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Assessment of Soil Fertility Variation in Different Land Uses and Management Practices in Maybar Watershed, South Wollo Zone, North Ethiopia

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Abstract The study was conducted at the Maybar watershed, which is located in the Albuko District of South Wello Zone in the Amhara National Regional State. The aims of the study were to identify the effects of different land uses on the magnitudes and directions of major soil fertility parameters and within and among land use types and soil depths. The results showed that soil organic carbon declined exponentially following deforestation and subsequent conversion to cultivated land. The imbalance in soil organic carbon addition from the crops and loss of soil organic carbon have led to the continuous decline of soil organic carbon in the cultivated land soils by 41.6% and 86.5% as compared to the forest and grazing lands, respectively. Soil texture (sand, silt and clay), water retention at field capacity and permanent wilting point and all of the soils chemical properties studied were significantly affected ($P \leq 0.05$ and/or $P \leq 0.01$) by land use. Generally, comparisons between the crop fields that have been prolongly cultivated on one hand and the forest and grazing lands on the other revealed a highly significant difference on major soil fertility parameters. For instance, the highest average mean values of exchangeable Ca (10.75 cmol(+)/kg), exchangeable Mg (5.02 cmol(+)/kg) and CEC (28.17 cmol(+)/kg) were observed under the forest land as compared to the lowest values (3.96, 0.81 and 11.83 cmol(+)/kg), respectively, in the cultivated land. Furthermore, considering the soil depths, higher mean values of total N (0.153%), exchangeable Ca (7.71 cmol(+)/kg), base saturation (58.11%) and Fe (38.59 mg/kg) were recorded in the surface (0-20 cm) soil layer than in the subsurface (20-40 cm) depth. The results obtained from the study indicated that the direction and magnitude of changes in soil attributes under land uses reflect the long-term impact of human being on the landscape as the consequences of increasing human as well as livestock populations. The cumulative values of land use changes without proper management were negative. The manner in which soils are managed has a major impact on agricultural productivity and its sustainability. In order to be sustainable, development must not be only economically sustainable but also socially acceptable and environmentally sound. Therefore, strategies to feed the expanding population in the country have to seek a sustainable solution that better addresses soil fertility management.

Keywords: *soil fertility, land uses, soil physical and chemical analysis*

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1. Introduction

The causes of land degradation in Ethiopia are cultivation on steep and fragile soils with inadequate investments in soil conservation or vegetation cover, erratic and erosive rainfall patterns, declining use of fallow, limited recycling of dung and crop residues to the soil (Belay, 2003; Hurni, 1988). Changes in land use and soil management can have a marked effect on the soil organic matter. Several studies in the past have shown that deforestation and cultivation of virgin tropical soils often lead to depletion of nutrients (N, P, and S).

In mature and undisturbed tropical ecosystems, a balance exists between the organic carbon input and output of the soil because of mineralization and leaching of dissolved OM (Zech *et al*., 1997). keeping grasses in the crop rotation, returning all crop residues to the fields and cultivating no more than necessary, controlling erosion, using cover crops, returning all manures to the soil organic materials are considered as important sources of plant nutrients and improvement of soil physical and chemical properties (Campbell *et al*., 1996). The loss of soil nutrients in Ethiopia is related to cultural practices like cultivation. The removal of vegetative cover or burning plant residues as practiced under the traditional system of crop production (Mesfin, 1998), while the use of chemical fertilizer is also minimal. In traditional farming systems, farmers use bush fallow, plant residues, household refuse, animal manures and other organic nutrient sources to maintain soil fertility (Mulongey and Merck, 1993). However, little has been done to maintain the fertility of the soils in the area and the locally available data of soil fertility status are insufficient. As a consequence of land degradation, the productivity of the soils in the Ethiopian highlands including that of Maybar area is declining at a rate of 2-3% annually (Hurni, 1993).

On the other hand, shortage of grasslands has forced the farmers to remove crop residues for animal feed. Cow dung is used mainly for firewood rather than as manure. Almost all households (90%) in the study area use crop residues as feed to their livestock and only 10% are known to use manure on their farmlands. Therefore, this study was initiated to investigate the influence of different land uses on the fertility status of the soils in the Maybar areas in Albuko District.

2. Materials and Methods

2.1. Site Description

The study was conducted at the Maybar watershed, which is located in Albuko District of South Wello Zone in the Amhara National Regional State (ANRS). The ANRS is located in the northwestern part of Ethiopia between 9°00ˡ-13°45ˡ N latitude and 36°00'-40°30' E longitude covering a total land area of 170,152 km^2. Maybar is situated at about 25 km distance from Dessie city in the south-southeast direction and at about 425 km north of Addis Abeba. Geographically, the study site lies at 10°59ˡ N latitude and 39°39ˡ E longitude and at an altitude ranging from 1940 to 2850 meters above sea level. The cultivated land accounts for an average of about 40% and the grazing and forest lands and area closure sites together account for about 50% of the Maybar watershed area. The remaining 10% of the total area coverage of the watershed constitute settlement areas and others.

It is also representative of the moist agro-climatic zone, characteristically erosion prone, low potential, and oxen-plowed cereal belt of the northeastern escarpment regions of the Ethiopian highlands. Maybar areas are characterized by bimodal rainfall pattern with erratic distribution. The total annual rainfall is 1279 mm. The annual mean minimum and mean maximum temperatures at the study area are 11.43 and 21.6°C, respectively. According to Mulugeta (1988), the study area has quite marked topographic variation, of which steep and very steep slopes cover about three-forth of the total area. The rest is made up of moderately steep slopes of colluvial deposits. The watershed is dominated by hilly landforms with 25.82% of the total area being very steep (> 60% slope), 38.42% steep (30-60% slopes), 32.63% located in the upper most and foothill slope parts are moderately steep to sloping (5-30%) and the rest 3.13% is gently slopping to flat (0-5%).

2.2. Soil Sampling Techniques

A necessary assumption made in this research approach was that soil conditions or parameters for all the sites should be similar before changes in the land use have been introduced. Because any differences before land use changes should have been small and associated with lateral movement of soil materials on the watershed slopes, the observed differences in present soil conditions or other parameters can be assumed as being caused by the present land use practices or introduction of the new land management.

Three main factors such as depth, sampling intensity per unit area of site sampled, and the sampling design are usually considered when developing soil-sampling protocols to monitor change in major soil fertility parameters. At the beginning, a general visual field survey of the area was carried out to have a general view of the variations in the study area. Global Positioning System (GPS) readings were used to identify the geographical locations and the coordinate system where samples were taken, and clinometers were used to identify slopes of the sampling sites. Representative soil sampling fields were then selected based on vegetation and cultivation history and they are categorized forest, grazing and cultivated lands. Depending on their similarities three forest land representative fields, three grazing land representative fields and three cultivated land representative fields were selected, and from each representative field of land use types, fifteen soil samples were collected from the depths of 0-20 and 20-40 cm each in a radial sampling scheme using an auger (Wilding, 1985). We collected a total of two hundred seventy samples (ninety samples per land use type) of soil which is one hundred thirty five samples from 0-20 cm and one hundred thirty five samples from 20-40 cm of soil horizon. A total of eighteen composite samples were collected and each composite sample is made from a pool of fifteen samples. We placed the sample in a numbered calico bag with tightly fitting lid and labeled carefully with the location, representative field and depth of soil. The soil samples collected from representative fields' were then air-dried, mixed well and passed through a 2 mm sieve for the analysis of selected soil physical and chemical properties. Separate soil core samples from the 0-20 and 20-40 cm depths were taken with a sharp-edged steel cylinder forced manually into the soil for bulk density determination. Before sampling, forest litter, grass, dead plants and any other materials on the soil surface were removed, and during collection of samples; furrow, old manures, wet spots, areas near trees and compost pits were excluded.

2.3. Soil Laboratory Analysis

Soil particle size distribution was determined by the Boycouos hydrometric method **(Bouyoucos, 1962)** after destroying OM using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexameta phosphate ($NaPO_3$). Soil bulk density was determined by the undisturbed core sampling method after drying the soil samples in an oven at 105°C to constant weights (Black, 1965). In order to determine the available water holding capacity (AWHC) of the soil, the field capacity (FC) and permanent wilting point (PWP) were measured at -1/3 and -15 bars soil water potential, respectively, using the pressure plate apparatus (Klute, 1965). The AWHC was obtained by subtracting PWP from FC. The pH of the soils was measured in water and potassium chloride (1M KCl) suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combination electrode (Van Reeuwijk, 1992). The Walkley and Black (1934) wet digestion method was used to determine soil carbon content and percent soil OM was obtained by multiplying percent soil OC by a factor of 1.724 following the assumptions that OM is composed of 58% carbon. Cation exchange capacity (CEC) and exchangeable bases (Ca, Mg, K and Na) were determined after extracting the soil samples by ammonium acetate (1N NH_4OAc) at pH 7.0. Exchangeable Ca and Mg in the extracts was analyzed using atomic absorption spectrophotometer, while Na and K were analyzed by flame photometer **(Rowell, 1994).** Cation exchange capacity was thereafter estimated titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution (Chapman, 1965). Since the Olsen method is the most widely used for P extraction under wide range of pH both in Ethiopia and elsewhere in the world (Landon, 1991; Tekalign and Haque, 1991), available soil P was analysed according to the standard procedure of Olsen *et al.* (1954) extraction method.

2.4. Data Analysis

The soil physical and chemical properties were analysis using the general linear model procedure of the statistical analysis system (SAS, 1999). The least significance difference (LSD) test was used to separate significantly difference after main effects were found. Moreover, simple correlation analysis was executed with the help of Gomez and Gomez (1984) to reveal the magnitudes and directions of relationships between selected soil fertility parameters and within and among land use types and soil depths.

3. Results and Discusion

3.1. Soil Texture

The sand and clay fractions were significantly ($P \leq 0.01$) affected by land use, soil depth and the interaction of land use and soil depth. Similarly, the silt fraction was highly significantly affected by land use and significantly ($P \leq 0.05$) by the interaction of the two factors (Table 1 and Table 2). The highest average (surface and subsurface) sand content (66%) was observed under the grazing land and the lowest (60%) was recorded in the forest land, Whereas the average clay fraction of the forest, grazing and crop lands were 23, 9 and 14%, respectively (Table 1). In all the land use types, the contents of sand and silt fractions decreased with soil depth except for sand in the forest land and silt in the cultivated land soils (Table 2). Considering the two soil depths, higher mean sand fraction (64.66%) was observed within the surface soils (Table 1). Opposite to sand, higher clay fraction (16.67%) was found in the subsurface soil. Unlike the other land use types, the clay fraction in both layers of the cultivated land was the same (14%) (Table 2). This may be due to the intensive and continuous cultivation which might cause compaction on the surface that reduces translocation of clay particles within the different layers and due to mixing up by tillage activities in agreement with the findings reported by Jaiyeoba (2001).

Table 1. Main effects of land use and soil depth on selected physical properties of the soils in the Maybar watershed

Treatments	Sand (%)	Silt (%)	Clay (%)	STC	FC (%)	PWP (%)	AWHC (%)
				Land use			
Forest	60.00^c	17.00^c	23.00^a	SL	27.35^a	19.40^a	7.95^b
Grazing	66.00^a	25.00^a	9.00^c	SL	25.76^b	16.44^b	9.32^a
Cultivated	65.00^b	21.00^b	14.00^b	SL	24.40^c	16.59^b	7.81^b
LSD (0.05)	0.814	1.575	1.076		1.087	1.405	1.228
SEM (±)	0.365	0.706	0.483		0.488	0.631	0.551
				Soil depth			
0-20 cm	64.66^a	21.33	14.00^b	SL	25.53	17.48	8.05
20-40 cm	62.66^b	20.66	16.67^a	SL	26.15	17.47	8.68
LSD (0.05)	0.664	NS	0.878		NS	NS	NS
SEM (±)	0.296	0.577	0.394		0.398	0.515	0.450

Main effect means within a column followed by the same letter are not significantly different from each other at $P \leq 0.05$; NS = not significant; STC = soil texture class; SL = sandy loam

Table 2. Interaction effects of land use and soil depth on particle size (sand, silt and clay) distribution of the soils in the Maybar watershed

Land use type	Sand (%)*		Silt (%)*		Clay (%)*	
	Soil depth (cm)		Soil depth (cm)		Soil depth (cm)	
	0-20	20-40	0-20	20-40	0-20	20-40
Forest	60^d	60^d	18de	16^e	22^b	24^a
Grazing	68^a	64^c	26^a	24^{ab}	6^e	12^d
Cultivated	66^b	64^c	20^{cd}	22^{bc}	14^c	14^c
LSD (0.05)	1.151		2.228		1.522	
SEM (±)	0.365		0.707		0.483	

*Interaction means within a specific soil parameter followed by the same letter(s) are not significantly different from each other at $P \leq 0.05$; LSD = least significant difference; SEM = standard error of mean

Considering the interaction effects of land use by soil depth, the highest values of both sand (68%) and silt (26%) contents were recorded at the surface (0-20 cm) layer of the grazing land while clay content was highest (24%) at the subsoil (20-40 cm) layer of the forest land (Table 2). On the other hand, the lowest interaction mean values of sand, silt and clay were observed in both the surface and subsoil layers of the forest land, the subsurface layer of the forest land and the surface layer of the grazing land, respectively. With the exception of the two soil depths in the cultivated land, which had the same clay content, the mean clay contents of the remaining treatment combinations were significantly different ($P \leq 0.05$) from each other due to the interaction effects (Table 2). Sand was positively and significantly ($r = 0.64^{**}$) correlated with the exchangeable acidity and negatively ($r = -0.68^{**}$) with the CEC of the soils while clay was positively and significantly ($r = 0.70^{**}$) correlated with the CEC and negatively ($r = -0.57^{**}$) with the exchangeable acidity of the soils (Table 7). In this study, there were relatively less differences in particle size distribution among the subsurface layers of the soils under different land use types because these depths are relatively little affected by changes in land management. The results were in agreement with those reported by Sanchez *et al.* (1985) and these also support the assumption that the soil conditions prior to the shifts in land management were more or less similar.

3.2. Soil Water Content and Retention Capacity

Water contents at field capacity (FC) and permanent wilting point (PWP) were significantly ($P \leq 0.01$) affected by land use, whereas Available Water Holding Capacity (AWHC) of the soils was significantly ($P \leq 0.05$) affected by land use types (Table 1). On the other hand, none of the three components of soil moisture were affected either by soil depth or the interaction of land use by soil depth (Table 1 and Table 2). Considering the main effects of land use, the highest (27.35%) and lowest (24.40%) water contents at FC were found in the forest and cultivated lands, respectively. Similarly, the highest (19.40%) and lowest (16.44%) water contents at PWP were recorded in the forest and grazing lands, respectively (Table 1). On the contrary, the highest AWHC of 9.32% among the land use types was obtained in the grazing land and the lowest (7.81%) in the cultivated land. Similar results were reported by Wakene (2001) that the water content at PWP was highest (19.71%) under the forest land and lowest (16.17%) in the grazing land and the cultivated land had 16.56%. The observed results generally showed that the soils under different land uses differed in their water content both at FC and PWP because they vary in sand, silt and clay contents. Permanent wilting point was positively and significantly ($r = 0.56^{*}$) correlated with clay content of the soils (Table 7). Accordingly, both FC and PWP were positively and significantly ($P \leq 0.01$) associated with the exchangeable basic cations (such as Ca and Mg) and CEC of the soils. On the other hand, FC was negatively and significantly ($P \leq 0.01$) associated with the exchangeable acidity of the soils (Table 7).

3.3. Soil Reaction (pH)

The soils pH-H_2O value was significantly affected by land use ($P \leq 0.01$) and soil depth ($P \leq 0.05$), whereas pH-KCl was significantly ($P \leq 0.01$) affected only by land use (Table 3). On the other hand, both pH-H_2O and pH-KCl values were not affected by the interaction of land use by soil depth (Table 4). Land use changes for example from forest to crop land, resulted in reduction of soil pH of the study area. For instance, the highest (6.82) and the lowest (5.83) soil pH-H_2O values were recorded under the forest and the cultivated lands, respectively (Table 3). The lowest value of pH under the cultivated land may be due to two major reasons. The first is the depletion of basic cations in crop harvest and drainage to streams in runoff generated from accelerated erosions. Secondly, it may be due to its highest microbial oxidation that produces organic acids, which provide H ions to the soil solution and thereby lowers soil pH. Generally, the pH values observed in the study area are within the ranges of moderately acidic to neutral soil reactions as indicated by Foth and Ellis (1997). Considering the two soil depths, the higher mean values of pH-H_2O (6.50) and pH-KCl (5.58) were observed within the surface soils. In general, pH values decreased with increasing soil depth (Table 3 and Table 4). The reason can be the reduction of Ca and Mg ions along soil depth which lowers soil pH from top to down the soil layers. Accordingly, basic cations, CEC and pH have had strong positive relations with each other (Table 7).

Table 3. Main effects of land use and soil depth on some chemical properties of the soils in the Maybar watershed

Treatment	pH (H_2O)	pH (KCl)	OM (%)	Av. P (mg/kg)
Land use				
Forest	6.82^a	6.05^a	1.42^b	3.53^c
Grazing	6.52^b	5.62^b	1.85^a	3.82^b
Cultivated	5.83^c	4.80^c	0.99^c	4.51^a
LSD (0.05)	0.222	0.332	0.028	0.082
SEM (±)	0.100	0.149	0.013	0.037
Soil depth				
0-20 cm	6.50^a	5.57	1.55^a	3.69^b
20-40 cm	6.28^b	5.40	1.28^b	4.21^a
LSD (0.05)	0.182	NS	0.023	0.067
SEM (±)	0.081	0.122	0.010	0.030

Main effect means within a column followed by the same letter are not significantly different from each other at $P \leq 0.05$; NS = not significant

3.4. Soil Organic Matter (OM)

Organic matter content was significantly ($P \leq 0.01$) affected by land use, soil depth and the interaction of land use by soil depth (Table 3 and Table 4). Soil OM content was highest (1.85%) under the grazing land and lowest (0.99%) on the cultivated land (Table 3). The decline in soil OM content in the cultivated land following deforestation and conversion to farm fields might have been aggravated by the insufficient inputs of organic substrate from the farming system due to residue removal and zero crop rotation**.** This general truth was assured by different individuals (Duff *et al*., 1995). Besides this, leaching problem that can be attributed to the relatively high sand content (Table 1 and Table 2) and the resultant light texture of soils also might be the cause of OM reduction. This is apparent because the clay particles unlike the sand particles, have substantial exchange surface areas, and therefore adsorb and stabilize OM and soil nutrients Saggar *et al*., 1996). Considering the two soil depths, higher average OM (1.55%) was observed in the surface (0-20 cm) than subsoil (20-40 cm) layers (Table 3). Soil OM contents in the 0-20 cm and 20-40 cm soil depths were highest on the grazing lands and lowest under the cultivated lands (Table 4). Similarly, unlike to other land use types, OM content under the cultivated land was higher in the subsoil layers than in the surface layers. This might be due to soil OM incorporation from surface layer to subsoil layer as a result of the mixing effect of tillage activities and down ward movement due to its higher sand content. Furthermore, the substantial amount of organic materials added from root biomass after the crop is harvested as stated by Van Noordwijk *et al*. (1997) coupled with rapid decrease of soil microorganism activity with increasing soil depth may explain the higher soil OM stocks in the subsoil of the crop fields. According to the classification of soil OM as per the ranges suggested by Landon (1991), the soils of Maybar are very low to low (0.99-1.85%) in OM content.

With regard to the interaction effect of land use by soil depth, the highest (2.16%) and the lowest (0.92%) values of OM contents were recorded at the surface (0-20 cm) layer of the grazing and the cultivated lands, respectively (Table 4). With the exception of the surface layer in the forest land and the subsoil layer in the grazing land which had almost the same OM content, the mean OM contents of the remaining treatments combination were significantly different (P ≤ 0.05) from each other due to the interaction effects (Table 4).

Table 4. Interaction effects of land use and soil depth (cm) on, soil OM and available P of the soils in the Maybar watershed

Land use type	OM (%)*		Av. P (mg/kg)*	
	Soil depth		Soil depth	
	0-20	20-40	0-20	20-40
Forest	1.58[b]	1.23[c]	4.80[b]	2.26[f]
Grazing	2.16[a]	1.54[b]	3.50[d]	4.14[c]
Cultivated	0.92[e]	1.06[d]	2.78[e]	6.24[a]
LSD (0.05)	0.041		0.115	
SEM (±)	0.013		0.037	

*Interaction means within a specific soil parameter followed by the same letter (s) are not significantly different from each other at P ≤ 0.05

3.5. Available Phosphorus (P)

The available phosphorus was significantly (P ≤ 0.01) affected by land use, soil depth and the interaction of land use with soil depth (Table 3 and Table 4). The content of available P in the cultivated land appeared to be significantly higher than the rest two land use types. Accordingly, the highest (4.51 mg/kg) and the lowest (3.53 mg/kg) available P contents were observed under the cultivated and the forest lands, respectively (Table 3). The data also revealed that available P was higher (4.21 mg/kg) in the subsoil (20-40 cm) than in the surface layer. According to Landon (1991) available soil P level of < 5 mg/kg is rated as low, 5-15 mg/kg as medium and > 15 mg/kg is rated as high. Thus, the available P of the soils of the study area, with the exception of the subsoil layer of the cultivated land, were less than 5 mg/kg qualifying for the low range. The low contents available P observed in the soil of the study area are in agreement with the results reported by many authors (Murphy, 1968; Eylachew, 1987) that the availability of P under most soils of Ethiopia decline by the impacts of fixation, abundant crop harvest and erosion. Considering the interaction effect of land use with soil depth, the highest (6.24 mg/kg) and the lowest (2.26 mg/kg) of available P contents were recorded at the subsoil (20-40 cm) layer of the cultivated and the forest lands, respectively (Table 4). In general, all treatments combination were significantly different (P ≤ 0.05) from each other due to the interaction effects.

3.6. Basic Exchangeable Cations

The content of exchangeable calcium (Ca) was significantly (P ≤ 0.01) affected by land use, soil depth and the interaction of land use by soil depth (Table 5 and Table 6). The mean values of exchangeable calcium (Ca) under the forest, the grazing and the cultivated lands were 10.75, 3.26 and 3.96 $cmol_{(+)}/kg$, respectively (Table 5). Considering the two soil depths, it was higher (7.71 $cmol_{(+)}/kg$) at the surface layer than at the subsoil (20-40 cm) depth. Considering the interaction of land use by soil depth, the highest (15.23 $cmol_{(+)}/kg$) exchangeable Ca was recorded at the surface (0-20 cm) layer of the forest land, and the lowest (2.41 $cmol_{(+)}/kg$) was obtained at the subsoil layer of the grazing land (Table 6). With the exception of the two soil depths in the cultivated land and the surface layer of the grazing land, which had statistically the same exchangeable Ca content, the mean exchangeable Ca contents of the remaining treatment combinations were significantly different (P ≤ 0.05) from each other due to the interaction effects.

Table 5. Main effects of land use and soil depth on exchangeable cations, exchangeable acidity, CEC and PBS

Treatment	Basic exchangeable cations-$cmol_{(+)}/kg$				Ex. acidity	CEC	PBS
	Ca	Mg	K	Na	($cmol_{(+)}/kg$)		%
Land use							
Forest	10.75[a]	5.02[a]	2.00[a]	0.30[b]	0.03[c]	28.17[a]	63.38[a]
Grazing	3.26[c]	0.88[b]	0.93[b]	0.34[a]	0.04[b]	17.17[b]	32.32[c]
Cultivated	3.96[b]	0.81[b]	0.85[b]	0.20[c]	0.06[a]	11.83[c]	50.92[b]
LSD (0.05)	0.541	0.602	0.092	0.024	0.010	1.672	5.863
SEM (±)	0.243	0.270	0.041	0.011	0.004	0.751	2.632
Soil depth							
0-20 cm	7.71[a]	2.46	1.28	0.28	0.04	19.00	58.11[a]
20-40 cm	4.27[b]	2.02	1.24	0.27	0.04	19.11	39.63[b]
LSD (0.05)	0.442	NS	NS	NS	NS	NS	4.790
SEM (±)	0.198	0.221	0.034	0.009	0.0036	0.613	2.150

Main effect means within a column followed by the same letter are not significantly different from each other at P ≤ 0.05; NS = not significant; Ex. acidity = exchangeable acidity

Exchangeable magnesium content was significantly (P ≤ 0.01) affected only by land use types (Table 5). Considering the main effects of land use, the mean exchangeable magnesium (Mg) value was highest (5.02 $cmol_{(+)}/kg$) under the forest land and lowest (0.81 $cmol_{(+)}/kg$) on the cultivated land (Table 5).

The contents of both exchangeable Ca and Mg decreased with soil depth except under the cultivated land (Table 6). These indicate that there was higher down ward leaching of basic cations in the crop field than in the other land use practices. The lowest value obtained on the cultivated land could be also be related to influence of intensity of cultivation and abundant crop harvest with little or no use of input as reported by Singh *et al*. (1995) and He *et al*. (1999). Exchangeable Ca was positively and significantly correlated with exchangeable Mg ($r = 0.85^{**}$), PBS ($r = 0.81^{**}$), CEC ($r = 0.80^{**}$), exchangeable K ($r = 0.68^{**}$), PWP ($r = 0.63^{**}$), FC ($r = 0.62^{**}$), clay ($r = 0.61^{**}$) and total N ($r = 0.48^{*}$), while it was inversely and significantly (P ≤ 0.05) correlated with sand and exchangeable acidity (Table 7). Similar correlations both in magnitude and directions were observed between exchangeable Mg and most of the soil properties correlated with exchangeable Ca.

Exchangeable K content was significantly (P ≤ 0.01) affected by land use and the interaction of land use by soil depth (Table 5 and Table 6). It was highest (2.00 $cmol_{(+)}/kg$) in the forest land and lowest (0.85 $cmol_{(+)}/kg$) in the cultivated land. The highest content in the forest land was related with its high pH value and was in agreement with study results reported by Mesfin (1996) that high K was recorded under high pH tropical soils.

Considering the interaction effects of land use by soil depth, the highest (2.11 cmol$_{(+)}$/kg) and the lowest (0.66 cmol$_{(+)}$/kg) exchangeable K contents were recorded at the surface (0-20 cm) layers of the forest and the cultivated lands, respectively (Table 6). With the exceptions of the surface layers of the grazing and the subsurface layer of the cultivated lands, which were statistically at par, the mean exchangeable K contents of the remaining treatment combinations were significantly different ($P \leq 0.05$) from each other due to the interaction effects.

The ranges of mean exchangeable K values observed in this study show that K^+ was above the critical levels (0.38 cmol$_{(+)}$/kg) for the production of most crop plants as indicated by Barber (1984). Generally, the lower exchangeable K contents in the cultivated and the grazing lands than in the forest land might be due to its continuous losses in the harvested and grazed parts of the plants from the cultivated and grazing lands, respectively. Previous findings have also considered these factors and the application of acid forming fertilizers as major factors affecting the distribution of K^+ in soil systems mainly enhancing its depletion especially in tropical soils (Baker *et al*., 1997; Wakene, 2001).

Table 6. Interaction effects of land use and soil depth on exchangeable cations (Ca, K and Na) and CEC of the soils in the Maybar watershed

Land use type	Ca (cmol$_{(+)}$/kg)*		K (cmol$_{(+)}$/kg)*		Na (cmol$_{(+)}$/kg)*		CEC (cmol$_{(+)}$/kg)*	
	Soil depth (cm)		Soil depth (cm)		Soil depth (cm)		Soil depth (cm)	
	0-20	20-40	0-20	20-40	0-20	20-40	0-20	20-40
Forest	15.23^a	6.27^b	2.11^a	1.89^b	0.32^a	0.28^b	30.33^a	26.00^b
Grazing	4.10c	2.41^d	1.06^c	0.79^d	0.32^a	0.35^a	16.00^c	18.33^c
Cultivated	3.79^c	4.13^c	0.66^e	1.03^c	0.21^c	0.18^c	10.66^e	13.00^d
LSD (0.05)	0.765		0.129		0.036		2.244	
SEM (±)	0.243		0.041		0.011		0.712	

*Interaction means within a specific soil parameter followed by the same letter (s) are not significantly different from each other at $P \leq 0.05$

The content of exchangeable Na was significantly affected by land use ($P \leq 0.01$) and by the interaction of land use by soil depth ($P \leq 0.05$) (Table 5 and Table 6). On the other hand, it was not significantly ($P > 0.05$) affected by soil depth. Considering the main effects of land use, exchangeable Na content was highest (0.34 cmol$_{(+)}$/kg) under the grazing land and lowest (0.20 cmol$_{(+)}$/kg) in the cultivated land (Table 5). Similarly, the highest (0.35 cmol$_{(+)}$/kg) and the lowest (0.18 cmol$_{(+)}$/kg) exchangeable Na contents as affected by the interaction of land use by soil depth were recorded at the subsoil layer of the grazing and the cultivated lands, respectively (Table 6). Specifically, the interaction of land use by subsoil layer treatment combinations were significantly different ($P \leq 0.05$) (Table 6).

In general, deforestation, leaching, limited recycling of dung and crop residue in the soil, very low use of chemical fertilizers, declining fallow periods or continuous cropping and soil erosion have contributed to depletion of basic cations and CEC on the cultivated land as compared to the adjust forest land.

3.7. Exchangeable Acidity

The exchangeable acidity was significantly ($P \leq 0.01$) affected by land use, while it was not significantly ($P > 0.05$) affected by soil depth and the interaction of land use by soil depth (Table 5 and Table 6). The highest (0.06 cmol$_{(+)}$/kg) and the lowest (0.03 cmol$_{(+)}$/kg) exchangeable acidity were recorded under the cultivated and the forest lands, respectively (Table 5). These results show that deforestation, intensive cultivation and application of inorganic fertilizers leads to the higher exchangeable acidity content under the crop field. The results of this study were in agreement with those reported by different researchers (Baligar *et al.*, 1997; Wakene, 2001), who reported that inorganic fertilizer application is the root cause of soil acidity. Furthermore, except the grazing land which had the same content in the two soil depths, exchangeable acidity values decreased from the surface to the subsoil layer under different land use types (Table 6). Exchangeable acidity was negatively and significantly correlated with pH ($r = -0.78^{**}$) and exchangeable basic cations such as Ca ($r = -0.49^{**}$), Mg ($r = -0.73^{**}$), K ($r = -0.70^{**}$) and Na ($r = -0.54^{*}$) (Table 7). Nair and Chamuah (1993) reported that the concentration of the H^+ to cause acidity is pronounced at pH value below 4 while excess concentration of Al^{3+} is observed at pH below 5.5. However, the results of this study indicate that the pH of the study area was above 5.5 and basic cations had occupied the site. Therefore, the concentration of exchangeable Al^{+3} was trace and Al toxicity is not expected in the area.

3.8. Cation Exchange Capacity (CEC)

The CEC values of the soils in the study area were significantly ($P \leq 0.01$) affected by land use and the interaction of land use by soil depth, but not significantly ($P > 0.05$) affected by soil depth (Tables 5 and 6). Considering the main effects of land use, the highest (28.17 cmol $_{(+)}$/kg) and the lowest (11.83 cmol $_{(+)}$/ kg) values of CEC were observed under the forest and the cultivated lands, respectively (Table 5). Considering the interaction effect of land use by soil depth, the highest CEC value (30.33 cmol $_{(+)}$/ kg) was recorded at the surface layer of the forest land, whereas the lowest (10. 66 cmol $_{(+)}$/ kg) was observed at surface layer of the cultivated land (Table 6). With the exception of the two soil depths in the grazing land, which were statistically at par, the mean CEC values of the remaining treatment combinations were significantly different ($P \leq 0.05$) from each other due to the interaction effects.

It is a general truth that both clay and colloidal OM have the ability to absorb and hold positively charged ions. Thus, soils containing high clay and organic matter contents have high cation exchange capacity. The increment of clay content from the surface to the subsurface layer was 50% under the grazing land and 2% on the forest land (Table 2). While, in the case of the cultivated land, OM increased with soil depth rather than clay. Therefore, the CEC under the grazing and cultivated lands increased from the overlying to the underlying soil layer (Table 5 and Table 6), which might be attributed to the increase in clay and OM contents with depth, respectively. Cation exchange capacity was significantly and positively correlated with clay and OM (Table 7). According to Landon (1991), the top soils having CEC of > 25, 15-25 $cmol_{(+)}$/kg, 5-15 $cmol_{(+)}$/kg and < 5 $cmol_{(+)}$/kg are classified as high, medium, low and very low, respectively. Based on the above ratings, the surface soils of the forest, the grazing and the cultivated lands qualify for high, medium and low status of CEC, respectively (Table 6). Therefore, deforestation, overgrazing and changing of land from forest to crop land without proper management aggravates soil fertility reduction. Therefore, the result of this study indicated that the CEC of the forest land was significantly higher than the adjacent two land use types.

Percentage base saturation (PBS) was significantly ($P \leq 0.01$) influenced by land use and soil depth (Table 5), whereas it was not significantly ($P > 0.05$) affected by the interaction of land use by soil depth. Considering the main effects of land use, the highest (63.38%) and the lowest (32.32%) values of PBS were recorded under the forest and the grazing lands, respectively (Table 5). On the other hand, among the two soil depths, higher (58.11%) was observed in the surface layer than the subsoil layer. In general, processes that affect the extent of basic cations also affect percent base saturation.

Table 7. Pearson's correlation matrix for various soil physicochemical parameters

	Sand	Silt	Clay	FC	PWP	pH	Ex. A	OM	Ca	Mg	K	Na	CEC	PBS
Sand	1													
Silt	0..61**	1												
Clay	-0.89**	-0.90**	1											
FC	-0.53*	-0.26	0.44	1										
PWP	-0.42	-0.58*	0.56*	0.74**	1									
pH	-0.39	-0.29	0.38	0.74**	0.53*	1								
Ex. A	0.64**	0.39	-0.57*	-0.67**	-0.33	-0.78**	1							
OM	0.34	0.51*	-0.47*	0.32	0.03	0.48*	-0.30	1						
Ca	-0.56*	-0.54*	0.61**	0.62**	0.63**	0.41	-0.49*	0.13	1					
Mg	-0.75**	-0.70**	0.81**	0.73**	0.74**	0.62**	-0.73**	0.06	0.85**	1				
K	-0.66**	-0.77**	0.80**	0.51*	0.68**	0.60**	-0.70**	0.04	0.68**	0.91**	1			
Na	-0.02	0.21	-0.11	0.56*	0.25	0.76**	-0.54*	0.77**	0.24	0.27	0.26	1		
CEC	-0.68**	-0.57*	0.70**	0.80**	0.67**	0.84**	-0.84**	0.37*	0.80**	0.91**	0.83**	0.55*	1	
PBS	-0.41	-0.59*	0.56*	0.24	0.51*	-0.06	-0.14	-0.20	0.81**	0.67**	0.59**	-0.21	0.41	1

**Significant at P = 0.01 level; * significant at P = 0.05 level; pH = pH (H_2O); Ex. A = exchangeable acidity

4. Summary and Conclusions

Deforestation for crop production and intensive cultivation of soils with very low inputs has been practiced in the study area. Soil erosion has been a severe problem in sloping areas. Both governmental and non-governmental organizations have worked to introduce conservation technologies, but these have received little attention on the farmers'. The direct causes of land degradation, including decline in the use of fallow, limited recycling of dung and crop residues to the soil, limited application of external sources of plant nutrients, deforestation, and overgrazing, are apparent and generally agreed. Underlying these direct causes include population pressure, poverty, high cost and limited access to agricultural inputs and credit, fragmented land holdings and insecure land tenure, and farmers' lack of information about alternative appropriate technologies. Although the farming system in Maybar area of south Wello is predominantly mixed crop-livestock, nutrient flows between the two are predominantly one sided, with feeding of crop residue to livestock but little or no dung returned to the soil. The attributes of the soils under the cultivated lands showed overall change towards the direction of loss of their fertility compared to the soils attributes of the adjacent forest and grazing land soils. Major declines were observed for soil organic matter, which is the principal source of plant nutrients (such as N, S and P) and helps to sustain soil fertility by mineralization and nutrient retention in low input tropical farming systems. Therefore, strategies to feed the expanding population in the study areas will have to seek a sustainable solution that better addresses integrated soil management.

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