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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 (H₂O), 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). 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).

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 380 37' to 380 42' E longitude and 70 02' to 70 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 17oC and 19oC, respectively. The mean annual rainfall of the study area is 1214mm (EOSA 2007).

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 Resource 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

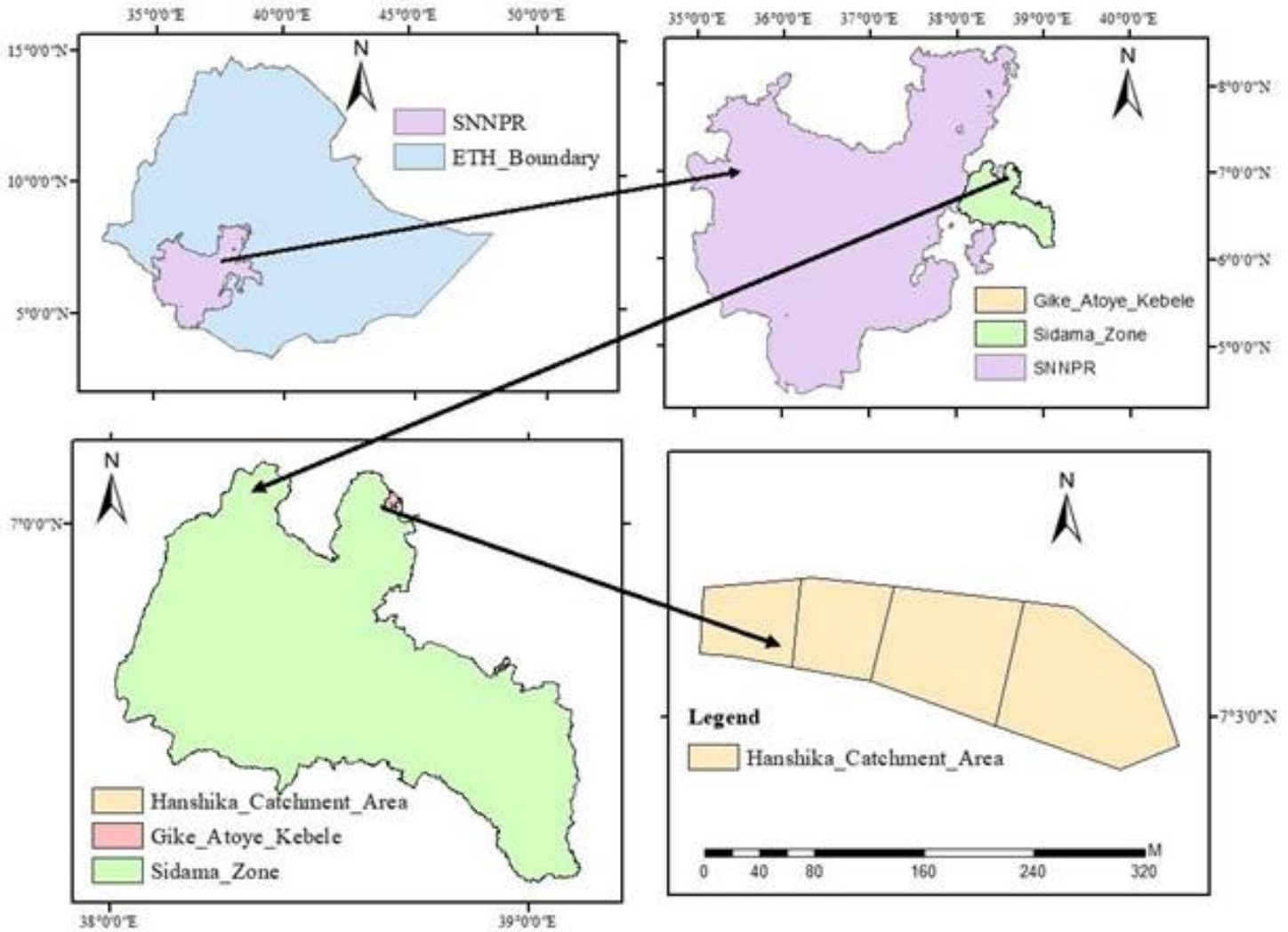


Figure 1: Location map of the study area

in a mixer with hexametaphosphate. Soil bulk density was determined after drying the soil samples in an oven at 105°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/cm³

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

The soil pH-H₂O 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 (NaHCO₃) 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).

3.2 Soil bulk density

The soil bulk density showed significant variation with land use types ($p < 0.05$). The highest mean soil bulk density was recorded under Khat (*Catha edulis*) (0.98 g/cm³) while the lowest was under the Enset (*Ensete ventricosum*) (0.86 g/cm³) 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).

3.3 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).

3.4 Soil Chemical Properties

3.4.1 Soil pH (H₂O: 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.

3.5 Soil organic carbon (OC, %)

The soil organic carbon showed significant ($p \leq 0.01$) 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).

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).

3.6 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

Table 1: Mean (\pm 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 \pm 0.33 ^a	18 \pm 0.23 ^a	30 \pm 0.06 ^a	SCL	0.98 \pm 0.00 ^a	63.02 \pm 0.09 ^a
Enset	49 \pm 0.28 ^a	21 \pm 0.25 ^a	30 \pm 0.06 ^a	SCL	0.86 \pm 0.01 ^c	67.54 \pm 0.06 ^b
Khat-Enset	56 \pm 0.30 ^a	13 \pm 0.20 ^b	31 \pm 0.07 ^a	SCL	0.92 \pm 0.01 ^b	65.28 \pm 0.08 ^b
LSD (0.05)	6.45	0.82	NS		0.05	1.55

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 the $p=0.05$

Table 2: Mean (\pm SEM) of selected soil chemical properties at Hanshka Sub-watershed

Land use	pH-H ₂ O type (0-30 cm depth)	OC (%) (mg/kg)	Total N (%)	C:N	Av. P (mg/kg)	Av. K (mg/kg)
Khat	5.49 \pm 0.02 ^b	2.67 \pm 0.02 ^b	0.23 \pm 0.01 ^c	11.6 \pm 0.30 ^a	2.02 \pm 0.03 ^c	154 \pm 0.03 ^c
Enset	5.76 \pm 0.01 ^a	4.77 \pm 0.03 ^a	0.42 \pm 0.00 ^a	11.4 \pm 0.28 ^a	2.44 \pm 0.02 ^a	333 \pm 0.49 ^a
Khat-Enset	5.75 \pm 0.30 ^a	4.12 \pm 0.02 ^a	0.36 \pm 0.01 ^b	11.40 \pm 0.27 ^a	2.15 \pm 0.03 ^b	298 \pm 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 $p=0.05$

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.

3.7 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).

3.8 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 ap-

plication 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.

3.9 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.

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

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

Table 3: Mean (\pm SEM) exchangeable bases, CEC, and base saturation at Hanshka Subwatershed

Land use	Na	K	Ca	Mg	CEC	BS (%)
	(meq/100g)					
<i>Khat</i>	3.46 \pm 0.02	4.87 \pm 0.28 ^b	8.76 \pm 0.05 ^b	7.34 \pm 0.09 ^b	46.58 \pm 0.50 ^c	52.45 \pm 0.34 ^b
<i>Enset</i>	3.66 \pm 0.01	8.97 \pm 0.14 ^a	12.45 \pm 0.04 ^a	10.42 \pm 0.04 ^a	59.46 \pm 0.13 ^a	59.70 \pm 0.05 ^a
<i>Khat-Enset</i>	3.62 \pm 0.01	5.72 \pm 0.12 ^{ab}	10.90 \pm 0.08 ^a	8.50 \pm 0.04 ^b	52.78 \pm 0.27 ^b	54.45 \pm 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 $P = 0.05$

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

3.11 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 imogolite (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).

3.12 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 (H₂O), 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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Competing interests

The authors declare that they have no competing interests.



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