Seyoum *Environ Syst Res (2016) 5:18*
DOI 10.1186/s40068-016-0069-y

Environmental Systems Research

RESEARCH Open Access

Assessment of soil fertility status of Vertisols under selected three land uses in Girar Jarso District of North Shoa Zone, Oromia National Regional State, Ethiopia

Berhanu Seyoum*

Abstract

Background: Land use changes from forests to farmland and grazing land and subsequent changes in soil physical and chemical properties that results in soil fertility decline are widespread activities in Ethiopia. Particularly, this is the most practiced activities in highland areas of the country. The objective of this study was to assess the soil fertility status of Vertisols under different land uses in Girar Jarso District. A total of 18 disturbed and undisturbed soil samples were collected using augur and core samplers. Data were analyzed through analysis of variance (ANOVA) using the statistical analysis system (SAS version 9.00).

Results: The result showed that the soil physical parameters such as soil particle size, bulk density and total porosity, and most of soil chemical parameters (pH, organic carbon, total N, available P, cation exchange capacity and exchangeable acidity) were significantly different among land uses. Percent of sand content was lower in cultivated land than those of grazing and forest lands. On the other hand, the clay percent under cultivated land use was significantly higher than the grazing and forest lands. Bulk density was higher in cultivated land compared to grazing and forest lands; whereas, total porosity was lower in cultivated land than the others two. Soil pH in cultivated land was significantly lower than the grazing and forest lands. The results of organic carbon and total nitrogen were also lower in cultivated land than those of forest and grazing lands. Available phosphorus result was higher in soils of cultivated land than the soils of forest and grazing lands. Lower cation exchange capacity coupled with higher exchangeable acidity was recorded in cultivated land than the grazing and forest lands.

Conclusion: The result of this study implies that soil fertility management of Vertisols need to focus on strategies which improve the soil physical and chemical properties. Thus, integrated soil fertility management, particularly lime treatment should be applied on strong acidic soils of the cultivated land.

Keywords: Cultivated land, Grazing land, Forest land, Fertility status, Soil dept

Background

Land use/land cover changes that involve conversion of natural forest to farmland, open grazing and settlement are widely practiced in Ethiopia. Such change in land use is severe, particularly in the highlands where there is high population density that directly depend on the exploitation of natural resources (Tekle and Hedlund 2000). These practices have caused land degradation and soil fertility decline contributing to low agricultural productivity and food insecurity in the country (Desta et al. 2000). The quality of soils determines man's standard of living. The implication is that the survival and well being of the present and future generation in countries with subsistence agriculture and centuries old farming practices depend on the extent of maintaining soil fertility which is the basis of agricultural resources (Brady

*Correspondence: berhanuseyoumm@gmail.com
Wondo Genet College of Forestry and Natural Resources, School of Natural Resources and Environmental Studies, Hawassa University, P. O. Box 128, Shashemene, Ethiopia

and Weil 2002). On the other hand, the success in soil management to maintain the soil quality depends on an understanding of how the soil responds to agricultural practices over time (Negassa and Gebrekidan 2004).

Different land uses could significantly contribute to the variation in soil physicochemical properties. Physical and chemical properties of soils on land under continuous cultivation could vary from the land that remains uncultivated for a long period of time (Gebreyohannes 2001). Several studies in the tropics indicate significant changes in soil properties following deforestation and the subsequent conversion of the land into different land uses (Sombroek et al. 1993; Lal 1996; Islam and Weil 2000; Campos et al. 2007). A soil loss due to erosion is related to the processes of soil chemical, physical and biological degradation (Elias 2002). Soil degradation in this case refers to the reduction in soil fertility due to various human activities. It is this variability of human practices (application of fertilizer, removal of crop residues, plowing the land, etc.,) that is significant sources of the changes of soil physical and chemical properties in Ethiopia (Kippe 2002).

Despite the general understanding that land degradation is a threat to agricultural productivity, very few studies have been done to quantify the extent, rate and process of soil fertility depletion under different land uses and management practices in the country (Elias 2002). Among these, the study conducted by Solomon et al. (2002a) indicated that a significant decline in soil organic carbon after conversion of forest to maize cultivation in south-western Ethiopia. Similar study also reported a decline in soil organic carbon and total nitrogen in cultivated soils that converting from natural vegetation in southern Ethiopia (Lemenih and Itanna 2004). Another study also showed that a decline in the amount of available phosphorus following clear cutting and long term cultivation in south-west Ethiopia highlands (Solomon et al. 2002b). According to Desta (1983), considerable differences have been also observed in the micronutrient contents of cultivated lands in Ethiopia. While iron and manganese levels were reported adequate, zinc varied from low to high, and copper seemed to be the most deficient.

Even though, the consequences of converting forest land to farmland and grazing are well known, the study of these effects on soil physical and chemical properties with an evaluation of soil fertility status in north central highlands of Ethiopia is less adequate. With regard to this, there has been no available information produced in the current study area that concerning to the title here undertaken. Thus, assessing land use induced changes on soil properties and subsequent implication on soil fertility status is essential for understanding the influence of agro-ecosystem transformation on soil productivity and to indicate appropriate and sustainable soil and land management options. Therefore, this study was proposed with the specific objective of assessing the soil fertility status of Vertisols in Girar Jarso District based on some selected soil physicochemical properties in three land uses along soil depth.

Methods

Description of the study area

The study was conducted in Girar Jarso District, which is located in North Shoa Zone, Oromia National Regional State, Ethiopia (Fig. 1). It is situated at about 112 km north of Addis Ababa, the capital city of the country, on the main road to Gojjam. Geographically, it lies between 9°40′35″ and 9°42′38″ North latitude and 38°05′12″ to 38°08′25″ East longitude. The altitude of the area is on the average 2075 m above sea level (m a s l).

The study area is characterized by uni-modal rainfall pattern with the rainy season beginning in April and extending to September. The maximum rainfall is recorded in the month of August followed by July with a mean monthly rainfall exceeding 300 mm. The total annual rainfall ranges from 840.2 to 1266.0 mm with a mean annual of 1070 mm. The mean annual air temperature is 16.6 °C with mean maximum of 21.8 °C and minimum of 11.3 °C (Fig. 2).

Soils, land uses and vegetation

Depending on the field color observation, the soil of the study area is black that locally the farmers call the black soils *biyyee gurraacha*. According to (OPEDB 2001) the pellic Vertisols are the dominant soil types occurring in the study area.

Cultivated land and grazing land are the major land uses in the area. However, cultivated land is the dominant land use of the area because crop production is widely practiced through traditional subsistence peasant farming on individual holding under rain-fed condition. The second land use is the grazing land which is individually held by the farmers. Forest (natural) land that is found on the limited areas of the district, is the third land use observed in the study area.

The major annual crops grown in the study area under rain-fed conditions are *teff* (*Eragrostis tef*), bread wheat (*Triticum aestivum* and *Triticum durum)*, faba bean (*Vicia faba*), barley (*Hordeum vulgare*) and field peas (*Pisum sativum*). The dominant crop produced is *teff* followed by wheat and beans. With regards to the grazing land, different short grass species cover the grazing land. Based on the information obtained from an open interview, before 50–60 years ago, many areas of the district

Fig. 1 Location map of the study area

were covered with forest. Since then, the natural woodland vegetation of the study area gradually decreased due to population pressure that brought the land under cultivation and grazing lands, as well as increased demand for fuel-wood. Currently, in the study area, there is a very few forest.

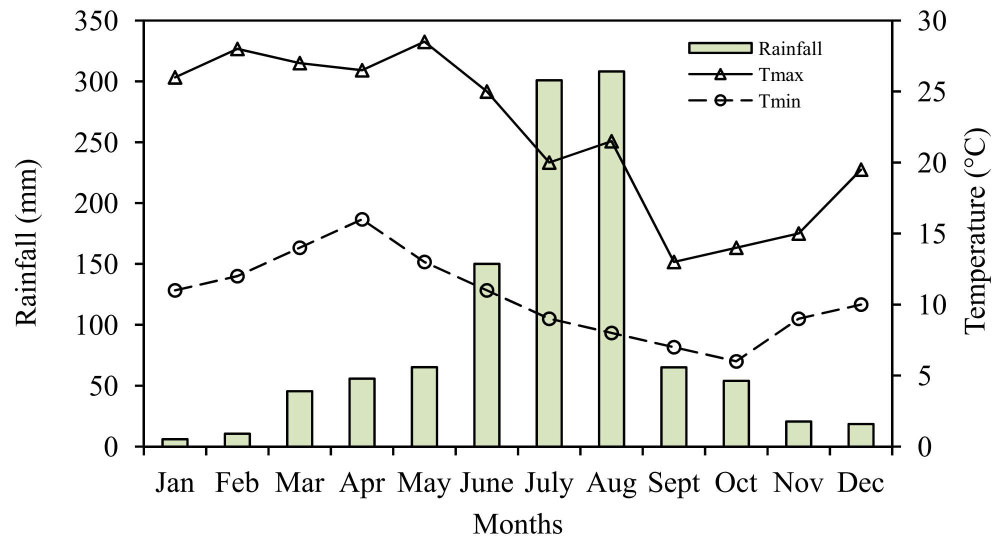

Fig. 2 Mean monthly rainfall (mm) and maximum and minimum air temperatures (°C) of the Girar Jarso District, North Shoa Zone

Site selection, soil sampling and sample preparation

Field observation was made to determine the representative land uses and soils of the study area. Thus, cultivated land, grazing land and forest land uses were identified for the study. The soils that are found at present in the different land uses are presumed to have similar morphological, physical and chemical properties prior to their disturbance by different land use impacts. For the determination of soil physical and chemical properties, representative soil samples were collected randomly from each land use at the depths of 0–20 and 20–40 cm in three replications based on similar slope. Ten sub-samples were taken from each depth in each treatment of the three land uses to prepare one composite soil sample. A total of eighteen (18) disturbed soil samples were collected and well mixed in a bucket. About 1 kg of the composite samples was then properly labeled, bagged and transported to the laboratory for the sample preparation and analysis of selected soil physicochemical properties. The soil samples were air-dried, ground and made to pass through a 2 mm diameter sieve. To determine the soil bulk density, undisturbed soil samples were collected in core samplers of known dimensions.

Analysis of soil physical properties

The particle size distribution of the soil was analyzed based on the standard procedures suggested by Bouyoucos with the help of the hydrometer method. Bulk density was determined from undisturbed soil samples collected in core samplers of known dimensions and finally calculated as the mass of the oven dry soil per unit volume of the soil including the pore spaces after drying in an oven at 105 °C (Blake 1965). Particle density was determined by the pycnometer method as stated by Blake (1965). Total porosity was computed from the values of bulk density (BD) and particle density (PD) as:

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

Analysis of soil chemical properties

The pH of the soil was measured potentiometrically using glass electrode pH meter in the supernatant suspension of 1:2.5 soil to water ratio (Jackson 1973). Electrical conductivity was determined from soluble salts in an extracted solution of 1:2.5 soil water ratios (Jackson 1973). Soil organic carbon was determined by the wet oxidation method as described by Walkley and Black (1934). Total nitrogen was measured titrimetrically following the Kjeldhal method as described by Jackson (1973). Available phosphorus was determined colorimetrically using spectrophotometer after the extraction of the soil samples with 0.5 M 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 1 N 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). Exchangeable acidity was determined by saturating the soil sample with 1 M KCl solution and titrating with 0.02 M NaOH as described by Rowell (1994). From the same extract, exchangeable aluminum (Al) in the soil sample was titrated with standard solution of 0.02 M HCl. Effective cation exchange capacity (ECEC) was determined by the summation of exchangeable bases and exchangeable acidity (Sahlemedhin and Taye 2000). Percent base saturation (PBS) was computed as the ratio of the sum of exchangeable bases to the CEC.

Soil micronutrient cations (Fe, Mn, Cu and Zn) were extracted with diethylene triamine pentaacetic acid (DTPA) method as described by Lindsay and Norvell (1978). The amount of the micronutrients in the extract were determined by atomic absorption spectrophotometer in comparison with the standards at 248.3, 279.5, 324.7 and 213.9 nm wavelengths for Fe, Mn, Cu and Zn, respectively.

Statistical analysis

The data obtained from the laboratory analysis were subjected to analysis of variance for two-factors RCBD (factorial) with land use and soil depth as factors using the general linear model (GLM) procedure of the statistical analysis system (SAS) version 9.00 (SAS 2002). Mean separation was done using the least significant difference (LSD) at 5 % probability level when the ANOVA showed significant effects. Simple linear correlation coefficient analysis was also carried out to examine the associations between different soil physicochemical parameters.

Table 1 Mean squares for two-way analysis of variance (ANOVA) for selected physicochemical properties of soils due to land uses, soil depths and their interaction effects of the study area

Soil parameters	Mean square estimates				
	Land use (2)	Depth (1)	LU × SD (2)	Error (10)	CV (%)
Sand	296.520**	82.350*	11.010^{NS}	9.020	8.50
Silt	34.890**	2.000^{NS}	24.670**	4.290	6.78
Clay	360.020**	110.010^{NS}	11.520^{NS}	4.420	11.62
BD	0.068**	0.077**	0.013**	0.001	2.70
PD	0.007**	0.020**	0.005**	0.0001	0.40
TP	78.000**	118.000*	2.500^{NS}	13.350	0.72
pH	2.030**	0.060^{NS}	0.005^{NS}	0.014	2.13
EC	0.015**	0.002**	0.006**	0.0001	10.38
OC	2.661**	8.147**	1.604**	0.001	2.04
TN	0.025**	0.050**	0.010**	0.0003	11.28
C:N	1.836^{NS}	0.565^{NS}	0.141^{NS}	0.863	8.17
AP	75.008**	200.868**	6.600**	0.899	5.87
EA	1.667**	1.318**	0.080**	0.010	6.11
EAl	0.139*	0.009^{NS}	0.023^{NS}	0.050	6.58
Ca	121.954**	12.937**	2.644*	0.648	7.48
Mg	28.806**	4.962**	0.065^{NS}	0.057	3.74
K	0.035**	0.027**	0.0004^{NS}	0.0002	3.34
Na	0.002**	0.0004*	0.0014**	0.00005	8.42
CEC	186.636**	11.616*	1.345^{NS}	2.023	2.88
ECEC	30.4928**	3.849**	0.558^{NS}	0.143	5.82
PBS	605.700**	0.405^{NS}	69.150**	1.668	3.68
Fe	2.785**	220.150**	27.030**	0.257	4.83
Mn	21.947**	86.461**	14.451**	4.173	6.22
Cu	1.785**	2.220**	0.249^{NS}	0.140	20.78
Zn	0.013*	0.194**	0.001^{NS}	0.003	8.83

Figures in parentheses are values of degrees of freedom for respective source of variation

NS not significant, *LU* land use, *SD* soil depth, *LU × SD* interaction effect of LU and SD, *CV* coefficient of variation, *BD* bulk density, *PD* particle density, *TP* total porosity, *EC* electrical conductivity, *OC* organic carbon, *TN* total nitrogen, *C:N* carbon to nitrogen ratio, *AP* available phosphorus, *EA* exchangeable acidity, *EAl* exchangeable aluminum, *CEC* cation exchange capacity, *ECEC* effective cation exchange capacity, *PBS* percent base saturation

* Significant at P = 0.05, ** significant at P = 0.01

Results and discussion

Soil physical analysis

Particle size distribution

The soil separates (sand, silt and clay fractions) were significantly ($P \leq 0.01$) different across the land uses. The sand fraction was significantly ($P \leq 0.05$) different along soil depths, while the silt and clay fractions were not statistically different due to soil depths. Except the silt fraction ($P \leq 0.01$), the sand and clay fractions were not significantly ($P > 0.05$) different due to the interaction effects of land use by soil depth (Table 1). Considering the main effects of the land uses, the highest mean clay fraction (43.08 %) was recorded in the soils of the cultivated land and the lowest was observed in the soils of the grazing land followed by the forest land (Table 2). The highest clay percent observed in the soils of the cultivated land might be due to the degree of weathering and tillage activities. Contrary to the case of clay, the highest mean sand fraction (41.34 %) was observed in the soils of the grazing land and 37.42 % in the surface layer, whereas it was the lowest (27.59 %) in the soils of the cultivated land and 33.19 % in the subsurface layer (Table 2). On the other hand, considering the interaction effects of land uses by soil depths, the highest silt fractions was found in the subsurface layer of the forest land followed by the surface layer of the cultivated land while the lowest mean value was recorded in the subsurface layer of the cultivated land followed by the surface and subsurface layers of the grazing land use (Table 3). This result showed that the textural classes of these soils were clay domination in cultivated land and clay loam in grazing and forest lands. This may imply poor drainage that restricts high yield potential of Vertisols in the study area.

Table 2 Main effects of land uses and soil depths on some physical properties of soils of the study area

	Sand (%)	Silt (%)	Clay (%)	BD (g cm^{-3})	PD (g cm^{-3})	TP (%)
Land use						
CUL	27.59[c]	29.33[b]	43.08[a]	1.35[a]	2.56[a]	47.57[c]
GRL	41.34[a]	29.00[b]	29.66[b]	1.14[c]	2.50[b]	54.58[a]
NFL	36.98[b]	33.32[a]	29.70[b]	1.20[b]	2.51[b]	52.10[b]
LSD (0.05)	3.85	2.67	8.18	0.04	0.01	2.45
SEM (±)	1.23	0.85	2.60	0.01	0.00	1.49
Soil depth (cm)						
0–20	37.42[a]	30.88	31.70	1.16[b]	2.49[b]	53.34[a]
20–40	33.19[b]	30.22	36.59	1.29[a]	2.56[a]	49.43[b]
LSD (0.05)	3.16	NS	NS	0.04	0.01	3.84
SEM (±)	1.00	0.69	2.12	0.01	0.00	1.22
CV (%)	8.50	6.78	11.62	2.70	0.40	7.19

Means within a column for the same factor followed by the same letters are not significantly different from each other at P = 0.05

LSD least significant difference, *NS* not significant, *SEM* standard error of mean, *CV* coefficient of variation, *BD* bulk density, *PD* particle density, *TP* total porosity, *CUL* cultivated land, *GRL* grazing land, *NFL* natural forest land

Table 3 Interaction effects of land uses by soil depths on some physical properties of soils of the study area

Land use × soil depth	Soil parameters					
	Sand (%)	Silt (%)	Clay (%)	BD (g cm^{-3})	PD (g cm^{-3})	TP (%)
CUL						
0–20	28.67	32.00[ab]	39.33	1.28[b]	2.56[ab]	50.00
20–40	26.51	26.67[c]	46.82	1.41[a]	2.57[a]	45.14
GRL						
0–20	45.00	28.00[c]	27.00	1.03[d]	2.44[d]	57.79
20–40	37.69	30.00[bc]	32.31	1.25[b]	2.56[ab]	51.17
NFL						
0–20	38.00	32.64[ab]	28.76	1.18[c]	2.47[c]	52.23
20–40	35.36	34.00[a]	30.64	1.22[bc]	2.54[b]	51.97
LSD (0.05)	NS	3.77	NS	0.06	0.02	NS
SEM (±)	1.73	1.20	3.67	0.02	0.01	2.11
CV (%)	8.50	6.78	11.62	2.70	0.40	7.19

Means within a column for the same factor followed by the same letters are not significantly different from each other at P = 0.05

LSD least significant difference, *NS* not significant, *SEM* standard error of mean, *CV* coefficient of variation, *BD* bulk density, *PD* particle density, *TP* total porosity, *CUL* cultivated land, *GRL* grazing land, *NFL* natural forest land

Land uses might have contributed indirectly for the changes in particle size distribution particularly in the surface layers as a result of removal through pedologic processes such as erosion, deposition and weathering, which are shaped by management practice that can alter the texture of soils (Brady and Weil 2002).

Soil particle and bulk densities

The results of analysis of variance indicated significant differences for soil particle density due to land uses ($P \leq 0.01$), soil depths ($P \leq 0.01$) and interaction effects ($P \leq 0.01$) (Table 1). Based on the interaction effects, the highest mean soil particle density (2.57 g cm^{-3}) was recorded in the subsurface layer of the cultivated land followed by the surface layer of the cultivated land (2.56 g cm^{-3}) and subsurface layer of the grazing land (2.56 g cm^{-3}), whereas the lowest (2.44 g cm^{-3}) was obtained in the surface layer of the grazing land (Table 3). The lowest mean particle density in the surface layer of the grazing land might be attributed to the relatively higher organic carbon content observed in the surface layer of the grazing land than that of the surface layers of the cultivated and forest lands (Table 5). Generally, the observed mean values of the particle density in the soils of the study area were lower (Table 2) than the average value of the mineral soils world-wide, which is considered to be about 2.65 g cm^{-3} (Brady and Weil 2002).

Similar to the particle density, the bulk density of soils of the study area showed significant variations due to land uses ($P \leq 0.01$), soil depths ($P \leq 0.01$) and interaction effects of land uses by soil depth ($P \leq 0.01$) (Table 1).

Considering the interaction effects, the highest mean value of soil bulk density (1.41 g cm^{-3}) was recorded in the subsurface layer of the cultivated land whereas the lowest (1.03 g cm^{-3}) was observed in the surface layer of the grazing land (Table 3). The lowest organic carbon content observed in the cultivated soils might have contributed to its highest bulk density value. This is supported by the negative and significant ($P \leq 0.01$) correlation ($r = -0.85^{**}$) between the soil bulk density and organic carbon (Table 7). In this case, high bulk density coupled with low organic carbon in soils of cultivated land may restrict root penetration and air supply to plant roots due to compacting effect.

As many research results indicated, the change of bulk density in the cultivated land might be attributed to the commonly intense tillage activities practiced by the farmers. Intense tillage practices often temporarily loosen the tilled soil layer while compacting of the layer beneath, which then increases bulk density. Furthermore, the continuous exposure of the soil surface to the direct impact of rain drops under fields with long period of continuous cultivation might have also contributed to the increment of bulk density as raindrop impacts cause soil compaction through disintegration of the soil structure (Landon 1991; Brady and Weil 2002). The result obtained from this experiment is in agreement with that of Gebreyohannes (2001) who reported lower bulk density values in soils of virgin lands than in cultivated lands.

Total porosity

Statistically, the total porosity was significantly different among the land uses ($P \leq 0.01$) and within the soil depths ($P \leq 0.05$), but not in their interaction effects ($P > 0.05$) (Table 1). Accordingly, the highest (54.58 %) mean value of total porosity was observed in the soils of the grazing land, while the lowest (47.57 %) was recorded in the soils of the cultivated land (Table 2). Within a soil depth, the mean total porosity of the surface soil was significantly greater than that of the subsurface soil (Table 2). The total porosity increased from the cultivated land followed by the forest land to the grazing land and decreased along the soil depths of the study area. This trend could be attributed to the low OM content of the cultivated land and the subsurface soil depth and the increase in bulk density with soil depth, respectively. Finding reported by Negassa (2001) also indicated lower total porosity in the cultivated land and subsoil depths was a result of low OM in the Dystric Nitosols of Bako area. Hence, decreased total porosity of the cultivated land that affecting total coarse porosity might not allow for easily movement of air and water through soils. This in turn, may reduce plat growth and development of the study area.

Soil chemical properties

Soil reaction (pH) and electrical conductivity

The soil pH (H_2O) was found to be significantly ($P \leq 0.01$) different due to land uses, but did not vary significantly ($P > 0.05$) as a result of the influence of the soil depths and their interaction effects (Table 1). Based on the main effect of the land uses, the highest mean soil pH (H_2O) was recorded in the soils of the grazing land (pH 5.88) and forest land (pH 5.79) and the lowest (pH 4.84) was observed in the soils of the cultivated land (Table 4). The relatively higher soil pH (H_2O) observed in the grazing land followed by forest land could be partly due to the presence of higher total exchangeable bases and percent base saturation (Table 6) than in the soils of the cultivated land where relatively higher exchangeable acidity and exchangeable aluminum were recorded (Tables 4, 6). This result is in agreement with the report of Tegenu et al. (2008) who concluded that the soil pH of grazing and natural forest lands were higher than the soil pH of cultivated land at the Dibanke catchment area in northwestern Ethiopia.

Moreover, the land use practices such as cultivation and continuous use of inorganic fertilizers might have contributed to the decline in soil pH (increased soil acidity) at the surface soils of the cultivated land. In line with this, Kang and Osinama (1985) and Gebrekidan and Negassa (2006) reported that the use of acidifying mineral fertilizers and intensive cultivation enhanced leaching of basic cations and oxidation of organic matter that eventually reduced soil pH. In general, as per the soil pH (H_2O) rating scale of Tadesse (1991), the mean soil pH (H_2O) (1:2.5 H_2O) of the study area indicated moderate acid soils in grazing and forest lands and strong acid soils in cultivated land. This soil pH of cultivated land was also lower than the most suitable soil pH range (5.5–7) for most grain and vegetable crops that might affect their growth and development.

Electrical conductivity (EC) of soils was also significantly different due to the land uses ($P \leq 0.01$), soil depths ($P \leq 0.01$) and their interaction effects ($P \leq 0.01$) (Table 1). Considering the interaction effects of land use by soil depth, the lowest mean value (0.05 dS m^{-1}) of the electrical conductivity was observed in the surface layer of the cultivated land (Table 5), which could be associated to the profound loss of exchangeable bases (Table 8) and

Table 4 Main effects of land uses and soil depths on some chemical properties of soils of the study area

	pH-H_2O	EC (dS m^{-1})	OC (%)	Total N (%)	C:N	AP (mg kg^{-1})	EA (cmol(+) kg^{-1})
Land use							
CUL	4.84^{b}	0.07^{c}	1.04^{c}	0.09^{b}	12.16	20.07^{a}	2.21^{a}
GRL	5.88^{a}	0.16^{a}	2.24^{a}	0.20^{a}	11.63	12.98^{c}	1.27^{b}
NFL	5.79^{a}	0.11^{b}	2.15^{b}	0.20^{a}	10.79	15.42^{b}	1.33^{b}
LSD (0.05)	0.15	0.02	0.05	0.02	NS	1.23	0.12
SEM (±)	0.05	0.01	0.02	0.01	0.80	0.39	0.04
Soil depth							
0–20 cm	5.47	0.12^{a}	2.48^{a}	0.21^{a}	11.96	19.49^{a}	1.87^{a}
20–40 cm	5.53	0.10^{b}	1.13^{b}	0.11^{b}	11.09	12.81^{b}	1.41^{b}
LSD (0.05)	NS	0.01	0.04	0.02	NS	1.00	0.10
SEM (±)	0.04	0.00	0.01	0.01	0.77	0.32	0.03
CV (%)	2.13	10.38	2.04	11.28	8.17	5.87	6.11

Means within a column for the same factor followed by the same letters in superscripts are not significantly different from each other at P = 0.05

LSD least significant difference, *NS* not significant, *SEM* standard error of mean, *CV* coefficient of variation, *EC* electrical conductivity, *OC* organic carbon, *C:N* carbon to nitrogen ratio, *AP* available phosphorus, *EA* exchangeable acidity, *EAl* exchangeable aluminum, *CUL* cultivated land, *GRL* grazing land, *NFL* Natural forest land

Table 5 Interaction effects of land uses by soil depths on some chemical properties of soils of the study area

Land use × soil depth	pH-H_2O	Soil parameters					
		EC	OC	Total N	AP	C:N	EAl
CUL							
0–20	4.80	0.05^{c}	1.13^{d}	0.09^{c}	23.61^{a}	12.56	0.42
20–40	4.87	0.09^{b}	0.94^{e}	0.08^{c}	16.53^{c}	11.75	0.35
GRL							
0–20	5.92	0.22^{a}	3.33^{a}	0.28^{a}	15.46^{c}	11.89	0.07
20–40	5.83	0.10^{b}	1.14^{d}	0.11^{bc}	10.49^{d}	11.36	0.09
NFL							
0–20	5.70	0.10^{b}	2.97^{b}	0.26^{a}	19.41^{b}	11.42	0.12
20–40	5.88	0.11^{b}	1.32^{c}	0.13^{b}	11.42^{d}	10.15	0.30
LSD (0.05)	NS	0.02	0.07	0.03	1.72	NS	NS
SEM (±)	0.07	0.01	0.02	0.01	0.55	0.76	0.08
CV (%)	2.13	10.38	2.04	11.28	5.87	8.17	6.58

Means within a column for the same factor followed by the same letters are not significantly different from each other at P = 0.05

LSD least significant difference, *NS* not significant, *SEM* standard error of mean, *CV* coefficient of variation, *EC* electrical conductivity, *OC* organic carbon, *C:N* carbon to nitrogen ratio, *AP* available phosphorus, *EA* exchangeable acidity, *EAl* exchangeable aluminum, *CUL* cultivated land, *GRL* grazing land, *NFL* Natural forest land

the highest (0.22 dS m^{-1}) mean value of EC was recorded in the surface layer of the grazing land (Table 5).

Soil organic carbon

Analysis of variance revealed that soil organic carbon (OC) content was significantly influenced by land uses ($P \leq 0.01$), soil depths ($P \leq 0.01$) and their interaction effects ($P \leq 0.01$) (Table 1). Considering the interaction effects of land use by soil depth, the highest (3.33 %) mean OC was recorded in the surface layer of the grazing land, whereas the lowest (0.94 %) mean OC was observed in the subsurface layer of the cultivated land (Table 5). The results imply that under the cultivated land use system, losses of soil organic carbon were not fully compensated by organic matter inputs from the crop residues. These effects in such tropical soils could also be due to the effects of the often frequent tillage practices coupled with reduced soil organic matter inputs and almost complete removal of crop residues from the cultivated fields for various reasons. On the other hand, less soil disturbance in the grazing land and forest land might have apparently led to the observed increase in organic carbon content as compared to the soils under cultivated land. Moreover, the surface soils of the grazing land had shown

Table 6 Main effects of land uses and soil depths on exchangeable bases, exchangeable aluminum, CEC, PBS, and ECEC of soils of the study area

	Ca	Mg	K	Na	CEC	ECEC	EAl	PBS (%)
	(cmol(+) kg^{-1})							
Land use								
CUL	6.71^{c}	4.78^{c}	0.32^{b}	0.07^{b}	43.06^{c}	14.07^{c}	0.39^{a}	27.57^{c}
GRL	15.62^{a}	8.88^{a}	0.41^{a}	0.11^{a}	53.77^{a}	26.29^{a}	0.08^{c}	46.53^{a}
NFL	9.94^{b}	5.49^{b}	0.40^{a}	0.08^{b}	51.11^{b}	17.23^{b}	0.21^{b}	31.13^{b}
LSD (0.05)	1.04	0.31	0.02	0.01	1.83	1.50	0.12	1.66
SEM (±)	0.33	0.10	0.01	0.00	0.85	0.62	0.06	0.53
Soil depth (cm)								
0–20	10.97^{a}	6.59^{a}	0.39^{a}	0.07^{b}	50.11^{a}	19.90^{a}	0.20	35.98
20-40	10.55^{b}	6.17^{b}	0.36^{b}	0.10^{a}	48.51^{b}	18.49^{b}	0.25	35.42
LSD (0.05)	0.32	0.25	0.01	0.01	1.49	0.70	NS	NS
SEM (±)	0.27	0.08	0.00	0.00	0.48	0.50	0.05	0.43
CV (%)	7.48	3.74	3.34	8.42	2.88	5.82	6.58	3.68

Means within a column for the same factor followed by the same letters in superscripts are not significantly different from each other at P = 0.05

LSD least significant difference, *NS* not significant, *SEM* standard error of mean, *CEC* cation exchange capacity, *ECEC* effective cation exchange capacity, *PBS* percent base saturation, *CUL* cultivated land, *GRL* grazing land, *NFL* natural forest land

relatively higher OC content than the surface soils of the forest (where no grasses were observed on the surface of this field) (Table 5). As per OC rating proposed by Tadesse (1991), the OC content of the soils in the study area varied from low fertility status in the cultivated land to moderate in the grazing and forest lands.

Total nitrogen and C:N ratio

Analysis of variance showed that the total nitrogen was significantly influenced by land uses ($P \leq 0.01$), soil depths ($P \leq 0.01$) and their interaction effects ($P \leq 0.01$) (Table 1). Based on the interaction effect of land by soil depth, the highest mean value of the total nitrogen was recorded in the surface layers of the grazing and forest lands, while the lowest was observed in the surface and subsurface layers of the cultivated land (Table 5). In all land uses considered in this study, total N decreased consistently with soil depth (Table 5). The variation paralleled with that of the change in organic carbon content, which was also expressed by the positive and significant correlation between these two soil attributes ($r = 0.99^{**}$) (Table 7).

The relatively low total nitrogen content recorded in the soils of the cultivated land could be attributed to the usually anticipated rapid mineralization of soil organic matter following frequent tillage operations, which increase aeration and microbial accessibility to organic matter. Furthermore, reduced input of plant residues in such cereal-based farming systems into the soils is also expected to have contributed to the depletion of OM, thereby total N in these cultivated soils. On the other hand, nitrate ions which are not absorbed by the negatively charged colloids that dominate most soils, may move below the considered depth (0–40 cm) with drainage water and leached from the soil. The findings of this study are in consent with the findings of similar works reported by Tisdale et al. (2002) and Gebreselassie (2002) that the low input of plant residues results in low total N. Thus, as per the ratings of total nitrogen by Tadesse (1991), the total nitrogen content of soils of the study area was found to be low fertility status in the cultivated land and moderate in the grazing and forest lands.

Unlike the effects of land uses and soil depths on organic carbon and total nitrogen contents, the C:N ratio was not affected significantly ($P > 0.05$) by any of the factors or their interaction effects (Table 1). This might indicate that there were higher rates of decomposition of organic matter and mineralization of organic nitrogen in the soils of the present study area resulting in the ultimate increase in their total nitrogen contents. The C:N ratios of soils in the study area were within the range of 8:1–15:1 (Prasad and Power 1997), which is commonly cited as the general C:N ratio of mineral soils.

Available phosphorus

The results of analysis of variance indicated that available phosphorus (P) content was significantly affected by land uses ($P \leq 0.01$), soil depths ($P \leq 0.01$) and the interaction effects of land uses by soil depths ($P \leq 0.01$) (Table 1). Accordingly, considering the interaction effects, the highest (23.61 mg kg^{-1}) mean available P was recorded in the surface layer of the cultivated land whilst the lowest was

Table 7 Linear correlation coefficient (r) values between some physicochemical properties of soils of the study area

	Sand	Silt	Clay	BD	pH	OC	TN	AP	Ca	Mg	K	Na	CEC	EA	Fe	Mn	Cu
Silt	0.06																
Clay	−0.93**	−0.43															
BD	−0.92**	−0.01	0.90**														
pH	0.85**	0.41	−0.87**	−0.68**													
OC	0.87**	−0.05	−0.65**	−0.85**	0.47*												
TN	0.84**	0.03	−0.18	−0.86**	0.55**	0.99**											
AP	−0.03	0.07	0.31	0.42	−0.72**	0.13	0.03										
Ca	0.90**	−0.27	−0.74**	−0.78**	0.79**	0.57**	0.58**	−0.59**									
Mg	0.82**	−0.46*	−0.57**	−0.68**	0.65**	0.66**	0.34	−0.47*	0.95**								
K	0.84**	0.56**	−0.94**	−0.80**	0.81**	0.50*	0.55**	−0.38	0.71**	0.53*							
Na	0.44*	−0.51*	−0.21	−0.16	0.57**	0.03	0.07	−0.52*	0.79**	0.77**	0.06						
CEC	0.95**	0.21	−0.94**	−0.82**	0.96**	0.64**	0.65**	−0.50*	0.85**	0.75**	0.89**	0.51*					
Ex.A	−0.59*	0.07	0.42	0.37	−0.83**	−0.26	−0.35	0.89**	−0.66**	−0.55**	−0.42	−0.74**	−0.64**				
Fe	0.52*	0.28	−0.58**	−0.70**	−0.38	0.87**	0.85**	−0.51*	0.15	0.13	0.40	−0.46*	0.36	0.14			
Mn	−0.20	−0.03	0.19	−0.13	−0.62**	0.24	0.37	0.89**	−0.35	−0.32	−0.20	−0.41	−0.43	0.79**	0.56**		
Cu	0.89**	0.29	−0.91**	−0.93**	−0.32	0.91**	0.85**	−0.26	−0.12	0.01	0.24	−0.47*	0.94**	0.21	0.50*	0.49*	
Zn	0.65**	0.05	−0.35	−0.79**	0.03	0.86**	0.75**	0.08	−0.02	−0.02	0.08	−0.24	0.70**	0.24	0.74**	0.78**	0.79**

BD bulk density, *OC* organic carbon, *TN* total nitrogen, *AP* available phosphorus, *CEC* cation exchange capacity, *EA* exchangeable acidity

* Significant at P = 0.05, ** Significant at P = 0.01

Table 8 Interaction effects of land uses by soil depths on exchangeable bases, exchangeable acidity, CEC, PBS, and ECEC of soils of the study area

Land use × soil depth	Soil parameters							
	Ca	Mg	K	Na	PBS	CEC	ECEC	EA
CUL								
0–20	6.28[e]	4.30	0.37	0.05[e]	24.93[d]	44.21	13.78	2.76[a]
20–40	7.14[e]	5.25	0.26	0.09[bc]	30.31[c]	41.90	14.36	1.66[b]
GRL								
0–20	17.20[a]	9.52	0.42	0.10[b]	50.42[a]	54.03	28.55	1.31[c]
20–40	14.04[b]	8.23	0.40	0.12[a]	42.60[b]	53.50	24.02	1.23[c]
NFL								
0–20	9.42[d]	5.94	0.38	0.07[d]	30.36[c]	52.10	17.37	1.55[b]
20–40	10.48[c]	5.03	0.41	0.08[cd]	31.90[c]	50.12	17.09	1.10[d]
LSD (0.05)	0.96	NS	NS	0.01	2.35	NS	NS	0.12
SEM (±)	0.47	0.14	0.01	0.00	0.75	082	0.87	0.06
CV (%)	7.48	3.74	3.34	8.42	3.68	2.88	5.82	6.11

Means within a column for the same factor followed by the same letters in superscripts are not significantly different from each other at P = 0.05

LSD least significant difference, *NS* not significant, *SEM* standard error of mean, *CV* coefficient of variation, *CEC* cation exchange capacity, *ECEC* effective cation exchange capacity, *PBS* percent base saturation, *CUL* cultivated land, *GRL* grazing land, *NFL* natural forest land

observed in the subsurface layers of the grazing and forest lands (Table 5).

The highest available P content recorded in the surface (0–20 cm) soils of the cultivated land could be ascribed to carryover effects from the continuous application of P fertilizers. In support of the findings of this study, Samadi and Gilks (1998) reported higher available P in the surface soils than in the subsurface soils of cultivated land and attributed this to the addition of fertilizers and manures or easily mineralized organic P compounds. On the other hand, Whitebread et al. (1998) reported that the low concentrations of available P in the uncultivated lands could be due to the inherent P deficiency of the soils since little or no P fertilizers are applied. According to Bewket and Steroosnijder (2003), the inorganic sources of P from mineral weathering have considerable importance in their contribution to soil available P as intensified human practices increase the rate of weathering and encourage the decomposition. Furthermore, the results obtained indicate that the contribution of organic matter to available P in soils of the grazing and forest lands was not conspicuous. This was revealed by the insignificant ($P > 0.05$) correlation between soil organic carbon and available P (Table 7). Nevertheless, as compared with the rating scale proposed by Cottenie (1980), the available P contents ranges from medium fertility status in the grazing and forest lands to high in the cultivated land.

Cation exchange capacity

Analysis of variance for the cation exchange capacity (CEC) of the soil under the study area depicted significant differences across the land uses ($P \leq 0.01$) and along the soil depths ($P \leq 0.05$), but not in their interaction effects ($P > 0.05$) (Table 1). Accordingly, the highest mean CEC value (53.77 cmol(+) kg^{-1}) was observed in the soils of the grazing land and the lowest (43.06 cmol(+) kg^{-1}) was obtained in the soils of the cultivated land. Along the soil depths, the CEC of the surface soils (50.11 cmol(+) kg^{-1}) was significantly higher than the CEC of the subsurface soils (48.51 cmol(+) kg^{-1}) (Table 6).

In all the three land uses, CEC decreased from the grazing land followed by the forest land to the cultivated land and from the surface to subsurface layers in accordance with the OC contents (Tables 4, 6).

The decrease in the CEC of this study area with depth could be due to the positive and significant correlation ($r = 0.64^{**}$) between organic carbon and CEC (Table 7), as it is also evident from the fact that the higher CEC was obtained in the surface layer which also contained the highest organic carbon content (Tables 4, 6). The depletion of OM because of continuous cultivation might have reduced the CEC of the soils in the cultivated land of the study area, which is in line with the findings of Gao and Change (1996) who reported that the continuous cultivation decreases soil OM and resulted in CEC reduction in the cultivated land than that of uncultivated land.

Basically, CEC of a soil is determined by the relative amount and/or of two main colloidal substances; humus and clay. Particularly, organic matter plays an important role in exchange process, because it provides more negatively charged surfaces than clay particles do (Gao and Change 1996). As a result of this study, the CEC of soil of the district was positively and significantly correlated ($r = 0.64^{**}$) with OC than with clay, which was negatively and significantly correlated ($r = -0.94^{**}$) to CEC recorded both across the land uses and within the soil depths (Table 7). In general, higher CEC values might imply that the soils have high buffering capacity against induced change.

Effective cation exchange capacity (ECEC) followed similar trend as that of the CEC of the soils. Analysis of variance for the ECEC of the soil under the study area revealed significant differences across the land uses ($P \leq 0.01$) and along the soil depths ($P \leq 0.05$), but not in their interaction effects ($P > 0.05$) (Table 1). Considering the main effects, the highest ECEC value (26.29 cmol(+) kg^{-1}) was observed in the grazing land and the lowest ECEC (14.07 cmol(+) kg^{-1}) was obtained in the soils of the cultivated land (Table 6). Along the soil depths, the mean ECEC (19.90 cmol(+) kg^{-1}) of the surface layer was significantly higher than that of the subsurface layer (18.49 cmol(+) kg^{-1}). In general, the ECEC value of soils of the study area indicated association with CEC value. This is in agreement with the report of Moody et al. (1997) that ECEC is highly related to CEC and OM.

Exchangeable potassium and sodium

Exchangeable potassium (K) and sodium (Na) contents varied in response to variation in land uses and soil depths. Exchangeable K was significantly different across land uses ($P \leq 0.01$) and along soil depths ($P \leq 0.01$), but the interaction effects of land uses by soil depths did not show significant ($P > 0.05$) differences. On the other hand, exchangeable Na varied significantly due to land uses ($P \leq 0.01$), soil depths ($P \leq 0.05$) and their interaction effects ($P \leq 0.01$) (Table 1).

Considering the main effects, the highest mean value of exchangeable K was observed in the soils of the grazing and forest lands and the lowest (0.32 cmol(+) kg^{-1}) was recorded in the soils of the cultivated land (Table 6). Along the soil depths, higher exchangeable K (0.39 cmol(+) kg^{-1}) was recorded in the surface than in the subsurface (0.36 cmol(+) kg^{-1}) layer (Table 6). The highest exchangeable K content in the soils of the grazing land and forest land than that of the cultivated land could be attributed to the high organic matter content (Table 4).

As reported by Saikh et al. (1998), high intensity of weathering, intensive cultivation and use of acid forming inorganic fertilizers has been reported to affect the distribution of K in soils and enhance its depletion. This might be the possible reason for the relatively low exchangeable K in soils of the cultivated land. Nevertheless, according to the exchangeable K rating of FAO (2006) for topsoil, the observed mean values of the exchangeable K of the study area fall in the range of medium fertility status in all the three land uses.

Based on the interaction effects of land uses by soil depths, the highest mean value (0.12 cmol(+) kg^{-1}) of exchangeable Na was obtained in the subsurface layer of the grazing land and the lowest mean value (0.05 cmol(+) kg^{-1}) was observed in the surface layer of the cultivated land (Table 8). Apparently, this could be due to the high amount of annual rainfall in the study area, which leaches Na easily. Thus, as per exchangeable Na ratings of FAO (2006), the mean exchangeable Na values were very low fertility status in the soils of cultivated and forest lands and low in soils of the grazing land.

Exchangeable calcium and magnesium

Exchangeable calcium (Ca) and magnesium (Mg) contents of soils of the study area showed differences in response to variations in land uses and soil depths. Accordingly, exchangeable Ca was significantly different due to land uses ($P \leq 0.01$), soil depths ($P \leq 0.01$) and the interaction effects of land uses by soil depths ($P \leq 0.05$), while exchangeable Mg was significantly different due to land uses ($P \leq 0.01$) and soil depths ($P \leq 0.01$) only (Table 1).

On the basis of the interaction effects of land uses by soil depths, the highest exchangeable Ca (17.20 cmol(+) kg^{-1}) was recorded in the surface layer of the grazing land, whereas the lowest exchangeable Ca value was observed in the surface and subsurface layers of the cultivated land (Table 8). The highest exchangeable Ca observed in the surface soils of the grazing land could be due to the relatively higher OM content of this soil. On the other hand, the lowest exchangeable Ca recorded in the soils of the cultivated land could be due to its continuous removal in crop harvest with no or little organic matter input into the soil.

On the other hand, based on the main effects, the highest mean exchangeable Mg (8.88 cmol(+) kg^{-1}) was observed in soils of the grazing land and the lowest exchangeable Mg (4.78 cmol(+) kg^{-1}) was observed in soils of the cultivated land (Table 6). Furthermore, the exchangeable Mg decreased from the surface to subsurface soil depths, which could be attributed to the higher OM observed in the surface depth (Table 4). The relatively low exchangeable Mg observed in the soils of the cultivated land could be due to its continuous removal in crop harvest. This result is in agreement with the findings of (Baker et al. 1997; Negassa 2001; Gebrekidan and Negassa 2006) who reported that continuous cultivation enhances the depletion of Ca^{2+} and Mg^{2+}, especially in acidic tropical soils.

According to the ratings of exchangeable Ca and Mg of FAO (2006), the observed mean exchangeable Ca was medium fertility status in the soils of the cultivated land and forest land and high in the soils of the grazing land. On the other hand, the mean exchangeable Mg recorded was high status in the soils of the cultivated and forest lands and very high in the grazing land use (FAO 2006). This is supported by the positive and significant ($P \leq 0.01$) correlation between OC and Ca ($r = 0.57^{**}$) and OC and Mg ($r = 0.66^{**}$) (Table 7).

Percent base saturation

Percent base saturation of soils of the study area was significantly affected by the land uses ($P \leq 0.01$) and the interaction effects ($P \leq 0.01$) of land uses by soil depths, but not by the soil depths ($P > 0.05$) (Table 1). Considering the interaction effects, the highest mean value of PBS (50.42 %) was observed in the surface layer of the grazing land, while the lowest (24.93 %) was in the surface layer of the cultivated land (Table 8). The lowest PBS recorded in the surface layer of the cultivated land could be attributed to the low sum of bases in this layer (Table 8). This is in agreement with the finding of Abebe (1998) who indicated that virgin/grazing lands retain more basic cations than the cultivated land of Vertisols at the central highlands of Ethiopia.

On the other hand, unlike to the cultivated and forest lands, the mean values of PBS was significantly reduced from 50.42 % in the surface (0–20 cm) soil to 42.60 % in the subsurface (20–40 cm) soil of the grazing land (Table 8). This could be attributed to the high organic matter (organic carbon) and high sum of bases in the surface layer of the grazing land (Tables 5, 8). In general, according to the ratings of base saturation by Hazelton and Murphy (2007), the observed PBS of soils of the study area falls in the range of medium fertility status in all the three land uses.

Exchangeable acidity

Exchangeable acidity that can be expressed as the sum of hydrogen and aluminum ions, varied significantly across the land uses ($P \leq 0.01$), down the soil depths ($P \leq 0.01$) and in their interaction effects ($P \leq 0.01$) (Table 1). Considering the interaction effects of land uses by soil depths, the highest exchangeable acidity value (2.76 cmol(+) kg^{-1}) was recorded in the surface layer of the cultivated land and the lowest (1.10 cmol(+) kg^{-1}) exchangeable acidity was recorded in the subsurface layer of forest land (Table 8). The relatively high exchangeable acidity observed in the surface soils of the cultivated land could be related to the low content of base-forming cations recorded in this layer due to the cultivation and continuous use of inorganic fertilizers. This is clearly indicated by the negative and significant ($P \leq 0.01$) correlation between exchangeable acidity and Ca ($r = -0.66^{**}$), Mg ($r = -0.55^{**}$), and Na ($r = -0.74^{**}$) (Table 7). The results obtained in this study are in agreement with the findings of Baligar et al. (1997) and Blamey et al. (1997) who indicated that intensive cultivation and continuous use of inorganic fertilizers could intensify soil acidity.

Exchangeable aluminum

The results of analysis of variance revealed that the exchangeable aluminum (Al) was significantly affected by land uses ($P \leq 0.05$) but not by soil depths ($P > 0.05$) and the interaction effects of land uses by soil depths ($P > 0.05$) (Table 1). Consequently, the highest (0.39 cmol(+) kg^{-1}) mean exchangeable Al was recorded in the soils of the cultivated land and the lowest (0.08 cmol(+) kg^{-1}) was observed in the soils of the grazing land (Table 6).

In this study, hydrogen ions had contributed an appreciable amount of the exchangeable acidity in all of the land uses of the study area particularly under the grazing and forest lands where exchangeable Al is not commonly expected in an appreciable quantity in soils with pH values of greater than 5.5 (Nair and Chamuah 1993). On the other hand, though, the recorded exchangeable Al was lower in the study area compared to the exchangeable Al (1.0 cmol(+) kg^{-1}) reported by Nair and Chamuah (1993), exchangeable Al seems to have contributed significantly to the exchangeable acidity in soils of the cultivated land where the mean pH (H_2O) value was less than 5.5 (Tables 4, 6). This condition might increase the exchangeable Al that led to the level of Al toxicity to most plants.

Micronutrients (Fe, Mn, Zn and Cu)

The concentrations of the micronutrients (Fe, Mn, Zn and Cu) of the soils in the study area revealed the effects of the different land uses. The statistical analysis indicated that except Cu and Zn, the other micronutrients (Fe and Mn) were significantly affected by land uses ($P \leq 0.01$), soil depths ($P \leq 0.01$) and their interaction effects ($P \leq 0.01$) (Table 1). Following this, significantly highest mean iron content (16.25 mg kg^{-1}) was recorded in the surface layer of the forest land as compared to the other land uses while the lowest mean iron content was observed in the subsurface layers of the cultivated and grazing lands (Table 9). On the other hand, the highest mean Mn content (15.04 mg kg^{-1}) was found in the surface layer of the cultivated land and the lowest (5.91 mg kg^{-1}) was recorded in the subsurface layer of the grazing land (Table 9). According to Jones (2003) soil available Fe and Mn ratings, the available Fe contents of soils of all the three land uses of the study area falls within the range of high status and the available Mn is within the medium range.

Table 9 Interaction effects of land uses by soil depths on some micronutrients of soils of the study area

Land use × soil depth	Fe (mg kg^{-1})	Mn	Cu	Zn
CUL				
0–20	11.29^{c}	15.04^{a}	1.44	0.66
20–40	6.30^{e}	10.12^{c}	0.91	0.47
GRL				
0–20	14.45^{b}	12.17^{b}	2.65	0.78
20–40	5.54^{e}	5.91^{e}	1.48	0.54
NFL				
0–20	16.25^{a}	10.54^{c}	2.37	0.72
20–40	9.16^{d}	8.57^{d}	1.96	0.51
LSD (0.05)	0.91	1.17	NS	NS
SEM (±)	0.29	0.37	0.22	0.07
CV (%)	4.83	6.22	20.78	8.83

Means within a column for the same factor followed by the same letters in superscripts are not significantly different from each other at P = 0.05

LSD least significant difference, *NS* not significant, *SEM* standard error of mean, *CV* coefficient of variation, *EA* exchangeable acidity, *CUL* cultivated land, *GRL* grazing land, *NFL* natural forest land

Table 10 Main effects of land uses and soil depths on some micronutrients of soils of the study area

	Fe (mg kg^{-1})	Mn	Cu	Zn
Land use				
CUL	8.80^{c}	12.58^{a}	1.18^{b}	0.57^{c}
GRL	10.00^{b}	9.04^{b}	2.07^{a}	0.66^{a}
NFL	12.71^{a}	9.56^{b}	2.17^{a}	0.61^{b}
LSD (0.05)	0.65	0.83	0.48	0.03
SEM (±)	0.21	026	0.15	0.02
Soil depth (cm)				
0–20	13.99^{a}	12.58^{a}	2.15^{a}	0.71^{a}
20–40	7.00^{b}	8.20^{b}	1.45^{b}	0.50^{b}
LSD (0.05)	0.53	0.68	0.39	0.06
SEM (±)	0.17	0.22	0.13	0.02
CV (%)	4.83	6.22	20.78	8.82

Means within a column for the same factor followed by the same letters in superscripts are not significantly different from each other at P = 0.05

LSD least significant difference, *NS* not significant, *SEM* standard error of mean, *CV* coefficient of variation, *CUL* cultivated land, *GRL* grazing land, *NFL* natural forest land

As described by described by Kang and Osinama (1985), the available Fe and Mn elements have similar chemical properties in tropical soils. However, unlike Fe, the highest mean available Mn content of the study area was obtained in the surface layer of the cultivated land than the other layers of land uses. Consequently, the available Fe content seems to be more related to OM content. This could be supported by the positive and significant ($P \leq 0.01$) correlation ($r = 0.87^{**}$) of OC to available Fe, while insignificant ($P > 0.05$) correlation to available Mn (Table 7). On the other hand, linear correlation analysis reveals that the soil pH was negatively and significantly ($P \leq 0.01$) correlated ($r = -0.62^{**}$) with mean available Mn and insignificantly ($P > 0.05$) correlated with available Fe (Table 7).

Statistically, the highest available Cu was obtained in the soils of the forest and grazing lands while the lowest (1.18 mg kg^{-1}) available Cu was recorded in the soils of the cultivated land (Table 10). Moreover, the available Cu concentration of the study area significantly decreased from 2.15 to 1.45 mg kg^{-1} along the soil depths (0–20 to 20–40 cm) (Table 10) and it seems to be related with OM contents both across the land uses and down the soil depths. This is in agreement with the findings of Haque et al. (1992) who stated that OM enriched surface soils often contain high concentration of available Cu than the lower ones.

Considering the main effects of land uses and soil depths, the highest available Zn (0.66 mg kg^{-1}) was observed in the soils of the grazing land and the lowest (0.57 mg kg^{-1}) value was recorded in the soils of the cultivated land (Table 10). It also decreased from 0.71 to 0.50 mg kg^{-1} along the soil depths (Table 10).

Similar to the available Cu, the lowest available Zn in the soils of the cultivated field as compared to the other land uses could be due to the lower organic matter content and topsoil Zn removal by erosion which is also aggravated by tillage activities that is coupled with continuous removal in crop harvest. This is clearly indicated by the positive and significant ($P \leq 0.01$) correlation between OC and available Cu ($r = 0.91^{**}$) and available Zn ($r = 0.86^{**}$) (Table 7).

According to the rating level of Jones (2003), the mean available Cu and Zn in the soils of the three land uses of the study area are within the range of low and medium fertility status, respectively. The distribution of these micronutrients under this study area showed variations across the land uses and along the soil depths, which is in agreement with the findings of Nipunage et al. (1996) in swelling and shrinking characteristic of Vertisols, the distributions of micronutrients are varied. Moreover, these variations in micronutrients content of this study are in agreement with the finding of Gebrekidan and Negassa (2006) who reported that micronutrients are influenced by different land uses differently.

Summary and conclusions

This study was initiated with the objective of assessing the fertility status of Vertisols under selected land uses in Girar Jarso District of North Shoa Zone of Oromia

National Regional State. Field survey and laboratory analyses were carried out to study the fertility status of Vertisols based on selected physicochemical properties of the soils under three land uses in Girar Jarso District. Most of physicochemical properties of soils of the study area, such as particle size distribution, bulk and particle densities, total porosity, soil pH (H_2O), electrical conductivity (EC), CEC, effective cation exchange capacity (ECEC), exchangeable bases (Ca, Mg, K and Na), PBS, OC, total N, available P, exchangeable acidity and aluminum and micronutrients (Fe, Mn, Cu and Zn) showed fertility status variations in response to differences in land uses.

Considering the soil physical properties, the sand fraction increased in the cultivated land to the grazing land; the silt fraction increased in the grazing land to the forest land. Contrary to sand fraction, the clay fraction increased in the grazing land to the cultivated land. Bulk and particle densities increased in the grazing land to the cultivated land, respectively, whereas the total porosity decreased in the grazing land to the cultivated land.

Soil pH (H_2O) and electrical conductivity decreased in the grazing land to the cultivated land, respectively. As would be expected, the largest and the smallest values of soil OC and total N were observed in the uncultivated land and cultivated land, respectively and significantly reduced down the soil depths. Available P was also significantly reduced in the cultivated land to the grazing land and within the soil depths.

Attributed to its higher OM content compared to the cultivated land use, the highest CEC was observed in the soils of the grazing land. Contents of exchangeable bases (Ca, Mg, K and Na) were significantly reduced due to shift of land uses from uncultivated land uses to cultivated land. Moreover, PBS and ECEC of soils of the study area showed similar trends to CEC.

Exchangeable acidity with the highest value observed in the soils of the cultivated land as compared to the grazing and forest lands. The exchangeable aluminum also showed similar trend to the exchangeable acidity in that it increased from the uncultivated land to the cultivated land soil.

In general, the soil of the grazing land of the study area was higher in most fertility status of the soil physicochemical properties such as total porosity, soil pH (H_2O), electrical conductivity (EC), organic carbon (OC), exchangeable bases (Ca, Mg, K and Na), CEC, percent base saturation (PBS) and Zn as compared to the forest land and cultivated land. On the other hand, the forest land was higher in most fertility status of the soil physicochemical properties than the cultivated land. This indicates that the grazing land had high biomass that contributed to its high OC content and characterized with minimum soil disturbance. Continuous cultivation without proper soil management in the cultivated field, on the other hand, enhanced deterioration of OC and degradation of other soil physicochemical properties, which accounts for its poor fertility status as compared to the grazing and forest lands.

In conclusion, this study showed that conversion of natural ecosystem into crop/cultivated land ecosystem has resulted in deterioration of the soil resource base. Most of the physicochemical properties of soils of the study area were considerably influenced by the different land uses. Particularly, as the intensity of the soil degradation was severe under the cultivated land, reducing the intensity of cultivation, and adopting integrated soil fertility management could rehabilitate the existing soil conditions.

Besides, soil conservation through proper land use system and soil management should be considered in improving and maintaining the existing soil physicochemical properties. Appropriate crop species which are tolerant to the acidic soil condition should be adopted. Generally, while introducing new agricultural production technologies into areas under different land uses like the present study, the variations in soil physicochemical properties should be considered for sustainable production and productivity. Selected parameters of soil analysis give only the level of certain nutrients in the soil fertility status. Therefore, to give concrete recommendation on soil management for sustainable natural resources particularly in production and productivity of the soils in the study area, plant tissue analysis and field experiment on crop nutrient requirement should be undertaken.

Abbreviations

ANOVA: analysis of variance; AP: available phosphorus; BD: bulk density; CN: carbon to nitrogen ratio; CEC: cation exchange capacity; CV: coefficient of variation; CUL: cultivated land; DAP: diammonium phosphate; DTPA: diethylene triamine pentaacetic acid; ECEC: effective cation exchange capacity; EC: electrical conductivity; NFL: natural forest land; EA: exchangeable acidity; EAl: exchangeable aluminum; ESP: exchangeable sodium percentage; FAO: Food and Agriculture Organization; GLM: general linear model; GIS: geographic information system; GRL: grazing land; Ha: hectare; LU: land use; LSD: least significant difference; Masl: meters above sea level; OC: organic carbon; OM: organic matter; OPEDB: Oromia Planning And Economic Development Bureau; PD: particle density; PBS: percent base saturation; SD: soil depth; SEM: standard error of mean; SAS: statistical analysis software; TN: total nitrogen; TP: total porosity.

Authors' information

Berhanu Seyoum: Lecturer at Hawassa University, Wondo Genet College of Forestry and Natural Resources. He mostly teaches courses of soil science such as soil physics, soil chemistry, and soil fertility management and undertakes researches on impacts of Eucalyptus Plantation on soil and water accessibility, water accessibility impacts on women's economies and real property valuation and adequacy of compensation for expropriation.

Acknowledgements

First of all, I would like to express my appreciation to the Oromia Water Works and Soil Laboratory Staff for their cooperation during the analysis of soil physical and chemical parameters. I also like to acknowledge who directly or indirectly contributed to the success of this work.

Competing interests

The author declare that he has no competing interests.

Received: 28 January 2016 Accepted: 17 May 2016
Published online: 04 June 2016

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