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Impacts of land use on selected physicochemical properties of soils of Abobo area, western Ethiopia

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Abstract: Assessing land use-induced changes in soil properties are essential for addressing issues of agro-ecosystem transformation and sustainable land productivity. In view of this, a study was conducted to assess the impact of land use/land cover on the physicochemical properties of soils of Abobo area, western Ethiopia. Three adjacent land use types, namely forest, grazing and cultivated lands each falling under four land mapping units (1Ac, 1Bc, 2Cc and 3Cl) were considered for the study. A total of 40 random soil samples (0-20 cm depth) were collected to make three composite samples for each land use type across the land mapping units and analyzed for selected soil physical and chemical properties. The results of the study, on one hand, revealed that soil OM, total N, CEC, PBS and available micronutrients (Fe, Mn, Zn and Cu) contents of the cultivated land was significantly ($P < 0.001$) lower than the adjacent forest land. For instance, soil OM, total N, CEC, PBS, exchangeable Mg and available micronutrients (Mn, Zn and Cu) contents of cultivated land was significantly lower than the adjacent forest land by 32.98, 33.33, 16.16, 17.81, 21.88, 29.47, 40.05 and 53.92%, respectively. On the other hand, the results of the study revealed that exchangeable cations (Mg, K and Na), PBS and available micronutrients (Fe, Mn, Zn and Cu) contents of the gazing land was significantly ($P < 0.001$) lower than the adjacent forest land. However, significant differences were not observed between the forests and grazing lands in soil OM, total N, CEC and available P. From the present study, it could be concluded that the soil quality and health were maintained relatively under the forest, whereas the influence on most parameters were negative on the soils of the cultivated land, indicating the need for employing integrated soil fertility management in sustainable manner to optimize and maintain the favorable soil physicochemical properties.

Keywords: Land Use, Physicochemical Property, Soil Quality

1. Introduction

Assessing land use-induced changes in soil properties is essential for addressing the issue of agro-ecosystem transformation and sustainable land productivity [1]. Changes in land use and management practices often modify most soil morphological, physical, chemical and biological properties to the extent reflected in agricultural productivity [2].

The conversion of native forest and native rangeland into cultivated land is known to deteriorate soil properties [3-8]. The authors reported increment of bulk density, organic matter deterioration and reduction in cation exchange capacity (CEC), which in turn reduce the fertility status of the given soils, as main impacts. For instance, an increase in soil bulk density by 21.42% due to deforestation and subsequent cultivation [8] and decline in soil organic C and total N by 50.4 and 59.2%, respectively, after 53 years of continuous cropping compared to the natural forest [3]. Similarly, conversion of natural forest land into grazing and cultivated lands caused losses of cation exchange capacity (CEC) in the magnitude of 38 and 50%, respectively, in the surface (0-20 cm) soils [5].

Ethiopia was covered with substantial amount of forest until the 1940s, which eventually has changed to other land uses, such as grazing and cultivated lands. Despite the tremendous land use changes from forest to grazing and cultivated lands in Ethiopia, particularly during the last five to six decades, the impacts of these changes on soil properties are not well studied and documented [9]. It has also stated that information on the effect of land use and management practices on soil chemical properties in the country is generally very little [2]. Most of the studies conducted on the impact of land use on soil physicochemical properties (e.g., [2-5, 9, 11]) were carried out in the highlands of the country and did not address the lowland regions. Cognizant of this fact, the present study was initiated and carried out in Abobo area of Gambella, western Ethiopia, with the objective of assessing the impact of land use on soil physicochemical properties.

2. Materials and Methods

2.1. Description of the Study Area

The study area, Abobo District, is located at 42 km south of Gambella town and about 808 km from Addis Ababa in the western direction (Figure 1). It lies between 07^0 50' 47.3" to 08^0 01' 59.3" N and 34^0 28' 59.5" to 34^0 34' 37.1" E. The altitude of the study area ranges from 446 to 490 meter above sea level (masl) with slope ranging from level to gently sloping.

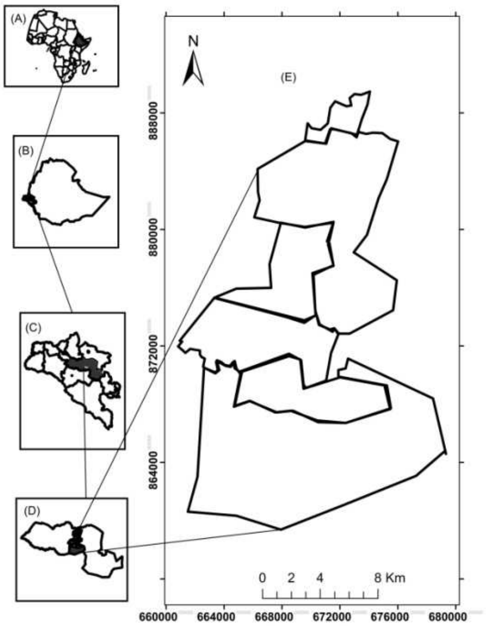

Figure 1. *Location of the study area: Ethiopia in Africa (A), Gambella Regional State in Ethiopia (B), Abobo District in Gambella Region (C), specific study area in Abobo District (D) and map of the study area (E).*

The climate of the region is influenced by the tropical monsoon which is characterized by high rainfall in the wet period from May to October and has little rainfall during the dry period from November to April [11]. The mean minimum monthly temperature of the area varies from 16.2 to 21.2 ^{0}C and the mean maximum monthly temperature ranges from 32.1 to 38.2 ^{0}C, whereas the average annual rainfall is 955.5 mm (Figure 2). The region is drained by a number of perennial rivers including, Baro, Alwero, Gillo and Akobo and their tributaries.

The geology of Abobo is characterized by undifferentiated Pleistocene Holocene deposits. Granite, gneisses, schist, sandstone and basalt are the rock types existed in the region [12]. The major soils of Abobo District include Dystric and Eutric Plinthosols, Dystric and Chromic Cambisols, Eutric Vertisols and Planosols, where Cambisols occur at the upper slope north of Abobo while Plinthosols and Vertisols exist at the middle and lower slopes, respectively [11].

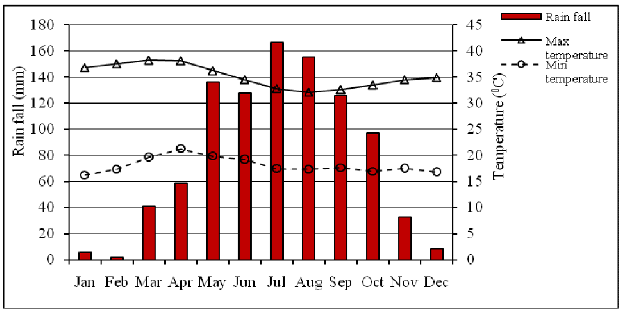

Figure 2*. Mean monthly rainfall, monthly minimum (Min) and maximum (Max) temperatures of Abobo area for the years 1975 to 2011*

The Abobo district encompasses forest land, wood land, shrub land, grass land and cultivated lands occupying, 143,086, 75,227, 5,793, 62,997 and 19,854 hectares (ha), respectively [13]. The forest cover is continuously declining due to settlement and agricultural expansion. The major crops grown by farmers include maize (*Zea mays L.*), sorghum (Sorghum bicolor), groundnut (*Arachis hypogae*) and sesame (*Sesamum astivum*), whereas cotton (*Gossypium sp.*) and rice (*Oryza sativa L.*) are cultivated by state farms and investors operating in and around the study area.

2.2. Site Selection and Sampling

Four land mapping units (1Ac, 1Bc, 2Cc and 3Cl) and three land use types (forest, grazing and cultivated lands) were considered for assessing the impact of land use on selected soil physicochemical properties (Table 1). Three adjacent land uses were selected from each land mapping units and 40 random soil samples (0-20 cm) were collected to make composite soil sample and replicated three times for each land use type, within the soil units.

Table 1. *Description of land use/cover classes identified in Abobo area, western Ethiopia*

Land use/cover	Description
Forest land	This category of land consisted indigenous tree and shrub species.
Grazing land	Land allocated for cattle grazing, which is dominated by tall grass with some scattered trees and bushes.
Cultivated land	Land allocated for annual crop production such as maize, sorghum, groundnut, sesame, cotton and rice.

2.3. Soil Sample Preparation and Laboratory Analysis

The soil samples were air-dried and ground to pass through 2 mm sieve. For the determinations of total N and organic carbon (OC), a 0.5 mm sieve was used. Analyses of the soil physicochemical properties considered in the study area were carried out following standard laboratory procedures.

Particle size distribution and bulk density were determined by the hydrometer [14] and the core sample [15] methods, respectively. Soil pH was measured in a 1:2.5 soil to water ratio suspension [16], whereas OC was determined by the wet digestion method [17]. Total N was determined by the micro-Kjeldahl wet digestion and distillation method [18], while available P was extracted by the modified Olsen method [19] and finally quantified by spectrophotometer. The cation exchange capacity (CEC) and exchangeable bases were extracted by 1M ammonium acetate (pH 7) method [20]. In the extract, exchangeable Ca and Mg were determined by atomic absorption spectrophotometer (AAS) and exchangeable K and Na by flame photometer, whereas CEC was determined from the displaced ammonium through distillation followed by titration. Available micronutrients (Fe, Mn, Zn and Cu) of the soil were extracted by diethylene triamine pentaacitic acid (DTPA) method as described in Tan [21] and determined using AAS at their respective wavelength.

2.4. Statistical Analysis

Laboratory analytical results on soil physicochemical properties were subjected to analysis of variance (ANOVA) using SAS software, version 9.2 [22]. Following significance variation, the least significant difference (LSD) test was employed to compare the means.

3. Results and Discussion

3.1. Impact of Land Use on Selected Physical Properties of the Soils

The results of the study revealed that the textural class of all the land use types was clay (Table 3), indicating the similarity in parent material. However, clay content in the surface layer (0-20 cm) of the soils varied significantly ($P < 0.05$) among the land use types (Table 2). Its content was significantly lower in cultivated land as compared to the forest and grazing lands. Similarly, previous authors reported lower clay content in cultivated land than the adjacent soils under natural forest [4, 8]. The reason for low clay in surface layers of cultivated lands might be due to selective removal of clay from the surface by erosion. A negative correlation ($r = -0.87$, $p < 0.001$) was observed between clay and sand (Table 7).

The silt content was significantly ($P < 0.001$) higher in cultivated land than the other land uses (Table 2), implying cultivated land is more susceptible to erosion than the adjacent forest and grazing lands. On the other hand, sand showed non-significant ($P > 0.05$) difference among the land uses (Table 2).

Table 2. *Analysis of variance (ANOVA) results of soils of Abobo area under the three land use types (forest, grazing and cultivated land)*

Soil property	SEM[a]	F- value (2)[b]	P- value
Sand	1.61	1.58	0.2224
Silt	1.98	13.35	< 0.0001
Clay	2.62	5.01	0.0133
Bulk density	0.24	16.47	< 0.0001
pH	0.10	11.12	0.1302
Soil OM	0.76	10.44	0.0004
Total N	0.02	26.31	< 0.0001
Available P	2.43	8.69	0.0011
Exchangeable Na	0.01	17.49	< 0.0001
Exchangeable K	0.16	10.97	0.0003
Exchangeable Ca	2.61	7.03	0.0031
Exchangeable Mg	0.45	47.71	< 0.0001
CEC	0.88	126.35	< 0.0001
Percent base saturation	2.83	30.18	< 0.0001
Available Fe	0.42	83.21	< 0.0001
Available Mn	0.51	69.78	< 0.0001
Available Zn	0.59	26.21	< 0.0001
Available Cu	0.33	155.59	< 0.0001

[a]SEM = Standard error of means; bFigure in parentheses = Degrees of freedom

Table 3. *Mean values of particle size distribution and bulk density as influenced by the different land uses*

Land use	Particle size distribution (%)			Textural class	ρb (g/cm³)
	Sand	Silt	Clay		
Forest land	28.42	21.25[b]	50.33[a]	Clay	1.20[c]
Grazing land	29.08	21.75[b]	49.17[ab]	Clay	1.26[a]
Cultivated land	27.91	25.08[a]	47.00[b]	Clay	1.23[b]
LSD (0.05)	NS	1.61	2.18		0.02
CV (%)	5.66	8.71	5.36		1.99

Means within column followed by the same letter are not statistically different from each other at P > 0.05; LSD = least significant difference; NS = non significant; CV = coefficient of variation. ρb = bulk density

The bulk density showed numerically narrow variation among land use types (Table 3). The reason might be due to the recent conversion of the forest land into grazing and cultivated lands in the study area. However, previous findings have reported higher bulk density in grazing and cultivated lands as compared to forest land. Soils in pasture land were found to be significantly more compacted than other land uses [23]. Previous authors stated that the bulk density in grazing and cultivated lands increased by 15.5 and 10.7%, respectively, [4] in relative to the natural forest. Similarly, an increase in soil bulk density by 21.42% due to deforestation and subsequent cultivation [8] was observed.

On the other hand, it was reported that soils under cultivated land having significantly higher bulk density than soils under forest and grazing lands [9]. Another authors also stated that bulk density increased significantly with increasing cultivation period [3].

3.2. The Impact of Land Use on Selected Chemical Prop erties of the Soils

3.2.1. Soil pH, Organic Matter, Total Nitrogen, C:N Ratio, and Available Phosphorus

There was no significant difference in soil pH among land use types (Table 4). Generally the pH ranges (5.9 to 6.1) among the land use types were narrow. There was no history of fertilizer application in the area, which could potentially affect the pH of the soils.

The soil organic matter OM content of cultivated land was significantly ($P < 0.001$) lower than forest and grazing lands (Table 2), while non significant ($P > 0.05$) difference was observed between forest and grazing land (Table 4). The soil OM content of cultivated land was depleted by 32.98% as compared to the forest land. Similarly, decline in soil OM contents by 63.04% [8], by 50.4% [3] and by 43.2% [4] were observed due to deforestation and subsequent cultivation. The relatively low soil OM under cultivated soils as compared to native ecosystems could be attributed to intensive cultivation, which aggravated oxidation of organic carbon corroborating previous findings [7, 10 and 24]. Additionally, complete removal of crop residues in the cultivated land might have resulted in declining soil OM [25]. Generally, the contents of soil OM was medium (2.52, 3.74 and 3.76 %, respectively) for cultivated, grazing and forest lands [26].

The contents of total N for all land use types were medium [26]. However, the content under cultivated land was significantly ($P < 0.001$) lower than the other land use types (Table 2). In line with this, previous authors reported that total N content of soils under cultivation were lower compared to contents in the natural forest soils [27-29]. Decline in total N contents by 61.82% [8], by 59.2% [3] and by 42.1% [4] were observed due *to* deforestation and subsequent cultivation. The total N under forest and grazing lands were statistically at par (Table 4). Generally, the organic carbon content and total N under forest land were higher than those under cultivated and grazing lands [9]. The correlation analysis result revealed that there was a positive strong correlation ($r = 0.94$, $p < 0.001$) between total N and soil OM (Table 7).

In accordance with C:N ratio, significant difference was not observed among land use types (Table 4). However, numerically the C:N ratio was higher under forest land as compared to cultivated land. The reason obviously could be the significantly ($P < 0.001$) higher contents of soil OM in case of forest land.

Table 4. *Mean values of pH, soil organic matter (OM), total N (TN), C:N ratio and available P as influenced by the different land uses*

Land use	pH (H_2O)	OM (%)	TN (%)	C:N ratio	Aval.P (mg kg^{-1})
Forest land	6.1	3.76^a	0.18^a	12.24	24.13^a
Grazing land	6.0	3.74^a	0.16^a	11.74	22.47a
Cultivated land	5.9	2.52^b	0.12^b	11.10	19.24^b
LSD (0.05)	NS	0.63	0.02	NS	2.43
CV (%)	1.73	22.78	13.14	15.01	13.31

Means within column followed by the same letter are not statistically significant from each other at $P > 0.05$. LSD = Least significant difference; NS = Non significant; CV = Coefficient of variation.

The available P contents of the soils under all land uses were generally high and very high [30], although cultivated land soils showed significant ($P < 0.01$) variation with forest and grazing lands (Table 2). The cultivated land showed 33% variation in available P content from the forest land which obviously could be due to crop mining, crop residue removal and erosion. Residual P content would not be expected from the soils because there was no history of application of fertilizers in the study area.

3.2.2. Cation Exchange Capacity, Exchangeable Bases and Percent Base Saturation

Cation exchange capacity of the soils under all land uses was high [31], although cultivated land showed significant ($P < 0.001$) difference with the other land use types (Table 2). The low CEC in cultivated land was in line with the low clay and organic matter contents of the soils under this land use (Tables 3 and 4). The soil CEC values in agricultural land uses decreased mainly due to the reduction in organic matter content [5]. The authors reported that conversion of natural forest land into shrub, grazing, and cultivated lands caused losses of CEC in the magnitude of 30, 38 and 50%, respectively, in the surface (0-20 cm) soils. Similarly, decline of CEC by 30.27% and by 38.8% were also observed [6, 8]. Significant ($P > 0.05$) difference was not recorded in CEC between forest and grazing lands (Table 5).

Considering exchangeable bases and percent base saturation, forest land showed significant ($P < 0.01$ for exchangeable Ca and $P < 0.001$ for exchangeable Mg, K, Na and percent base saturation) variation with cultivated and grazing lands (Table 2). The result demonstrated that the exchangeable base contents were well maintained in the forest ecosystem due to nutrient recycling in compared to grazing and cultivated lands, where basic nutrients loss upon grazing and harvesting prevailed. The exchange complex was dominated by Ca followed by Mg, K and Na, indicating productive agricultural soils [32].

The correlation analysis result revealed that there was a positive correlation ($r = 0.58$, $p < 0.05$) between CEC and clay (Table 7).

Table 5. *Exchangeable bases (Ca, Mg, K, and Na), CEC and percent base saturation (PBS) as influenced by the land uses*

Land use	Exchangeable bases ($cmol_c$ kg^{-1})				CEC	PBS (%)
	Ca	Mg	K	Na		
Forest land	18.85[a]	7.54[a]	1.08[a]	0.19[a]	31.37[a]	78.67[a]
Grazing land	15.70[b]	6.08[b]	0.86[b]	0.15[b]	31.16[a]	72.25[b]
Cultivated land	15.14[b]	5.89[b]	0.79[b]	0.11[c]	26.31[b]	70.00[b]
LSD (0.05)	2.18	0.38	0.13	0.01	0.73	2.36
CV (%)	15.80	6.95	17.47	9.74	2.98	3.85

Means with in column followed by the same letter are not statistically significant from each other at P > 0.05. LSD = Least significant difference; CV = Coefficient of variation

3.2.3. Available Micronutrients

The contents of Mn and Zn were high, whereas the content of Fe was medium, for all types of land use types [30]. On the other hand, the content of Cu was low for cultivated land and medium for forest and grazing land, respectively. Significantly (P < 0.001) highest values of micronutrients were recorded for forest land soils (Table 2), whereas the lowest values were recorded for cultivated land (Table 6). The available micronutrients (Fe, Mn, Zn and Cu) were declined by 6.79, 29.47, 40.05 and 53.92%, respectively, in cultivated land in comparison with the forest land. Generally, the status of micronutrients (Fe, Mn, Zn and Cu) significantly (P < 0.001) influenced by land use systems corroborating earlier works [4, 10, 34-35].

Table 6. *Mean values of available micronutrients (Fe, Mn, Zn and Cu) as influenced by land use*

Land use	Available micronutrients (mg kg^{-1})			
	Fe	Mn	Zn	Cu
Forest land	30.92[a]	42.18[a]	4.22[a]	4.34[a]
Grazing land	29.21[b]	40.54[b]	3.01[b]	2.68[b]
Cultivated land	28.82[c]	29.75[c]	2.53[b]	2.00[c]
LSD (0.05)	0.35	0.43	0.49	0.28
CV (%)	1.43	1.26	18.11	11.10

Means with in column followed by the same letter are not statistically significant from each other at P > 0.05. LSD = Least significant difference; CV = Coefficient of variation

The available micronutrients were found to increase with increase in CEC of soils due to more availability of exchange sites on soil colloids [35]. The authors' also stated that availability of micronutrients enhanced significantly with increase in organic matter because: (i) organic matter is helpful in improving soil structure and aeration, (ii) organic matter protects the oxidation and precipitation of micronutrients into unavailable forms and (iii) supply soluble chelating agents which increase the solubility of micronutrient contents.

Table 7. *Correlation matrix for linear relationships between selected soil parameters of Abobo area*

	Sand	Silt	Clay	ρb	pH	OM	TN	CEC	Mn	Zn	Cu
Sand	1.00										
Silt	0.47	1.00									
Clay	-0.87***	-0.85***	1.00								
ρb	0.38	0.38*	-0.45	1.00							
pH	0.08	-0.20	0.06	-0.21	1.00						
OM	0.03	-0.51*	0.27	0.08	-0.04	1.00					
TN	-0.09	-0.56*	0.37	-0.16	-0.01	0.94***	1.00				
CEC	-0.38	-0.62*	0.58*	-0.05	0.42	0.051	-0.01	1.00			
Mn	0.44	0.32	-0.45	-0.09	0.32	-0.01	0.05	-0.61*	1.00		
Zn	0.07	0.35	-0.24	-0.09	0.36	-0.19	-0.13	-0.46	0.80	1.00	
Cu	0.004	0.03	-0.02	-0.35	0.25	0.10	0.28	-0.51**	0.84	0.59*	1.00

*Significant at p < 0.05, ** p < 0.01 and *** p < 0.001; ρb = Bulk density; OM = Organic matter; TN = Total nitrogen; CEC = Cation exchange capacity

4. Conclusions

The present study indicated that the difference in land use systems (forest, cultivated and grazing) has significant influence on soil physicochemical properties. The influence on most parameters was negative on soils of the cultivated land. For instance, soil OM, available P, CEC and available Cu contents of cultivated land was significantly lower than the adjacent forest land by 33, 20.3, 16 and 53.9%, respectively. On the other hand, the results of the study revealed that exchangeable cations (Mg, K and Na), PBS and available micronutrients (Fe, Mn, Zn and Cu) contents of the gazing land was significantly (P < 0.001) lower than the adjacent forest land. However, significant differences were not observed between forests and grazing lands in soil

OM, total N, CEC and available P. From the present study, it could be concluded that the soil quality and health were maintained relatively under the forest, whereas the influence on most parameters were negative on the soils of the cultivated land, suggesting the need for intervention so as to optimize and sustain the soil quality in the case of cultivated land. Special emphasis should be given for the management of soil OM as many physicochemical properties are correlated with it. In the study area, the practice of slash and burn practice during field preparation should be ceased by creating awareness for the farmers about the use of crop residues. Generally, sustainable land management is required in the area to optimize and sustain crop and livestock production.

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