appropriate integrated soil management practice mainly focused on organic residue management. Further research is recommended need for valid generalization and knowledge on the soil quality indicators in relation to different local soil management practices.

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References

Blake GR (1965) Bulk Density. In: Blake Methods of soil analysis. Part I, No. 9, American Society of Agronomy. Madison, Wisconsin, USA, pp374-399.

Bohn HL, Mcneal BL, O'connor HL, Mcneal BL and Connor GA (2001) Soil Chemistry, John Wiley & Sons, New York, Ny, USA, 3rdedition.

Brejda J, Moorman T, Karlen B and Dao T (2000) Identification of regional soil quality factors and indicators: I. Central and southern high plains. Soil Sci Soc Am. J 64:2115–2124.

Carter MR, Andrews SS, Drinkwater LE (2004) Systems approaches for improving soil quality. In: Schjonning P, Elmholt S, Christensen BT (eds), Managing Soil Quality: Challenges in Modern Agriculture. CABI International, Wallingford, UK, pp. 261-281.

Chapman HD (1965) Total Exchangeable Bases. In: Black CA (eds), Methods of Soil Analysis. Part 2. Soil Science Society of America, Madison, WI.

Cottenie A (1980) Soil and plant testing as a basis of fertilizer recommendations. FAO soil Bulletin 38/2. Food and Agriculture Organization of the United Nations, Rome, Italy.

CSA (2015) Population and soil issues of Ethiopia: results for Oromia Region, vol 1, Tables 2.1, 2.5, 3.4.

Elias E (2002) Farmers’ perceptions of soil fertility change and management. SOS-Sahel and Institute for Sustainable Development, Addis Ababa.

EOSA (Ethio-Organic Seed Action) (2007) Baseline Survey of Dendi, Awassa Zuria and Hetosa Districts of Ethiopia, Ethio-organic seed action in collaboration with center for genetic resources, the Netherlands.

Erikson H and Stern M (1987) A soil Study at Hawassa Zuria, Ethiopia, Swedish University of Agricultural Science. International Rural Development Center-Uppsala, ISSN 0280-4301

Eylachew Zewdie (1999) Selected physical, chemical and mineralogical characteristics of major soils occurring in Character Highlands, Eastern Ethiopia. SINET: Ethiop. J. Sci. 1(2): 173–185

Fantaw Yimer (2017) Effect of Landscape Positions on Soil Properties in an Agricultural Land - A transect study in the Main Rift Valley area of Ethiopia. Journal of Science and Development 5 (1): 21-31.

FAO (Food and Agriculture Organization) (2006) Plant nutrition for food security: A guide for integrated nutrient management. FAO, Fertilizer and Plant Nutrition, Bulletin 16. FAO, Rome, Italy.

Foth HD (1990) Fundamentals of Soil Science, John Wiley and Sons, New York, NY, USA, 8th edition.

Gao G and Chang C (1996) Changes in cation exchange capacity and particle size distribution of soils associated with long-term annual applications of cattle feed lot manure. Soil Sci 161: 115-120.

Girma Abera and Endalkachew Wolde-Meskel (2013). Soil Properties, and Soil Organic Carbon Stocks of Tropical Andosol under Different Land Uses. Open Journal of soil science 3: 153-162

Girmay Gebresamuel, Singh BR, Mitiku Haile, Borresen T and Lal R (2008) Carbon stocks in Ethiopian soils in relation to land use and Soil management. Land Degradation and Development 19, (4): 351–367.

Jackson ML (1973) Soil Chemical Analysis. Prentice Hall, Inc., Engle wood Cliffs. New Jersey, p.183-204.

Karlen DL, Mausbach MJ, Doran JW, Cline RG, Harris RF and Schuman GE (1997) Soil quality: A concept, definition, and framework for evaluation. Soil Sci. Soc. Am. J. 61: 4-10.

Karlen DL, Andrews SS and Doran JW (2001) Soil quality: current concepts and application. Adv. Agronom. 74: 1-40.

Karlen DL, Ditzler CA and Andrews AS (2003) Soil quality: Why and how? Geoderma. 114: 145-156.

Makin MJ, Kingham JJ, Waddam AE, Birchall CJ and Tefera T (1975) Development Prospects in the Southern Rift valley. Land Resources Division, Ministry of Overseas Development, England.

Moges A and Holden NM (2008) Soil fertility in relation to slope position and agricultural land use: a case study of umbulo catchment in Southern Ethiopia. Environmental Management, 42 (5):753–763.

Landon JR (1991) Booker tropical soil manual: A handbook for soil survey and agricultural land evaluation in the tropics and sub-tropics. Longman Scientific and Technical, Essex, NewYork. 474p.

Mausbach MJ and Seybold CA (1998) Assessment of soil quality. In: Lal R. (eds), Soil Quality and Agricultural Sustainability. Ann Arbor Press, Chelsea, MI, pp. 33-43.

Olsen SR, Cole CV, Watanable FS and Dean LA (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939. U. S. Government Printing Office, Washington DC.

Prasad R and Power JF (1997) Soil Fertility Management for Sustainable Agriculture, Lewis Publisher. Boca Raton, New York Printed Hall, Inc., USA. 392p.

Reeuwijk Van (1993) Procedures for soil analysis.4th ed. International Soil Reference and Information Center, the Netherlands.

Southard SB and Southard RJ (1989) Mineralogy and Classification of Andic Soils in Northeastern California. Soil Sci. Soc. Am. J. 53: 1784-1791.

SAS (2002) Statistical Analysis Systems SAS/STAT User's Guide Version 9 Cary NC:SAS Institute Inc. USA.

Sintayehu Mesele (2006) Land Use Dynamics and its Impact on Selected Physicochemical Properties of Soils in Yabello District of Borana Lowlands, Southern Ethiopia [M.S. thesis], Haromaya University, Haromaya, Ethiopia.

Tekalign Tadesse (1991) Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa, Ethiopia.

Thompson LM and Troeh RF (1993) Soils and Soil Fertility, 5th ed., Oxford University Press. New York, USA

USDA-ERS (1997). Agricultural resources and environmental indicators 1996–1997. In: Agric. Handb., 712, U.S. Gov. Print. Office, Washington, DC.

Voundi Nkana JC Demeyer A and Verloo MG (1998). Chemical effects of wood ash on plant growth in tropical acid soils. BioresourceTechnology 63 (3): 251–260.

Wada K (1985) The distinctive properties of Andosols. Adv. Soil Sci. 2:173 - 229.

Walkley A and Black I A (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci., 37: 29-38.

Young FY and Hammer RD (2000) Soil-Landform Relationships on a loess-Mantled Upland landscape in Missouri. Soil Sci. Soc. Am. J. 64: 1443-1454