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ASSESSMENT OF SOIL PHYSICAL AND CHEMICAL PROPERTIES AS AFFECTED BY DIFFERENT LAND USE TYPES IN WARANDHAB AREA OF WOLLEGA ZONE, OROMIA REGIONAL STATE

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ABSTRACT
The study was conducted with the objective to identify the influence of different land use types and soil depths on selected soil physic-chemical properties related to soil fertility. Soil properties, pH, SOM, total nitrogen, available P, exchangeable Mg, K, Na, CEC and micronutrients were significantly affected ($P \leq 0.05$ and/or $P \leq 0.01$) by land use. The highest (1.45g/cm^3) and lowest mean (1.04g/cm^3) BD was obtained in subsurface of cultivated and surface layer of grazing land respectively. The highest soil water content at FC (47.13%) and AWHC (18.74%) and lowest (34.17 and 8.37%) were recorded in subsurface and surface of forest and cultivated land, respectively. The highest pH = 6.47 and lowest pH = 5.29, were obtained in subsurface of grass land and surface layers of cultivated land, respectively. The range of pH in surface and subsurface layers of all land use types were strongly acidic to slightly acidic. The highest means SOM (8.37%), and total nitrogen (0.42%) were recorded in surface layer of forest land compared to the lowest (1.83% and 0.09%), respectively, in subsurface layer of cultivated land. The higher (16.00, 20.04, 89.03, 2.49, 3.39) mg/kg available P, Fe, Mn, Zn, Cu, respectively and CEC (32.80 cmol$_{(+)}$/kg) were recorded in surface layer of cultivated land than in subsurface. Values of exchangeable bases (Na, K, Ca and Mg) were lower (0.13, 0.77, 10.82, and 3.03 cmol $_{(+)}$/kg) on surface of cultivated land than subsurface (0.14, 2.15, 11.00, and 4.20 cmol$_{(+)}$/kg) of forest land, respectively. The inappropriate land use management led to disturbance of soil nutrient status. Therefore, reducing intensity of cultivation, adopting integrated soil fertility management and application of organic fertilizers could maintain the existing soil condition and replenish degraded soil properties.

Key words/phrases: Land use types, soil depths, soil fertility, soil productivity

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1. INTRODUCTION

Soil as a vital natural resource which performs key environmental, economic, and social functions is non-renewable within human time scales. Soil quality has-been defined as the capacity of the soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality and promote plant, animal and human health (Doran and Jones, 1996). High quality soils not only produce better food and fiber, but also help to establish natural ecosystems and enhance air and water quality (Griffiths *et al*., 2010). Soil fertility changes and the nutrient balances are taken as key indicators of soil quality (Jansen *et al*., 1995).

Ethiopia has diverse topographic features which encompass high mountains, deep gorges, flat-topped plateaus, and rolling plains. The physical conditions and variations in altitude have resulted in a great diversity of climate, soil and vegetation (Asrat, 1992). 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 fallowing, limited recycling of dung and crop residues to the soil, limited application of external sources of plant nutrients, deforestation and overgrazing (Belay, 2003; Hurni, 1988).

Therefore, reducing resource degradation, increasing agricultural productivity, reducing poverty, and achieving food security are major challenges of the countries in tropical Africa. Thus, every effort should be directed to maintain the physical, biological and socio- economic environment for production of food crops, livestock, wood and other products through sustainable use of the ecosystem.

The loss of soil nutrients in Ethiopia is related to cultural cultivation practices. The removal of vegetative cover (such as straw or stubble) or burning plant residues as practiced under the traditional system of crop production or the annual burning of vegetation on grazing lands are major contributors to the loss of nutrients, while the use of chemical fertilizer is also minimal (Mesfin, 1998).

The rapid population growth resulted in increased number of newly emerging rural households and rose up the demand for increased food supply and income, which ultimately necessitated additional units of agricultural land. As a result, considerable mass of natural ecosystems are continuously altered into managed agro-ecosystems following deforestation and continuous cultivation. In such a manner, land use change in Ethiopian mixed crop-livestock systems has been tremendous.

Inappropriate use of land, mainly characterized by extensive deforestation and conversion into agricultural land, is the most widespread change in land use in Ethiopia as a means to compensate for the low agricultural productivity (Solomon *et al.,* 2002; Mulugeta, 2004). In this view, rate of deforestation in Ethiopia, which amounts to 163,000 - 200,000 ha per year, is one of the highest in tropical Africa (Reusing, 1998). As a result, the natural forest cover in the country has declined considerably from approximately 40% to just less than 3% during the last 100 years (Kuru, 1990; EFAP, 1993) a process that has further exacerbated land degradation in the country. On the other hand, as cultivated fields expanded at the expense of all other land uses, forests and grasslands are pushed into marginal areas and productivity continued to decline. In such traditional and subsistence systems where agriculture forms the main stay of the rural people and dominant consumer of land, it may not be surprising to see such striking changes. In these dynamic ecosystems, land use modifications and conversions are immense and driven by the interactions of various biophysical and socio-economic factors that determine actual land use systems at various scales. However, the amount, rate and magnitude of these changes are affected by the diverse environmental, economic, social and political factors.

The major agricultural problems at the study area are shortage of land for crop cultivation and livestock grazing, decline of soil fertility and rainfall variability resulting in low yield production. Gebeyaw

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(2006) reported that increasing population pressure and shortage of land, deforestation and cultivation activities are being carried out on steep slopes, practice of fallowing and crop rotation being eliminated. Besides this, shortage of grasslands has forced the farmers to remove crop residues for animal feed and firewood rather than doing it as manure for maintenance of soil fertility and productivity. Therefore, this study was initiated with the objective to investigate the influence of different land use types and soil depths on selected soil physical and chemical properties related to soil fertility in Warandhab areas of Jimma Rare District.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

2.1.1. Location: The study was conducted at Warandhab area in Jimma Rare District, Wollega Zone, Oromiya Regional State. It is about 255 km away from the capital, Addis Ababa, and located in the mid-west of Ethiopia and 10 km away from the district town, Wayu, to the west. Geographically, it is located between 9^{o} 13' 26'' to 9^{o} 15' 58'' north latitude, and 37^{o} 15' 14'' to 37^{o} 16' 02'' east longitude with an elevation ranging 2224-2243 metres above sea level. It covers an area of about 800 hectares and shares commonly with Dile Kolba Peasant Association to the west, Bikiltu Babala and Gudata Dobi Peasant Associations in the east, Bada Warke Peasant Association in the south and swamp/marsh area in the north.

Jimma Rare District shares boundaries in the west with Jimma Ganati and Bako Tibe Districts, in the north with Guduru District, in the south and east with Chaliya District. This district possesses a total area of 340.78 km^2.

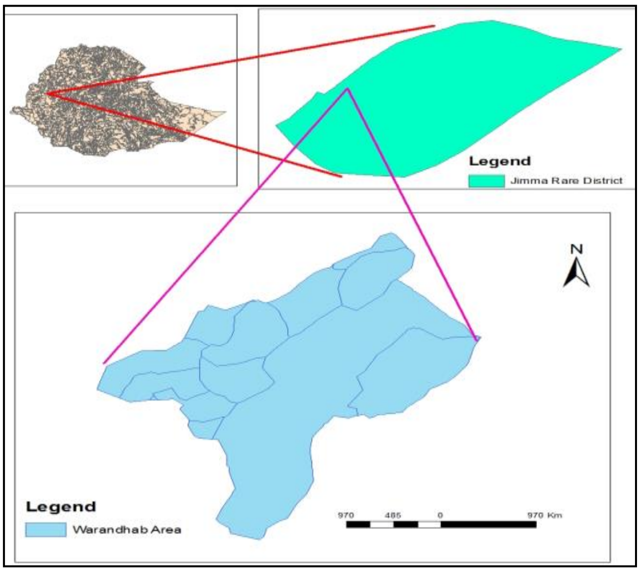

Figure 1. Location Map of the Research Site, Warandhab Area

2.1.2. Climate: The average weather data recorded at the weather station located at Wayu town near the study area from the year 2004-2010 indicates that the study area has a uni-modal rainfall pattern with mean annual rainfall of 1530.9 mm. The rainy season covers the period from mid-April to October and the maximum rain is received in the months of June, July and August. The annual mean minimum and maximum and the annual average air temperature for the year 2010 are 11.5, 23.8, and 17.625 ^{0}C, respectively (Figure 2).

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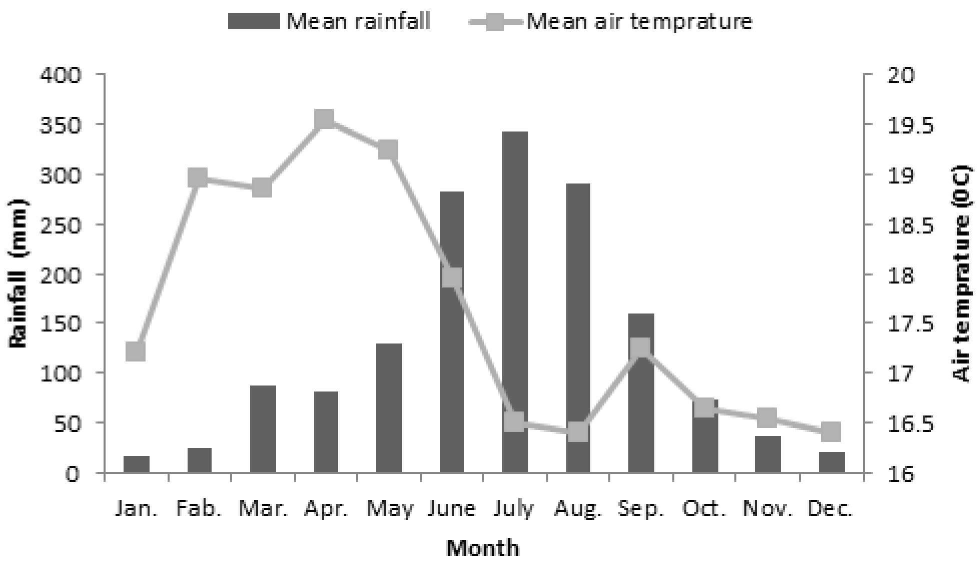

Figure 2. Mean monthly rainfall (mm) and minimum and maximum temperature (^{0}C) of the study area based on data collected from Wayu town weather station.

2.2. Site Selection, Soil Sampling and Preparation

Planning, surveying and appropriate sampling are important considerations when attempting to measure changes in surface soil chemical and physical properties to accommodate spatial variation. Primarily, a general visual field survey of the area was carried out to have a general view of the variations in the study area. Representative soil sampling site were then selected based on vegetation cover and cultivation history. Following this, three representative land uses (cultivated, forest and grass lands) were selected and Global Positioning System (GPS) and clinometer were used to identify the geographical locations and slopes of the sampling sites, respectively

Using Geographical Information System (GIS) and geographical coordinates for each sampling site, the sampling site was sketched. Composite soil samples were collected from the depths of 0-20 and 20-40 cm. Each composite soil samples was made from 5-10 sub-samples collected from within the respective area delineated as a replication of such land use. Dead plants, furrow, old manures, wet spots, areas near trees and compost pits were excluded during collection of samples. This was minimizing differences, which may arise because of the dilution of SOM due to mixing through cultivation and other factors.

The soil samples collected from representative land uses with its replications 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. To make one composite soil sample the sub-samples were mixed well and about 1 kg of the mixed sub-samples was properly labeled. Finally eighteen total composite soil samples were prepared and packed in a plastic bowl, and transported to Soil Testing Centre for further analysis.

2.3. Analysis of Soil Properties

Soil texture was determined by the Bouyoucos hydrometer method after destroying organic matter and dispersing the soil by using sodium hexametaphosphate as described by Day (1965). Bulk density was determined from undisturbed soil samples by the core method after drying a defined volume of soil in an oven

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at 105 °C to constant weight (Black, 1965). It was calculated as the ratio of mass of oven dried soil to the volume of the sampling core. The soil water content at PWP and FC was determined after soils were subjected to required pressures (15 and 1/3 bars, respectively) by the pressure plate apparatus.

Soil pH (H_2O) and pH (KCl) were measured by using a pH meter in a 1:2.5 soil: water and soil: KCl ratios, respectively (Peach, 1965). Soil organic carbon was estimated by the Walkley-Black wet oxidation method and converted to organic matter by multiplying the percent organic carbon content by a factor of 1.724, assuming that organic matter is composed of 58% carbon (Walkley and Black, 1934). Total nitrogen was determined by the micro-Kjeldahl digestion, distillation and titration method (Sahlemedhin and Taye, 2000), and available P was determined using the standard Olsen extraction method (Olsen *et al.*, 1954).

Total exchangeable bases were determined after leaching the soils with ammonium acetate (Thomas, 1990). Amounts of Ca^{2+} and Mg^{2+} in the leachate were analyzed by atomic absorption spectrophotometer and K^+ and Na^+ were analyzed by flame photometer. Cation exchange capacity was determined at soil pH level of 7 after displacement by using 1N ammonium acetate method in which it was estimated titrimeterically by distillation of ammonium that was displaced by sodium (Chapman, 1965). Percent base saturation was calculated by dividing the sum of the base forming cations (Ca, Mg, Na, and K) by the CEC of the soil and multiplying by 100. Total exchangeable acidity was determined by saturating the soil samples with potassium chloride solution and titrated with sodium hydroxide as described by Mclean (1965).

Extractable micronutrients (Fe, Cu, Zn, and Mn) were extracted by diethylene triamine pentaacetic acid (DTPA) as described in Sahlemedhin and Taye (2000). Finally, the amounts of all these micronutrients were measured by atomic absorption spectrophotometer at their respective wave lengths.

2.4. Fertility Mapping

The land units track and geographical coordinates of all land use types was taken by using GPS. The purpose was to develop soil fertility map for selected parameters such as: SOM, Total N, Available P, CEC, extractable micronutrients (Fe, Mn), and AWHC, and results were alternatively interpreted by ratings.

2.5. Statistical Analysis

The general linear model (GLM) ANOVA procedure of statistical analysis system (SAS Institute, 1996) was used for performing the significance of differences in soli parameters. A post hoc separation of means was done by least significant difference (LSD) test after main effects was found significant at $P \leq 0.05$. The analysis was performing for each land use types (cultivated, grass and forest lands) in six combined treatments. Correlation analysis was also computed to determine associations between various soil physical and chemical parameter.

3. RESULTS AND DISCUSSION

3.1. Soil Physical Properties

3.1.1. 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 significantly ($P \leq 0.01$) affected by land use and soil depth (Appendix Table 5).

Considering the interaction effects of land use and soil depth, the highest (51%) sand and (31%) silt contents were recorded at the surface layer of forest land than cultivated land. In contrast, the highest (58%) clay content was recorded at the subsurface layer of the cultivated land, whereas the lowest (18.00) clay content was observed in the surface layer of the forest land (Table 1). Sand and silt content decrease while clay content increases across depth from surface to subsurface soils. The increase in clay contents with depth under all land use types may be due to translocation of clay from surface to subsurface layers, which ultimately increase the proportion of sand and silt contents in the surface soil layers.

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The current results are in agreement with the findings of Shiferaw (2004) who reported an increase in clay content with depth under cultivated lands due to long period of cultivation. Buol *et al*., (1997) also observed that the accumulation of clay in the subsurface horizon could also be contributed by the in situ synthesis of secondary clays or the residual concentration of clays from the selective dissolution of more soluble minerals of coarser grain size in the B horizon.

3.1.2. Bulk density: Bulk density value was significantly ($P \leq 0.05$) affected by land use, but not affected by soil depth and their interaction effects (Appendix Table 5). Therefore, the highest (1.41 g/cm^3) mean value of bulk density was recorded on the cultivated land and the lowest (1.11 g/cm^3) mean value under the grass land (Appendix Table 1).

Compaction resulting from intensive cultivation might have caused the relatively higher bulk density values in the surface soil layers of the cultivated land than that of the respective soil depths in the grass land. The reason for the relatively low soil bulk density on the grass and forest lands as well as surface soil layer could be due to the highest SOM content and low clay content, respectively.

Soil bulk density was negatively correlated with SOM, total N, CEC, AWHC, and sand at correlation coefficients r = -0.52*, -0.52*, -0.63**, -0.53*, and -0.47*, respectively (Table 5).

3.1.3. Soil water characteristics: Water retention at both FC and PWP was significantly affected by main effects ($P \leq 0.01$) and their interaction. Moreover, AWHC was significantly ($P \leq 0.01$) affected by land use and soil depth but not significantly ($P > 0.05$) affected by their interactions (Appendix Table 5).

Significant difference in FC and PWP due to the interaction of land use and soil depth as observed in the study area was high at subsurface layers of the forest and cultivated lands and low at the surface layers of the cultivated and grass lands, respectively (Table 1). On the other hand, the highest (17.98%) and the lowest (9.67%) AWHC among the land use types was obtained in the forest and cultivated lands, respectively. The soil water content at FC, PWP and AWHC increased with soil depth (Appendix Table 1).

The result of this study are in agreement with Wakene (2001) and Ahmed (2002) who reported that soil water content at FC, PWP and AWHC were found to increase with depth for soils under different management practice. As per AWHC rating developed by Beernaert (1990), the AWHC of the surface soils of the study area was in the range of low in cultivated land to medium in forest land (Appendix Table 1).

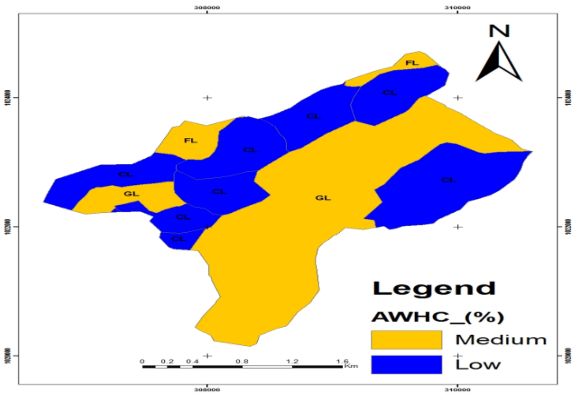

Figure 3. Spatial variability of AWHC content across major land uses in Warandhab area

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Table 1. Interaction effects of land use and soil depth (cm) on soil physical properties of the soils in Warandhab area

Land use type	Sand (%)*		Silt (%)*		Clay (%)*		BD (gcm^{-3})*		FC (%)*		PWP (%)*		AWHC (%)*	
	Soil depth (cm)		Soil depth (cm)		Soil depth (cm)		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	0-20	20-40	0-20	20-40	0-20	20-40
Cultivated land	28.33c	21.00d	27.00b	20.33c	44.67c	58.67a	1.36ab	1.45a	34.17e	40.91c	25.80cd	29.95a	8.37e	10.96d
Grass land	35.00b	27.67c	29.00ab	22.33c	36.00d	50.00b	1.04c	1.17bc	35.16d	40.83c	23.14e	25.06d	12.02d	15.77c
Forest land	51.00a	33.00b	31.00a	31.00a	18.00e	36.00d	1.09c	1.14bc	43.87b	47.13a	26.66c	28.39b	17.21b	18.74a
LSD(0.05)	2.90		2.95		3.09		0.26		0.85		2.23		1.25	
SEM(±)	0.800		0.274		0.156		0.079		0.291		0.364		0.384	

*Main effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference; SEM = standard error of the mean; BD = bulk density; FC = field capacity; PWP = permanent wilting point; AWHC = available water holding capacity.

Table 2. Interaction effects of land use and soil depth (cm) on some chemical properties of soils in Warandhab area

Land use type	pH (H_2O)*		pH (KCl)*		SOM (%)*		Total N (%)*		C/N ratio*		AvP ($mg\ kg^{-1}$)*		EA ($cmol_{(+)}kg^{-1}$)*	
	Soil depth (cm)		Soil depth (cm)		Soil depth (cm)		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	0-20	20-40	0-20	20-40	0-20	20-40
Cultivated land	5.29f	5.72d	4.17e	4.43d	3.60d	1.83f	0.18d	0.09f	11.60bc	11.65a	16.00a	14.67b	0.27a	0.20ab
Grass land	5.99b	6.47a	4.83b	5.59a	6.21b	3.30e	0.31b	0.17e	11.60bc	11.58c	4.00c	1.67d	0.20ab	0.10b
Forest land	5.36e	5.83c	4.42d	4.60c	8.37a	4.75c	0.42a	0.24c	11.59bc	11.62b	14.67b	2.67d	0.17ab	0.17ab
LSD(0.05)	0.02		0.01		0.11		0.01		0.02		1.13		0.11	
SEM(±)	0.005		0.003		0.032		0.002		0.007		0.389		0.026	

*Main effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference; SEM = standard error of the mean; SOM = soil organic matter; total N = total nitrogen; C/N = carbon to nitrogen ratio; AvP = available phosphorus; EA = exchangeable acidity.

FC was positively and significantly associated with PWP (r =0.59*), and AWHC (r =0.87**). On the other hand, PWP was positively and significantly associated with C/N (r = 0.67**) and negatively and significantly associated with CEC (r = -0.74**) of the soil content. Moreover, AWHC was negatively and significantly correlated with available P (r = -0.52*), BD (r = -0.53*), and clay (r = -0.51*), and positively and significantly associated with Ca (r = 0.47*), Mg (r = 0.81**), and sand (r = 0.52*) (Table 5).

3.2. Soil Chemical Properties

3.2.1. Soil reaction (pH): Soil pH values measured in a suspension of soil to water ratio are greater than that of in soil to KCl solution ratio. The pH (H_2O) value of the soils content was significantly ($P \leq 0.01$) affected by all land use types and their interaction effects (Appendix Table 5). The highest (6.23) and the lowest (5.50) soil pH-H2O values were recorded under the grass and the cultivated lands, respectively. Considering the two soil depths, the mean values of pH increased from 0-20 cm to 20-40 cm soil layers (Appendix Table 2). Continuous cultivation practices, excessive precipitation, and application of inorganic fertilizers could be some of the factors which are responsible for the variation in pH in the soil profiles (Ahmed, 2002). In line with the findings of this study, soil pH increased with depth of soil profile and relatively high pH was observed at subsoil horizons in Alfisols of Bako area (Wakene, 2001) and in Vertisols of the central highlands of Ethiopia (Tamirat, 1992).

Generally, the pH (H_2O) values observed in the study area were within the ranges of moderately acidic to slightly acidic (5.50-6.23), and pH (KCl) values ranged from very strongly acidic to strongly acidic (4.30-5.21) soil reactions as indicated by Foth and Ellis (1997). Accordingly, the pH (H_2O) of the soil positively and

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significantly ($P \leq 0.05$) correlated with Ca and Mg with r = 0.53* and 0.49*, and respectively, and it was negatively and significantly ($P \leq 0.01$) correlated with exchangeable acidity (Table 5).

3.2.2. Soil organic matter, total nitrogen, and carbon to nitrogen ratio: Soil organic matter content was significantly ($P \leq 0.01$) affected by land use, soil depth and their interaction (Appendix Table 5).

The interaction effect of land use by soil depth, on the variability of SOM was significantly higher (8.37%) at surface layer of the forest land and lower (1.83%) at subsurface layer of cultivated land (Table 2). The reason may be due to intensive cultivation of the land and the total removal of crop residues for animal feed and source of energy.

Based on the distribution of SOM ranges suggested by Berhanu (1980), the soils of the study area were ranged from medium in cultivated land to very high in forest land (Appendix Table 4 and 9). This result is in agreement with Eylachew (1999) and Dawit *et al.* (2002) who reported that SOM content is lower in cultivated soils than those under natural vegetations. Soil organic matter was associated positively and significantly ($P \leq 0.01$) with available P, CEC, and sand whereas it was negatively and significantly ($P \leq 0.01$) correlated with clay, further negatively and significantly ($P \leq 0.05$) correlated with bulk density (Table 5).

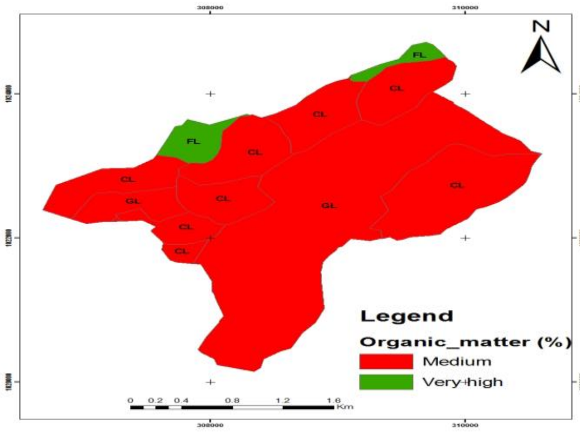

Figure 4. Spatial variability of SOM content across major land uses in Warandhab area

Total N content of soils was significantly ($P \leq 0.01$) affected by land use, soil depth and the interaction of land use by soil depth (Appendix Table 5). The effect of land use by soil depth on total N was significantly higher (0.42%) at the surface layer of the forest land than (0.09%) in the subsurface layer of the cultivated land (Table 2). The mean total N content of the surface soils of the study area was within the range of low in soils of cultivated land to very high in soils of forest land as per total N rating suggested by Berhanu (1980) (Appendix Table 2).

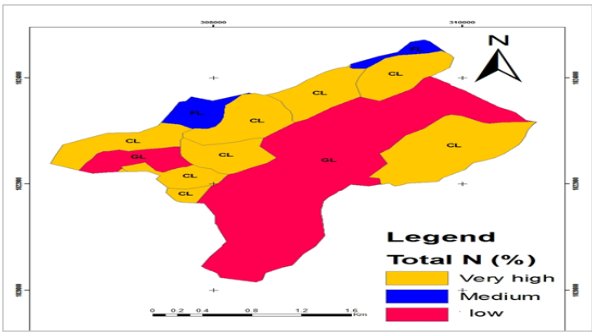

Figure 5. Spatial variability of total N content across major land uses in Warandhab area

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The very high total N content in soils of the forest land could be associated with the high available P and CEC contents of these soils. This is confirmed by the positive and highly significant correlation (r = 0.62** and 0.82**) respectively, obtained between these parameters (Table 5).

The carbon to nitrogen (C/N) ratio of the soils at the study area was significantly affected by land use ($P \leq 0.05$) and by the interaction of land use with soil depth ($P \leq 0.01$). On the other hand, it was not significantly ($P > 0.05$) affected by soil depth (Appendix Table 5).

Carbon to nitrogen ratio of the subsurface layer of the cultivated land was significantly higher (11.62) than those under forest and grazing lands. Generally, the C/N ratios were numerically high in the subsurface than surface soil layers (Appendix Table 2). Yihenew (2002) indicated that the optimum range of the C/N ratio is about 10:1 to 12:1 that provides nitrogen in excess of microbial needs. Accordingly, the C/N ratio of the soil across the study area may be considered to be within the optimum range in all land use types and soil depth. C/N ratio was significantly and negatively ($P \leq 0.01$) correlated with available P and CEC of the soil content at a correlation coefficient (r) = -0.65** and -0.74** (Table 5).

3.2.3. Available phosphorus: The available phosphorus (P) was significantly ($P \leq 0.01$) affected by land use, soil depth and the interaction of land use with soil depth (Appendix Table 7). The content of available P in the cultivated land appeared to be significantly higher than the other two land use types. Accordingly, by considering the interaction effect of land use with soil depth, the highest (16.00 mg kg^{-1}) and the lowest (1.67 mg kg^{-1}) available P contents were recorded at the surface soil layer of the cultivated and subsurface soil layer of the grass lands, respectively (Table 2).

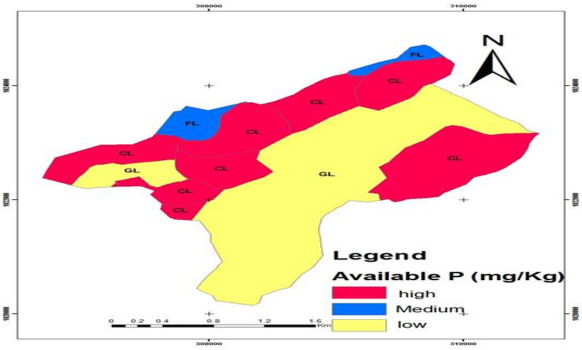

Figure 6. Spatial variability of available P content across major land uses in Warandhab area

The higher in available P contents in soils of cultivated land were due to continuous application of mineral P fertilizer for few years as indicated by different farmers in the area. The mean available P content of the soils of the study area was within the range of low in soils of grass land to high in soils of cultivated land as per available P rating suggested by Olsen *et al.* (1954) (Appendix Table 2)

On the other hand, available P was associated with pH, SOM, and Cu, at r = 0.56*, 0.62**, and -0.69** respectively (Table 5).

3.2.4. Exchangeable acidity: The exchangeable acidity was not significantly ($P > 0.05$) affected by land use, soil depth and their interaction (Appendix Table 5). Considering the absolute figures, relatively higher EA was recorded in soils of the cultivated land as compared to the other land use types (Appendix Table 2). These results show that intensive cultivation and application of inorganic fertilizers leads to the higher exchangeable acidity content under the crop field than the other land uses. The results of this study were in agreement with those reported by Wakene (2001), who reported that inorganic fertilizer application is the root cause of soil acidity.

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3.2.5. Exchangeable bases : The content of exchangeable calcium (Ca) was not significantly (P > 0.05) affected by land use, soil depth and the interaction of land use with soil depth (Appendix Table 5). Based on the data obtained in the study area, relatively higher exchangeable Ca was recorded in subsurface soil layer of the forest land as compared to the other land use types and their depths (Table 3). According to the rating set by Landon (1991), the Ca contents of soils in the study area ranged from high in surface cultivated land to very high in subsurface forest land (Table 3). Exchangeable Ca was positively and significantly correlated with pH (H_2O) (r = 0.53*, while it was negatively and significantly associated with Fe, Cu, and Mn at r = -0.56*, -0.56*, and -0.48* respectively (Table 5).

Exchangeable magnesium (Mg) was significantly (P ≤ 0.01) affected by land use, but not significantly (P > 0.05) affected by soil depth and the interaction of land use with soil depth (Appendix Table 5). The mean values of exchangeable magnesium (Mg) was higher (8.51 $cmol_{(+)}$/kg) under the forest land and lower (3.62 $cmol_{(+)}$/kg) under the cultivated land. (Appendix Table 3). As per exchangeable Mg rating set by Landon (1991), the Mg contents of soils in the study area was in the range of high in cultivated land to very high in forest land (Table 3).

Exchangeable Mg was positively and significantly correlated with pH, CEC (r = 0.63**), and AWHC while it was negatively and significantly associated with Fe (r = -0.73**) and Cu (r = -0.68**) (Table 5).

Exchangeable K content was significantly (P ≤ 0.01) affected by land use and the interaction of land use and soil depth. On the other hand, it was not significantly (P > 0.05) affected by soil depth (Appendix Table 5).

Considering the interaction effects of land use by soil depth, the highest (2.15 cmol(+)/kg) and the lowest (0.77 cmol(+)/kg) exchangeable K contents were recorded at the subsurface layers of the forest land and the surface layers of the cultivated land, respectively (Table 3). With the exceptions of the surface layers of the forest land and the subsurface layer of the grass lands, the mean exchangeable K contents of the remaining treatment combinations were significantly different (P ≤ 0.05) from each other due to the interaction effects. The rate of mean exchangeable K values observed in this study ranged from high in cultivated land to very high in forest land (FAO, 2006a) (Table 3).

The content of exchangeable Na was significantly (P ≤ 0.01) affected by land use and the interaction of land use by soil depth. Moreover it was significantly (P ≤ 0.05) affected by soil depth (Appendix table 5). The effects of land use by soil depth on exchangeable Na was significantly high (0.25 $cmol_{(+)}$/kg) under subsoil layer of the forest land and low (0.13 $cmol_{(+)}$/kg) under surface soil layer of the cultivated land (Table 3). According to the rating set by Landon (1991), the Na contents of soils in the study area is low.

The increase in basic cations concentration as well as percent base saturation with depth may suggest the existence of downward movement of these constituents exchangeable Ca, Mg, Na and K within the profile.

3.2.6. Cation exchange capacity: The CEC values of the soils in the study area were significantly (P ≤ 0.01) affected by land use, soil depth and the interaction of land use with soil depth (Appendix Table 7). Significant difference in CEC contents due to the interaction of land use and soil depth was observed in the study area as highest (39.00 $cmol_{(+)}$/kg) in surface soil layer of the grass land and lowest (23.87 $cmol_{(+)}$/kg) in subsurface soil layer of the cultivated land. CEC values decreased from the surface to the subsurface layer under different land use types (Table 3). Based on CEC ratings developed by Landon (1991), the CEC content of soils of the study area was rated as high in their CEC.

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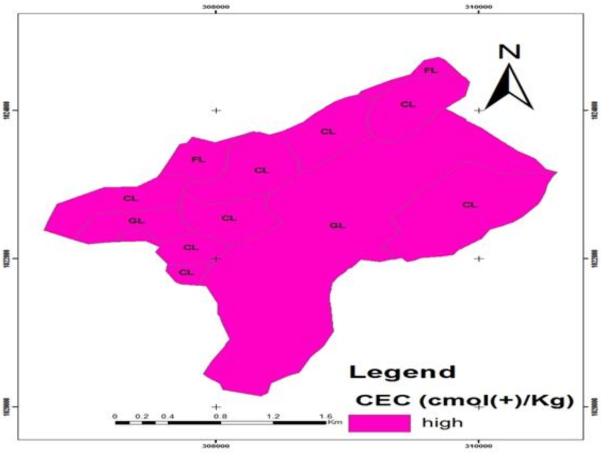

Figure 7. Spatial variability of CEC content across major land uses in Warandhab area

It was generally low in the cultivated land than in the other land use types (Table 3 and Appendix Table 3). As indicated by Mesfin (1998), the depletion of exchangeable bases as the result of intensive cultivation and application of acid forming inorganic fertilizers which reduced the CEC under the cultivated land.

Cation exchange capacity was positively and significantly associated with SOM, Total N, available P, and Mg, whereas it was negatively and significantly correlated with Fe, BD, PWP, and clay (Table 5).

3.2.7. Extractable micronutrients (Fe, Mn, Zn and Cu): The contents of extractable micronutrients (Zn and Cu) were significantly ($P \leq 0.01$) affected by land use, soil depth and the interaction of land use by soil depth, while Fe was significantly ($P \leq 0.01$) affected by land use and soil depth, but not significantly ($P > 0.05$) affected by the interaction of land use with soil depth. Similarly, Mn was significantly ($P \leq 0.01$) affected by land use and the interaction of land use with soil depth, but not significantly ($P > 0.05$) affected by soil depth (Appendix Table 5).

Considering the main effects of land use, the highest contents of Fe (19.74 mg/kg), Mn (84.04 mg/kg), Zn (1.87 mg/kg), and Cu (3.03 mg/kg) were recorded under the cultivated land (Table 10), while the lowest Fe (15.53 mg/kg), Mn (47.55 mg/kg), Zn (1.38 mg/kg), and Cu (1.51 mg/kg) were observed under the grass land (Appendix Table 4). Accordingly, the contents of all these micronutrients were higher at the surface (0-20 cm) layer than in the subsoil layer of all land use types (Table 4 and Appendix Table 4). This is due to the lower contents of exchangeable bases in the surface layer which is decreased as the result of leaching.

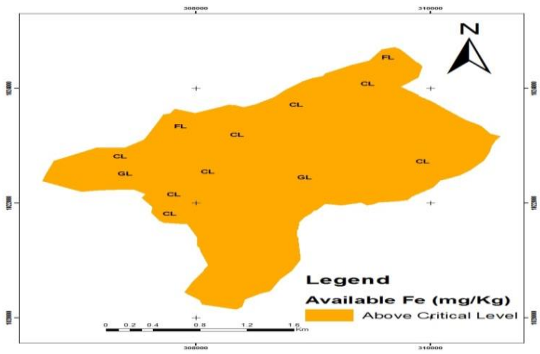

Figure 8. Spatial variability of available Fe content across major land uses in Warandhab area

According to the ratings of Sims and Johnson (1991), the critical level of soil available (DTPA extractable) Fe, Cu, and Mn are 2.5-4.5, 0.1-2.5, and 1-50 mg/kg, respectively. The deficiency level of Zn (Jones, 1972) in soils is 0.5 - 1.0 mg/kg. Therefore, the soil contents of extractable micronutrients in all land

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use types with depth were above the critical levels indicating that there is no deficiency of these micronutrients in the study area (Table 4).

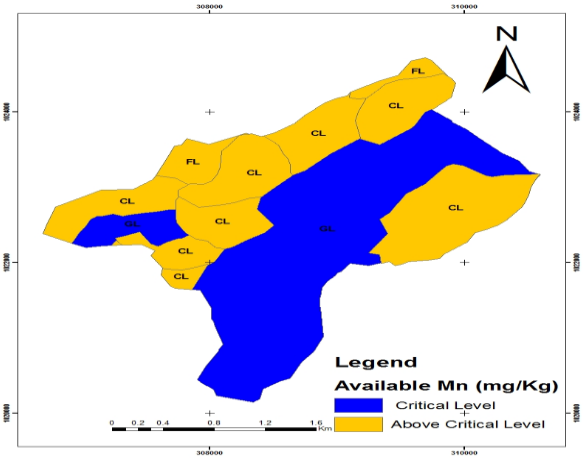

Figure 9. Spatial variability of available Mn content across major land uses in Warandhab area

Table 3. Interaction effects of land use and soil depth (cm) on exchangeable basic cations and CEC of soils in Warandhab area

Land use type	Na($cmol_{(+)}kg^{-1}$)*		K($cmol_{(+)}kg^{-1}$)*		Ca($cmol_{(+)}kg^{-1}$)*		Mg($cmol_{(+)}kg^{-1}$)*		CEC($cmol_{(+)}kg^{-1}$)*	
	Soil depth (cm)		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	0-20	20-40
Cultivated land	0.13c	0.14c	0.77e	1.36c	10.82b	11.00a	3.03c	4.20c	32.80d	23.87e
Grass land	0.16bc	0.21ab	1.04d	1.98b	14.18ab	15.67ab	8.50ab	7.80b	39.00a	35.40b
Forest land	0.17bc	0.25a	1.99b	2.15a	11.90ab	16.17a	7.73b	9.28a	38.60a	34.40c
LSD(0.05)	0.06		0.10		5.33		1.42		0.56	
SEM(±)	0.012		0.022		1.313		0.365		0.127	

*Main effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference; SEM = standard error of the mean; CEC = cation exchange capacity

Table 4. Interaction effects of land use and soil depth (cm) on available micronutrients of soils in Warandhab area

Land use type	Fe (mg kg^{-1})*		Mn (mg kg^{-1})*		Zn (mg kg^{-1})*		Cu (mg kg^{-1})*	
	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
Cultivated land	20.04a	19.44a	89.03a	79.05b	2.49a	1.24c	3.39a	2.67b
Grass land	16.77c	14.29d	67.61d	27.50e	1.42c	1.35c	1.57c	1.46c
Forest land	18.05b	16.48c	79.61b	70.99c	2.19b	1.16c	2.46b	2.38b
LSD(0.05)	1.20		2.74		0.27		0.34	
SEM(±)	0.294		0.803		0.057		0.070	

*Main effect means within a column followed by the same letter are not significantly different from each other at $p \leq 0.05$ LSD = least significant difference; SEM = standard error of the mean

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Table 5. Pearson's correlation matrix for various soil physicochemical parameters

	pH (H_2O)	pH (KCl)	SOM	Total N	C/N	AvP	EA	Na	K	Ca
pH (H_2O)	1.0									
pH (KCl)	0.95	1.0								
SOM	-0.29	-0.12	1.0							
Total N	-0.29	-0.12	1.00	1.0						
C/N	-0.20	-0.41	-0.44	-0.45	1.0					
AvP	0.37	0.56*	0.62**	0.62**	-0.65**	1.0				
EA	-0.55*	-0.60**	-0.06	-0.06	0.34	-0.35	1.0			
Na	0.41	0.40	0.10	0.10	-0.19	0.00	-0.33	1.0		
K	0.06	0.03	-0.87	-0.87	0.29	-0.57	0.03	-0.15	1.0	
Ca	0.53*	0.50*	0.05	0.05	-0.10	0.18	-0.29	0.41	-0.20	1.0
Mg	0.49*	0.50*	0.53	0.53	-0.30	0.49	-0.44	0.64	-0.67	0.48
CEC	0.11	0.29	0.82**	0.82**	-0.74**	0.77**	-0.17	0.24	-0.77**	0.48
Fe	-0.84**	-0.89**	-0.12	-0.12	0.49	-0.02	-0.61	-0.69**	0.22	-0.56*
Zn	-0.71**	-0.51*	0.34	0.34	-0.34	0.08	0.33	-0.46	0.00	-0.43
Cu	-0.85**	-0.85*	-0.18	-0.18	0.34	-0.69**	0.59**	-0.34	0.38	-0.56*
Mn	-0.93**	-0.99**	0.17	0.17	0.42	0.49	0.63**	-0.44	-0.12	-0.48*
BD	-0.28	-0.32	-0.52*	-0.52*	0.35	0.57	0.26	-0.39	0.60	-0.17
FC	0.10	0.09	0.16	0.16	0.17	-0.23	-0.40	0.64	-0.08	0.29
PWP	-0.28	-0.40	-0.39	-0.39	0.67**	0.36	-0.04	0.05	0.46	-0.17
AWHC	0.29	0.36	0.44	0.44	-0.20	-0.52*	-0.21	0.43	-0.38	0.47*
Sand	-0.35	-0.15	0.97**	0.97	-0.43	0.55	-0.47	0.75	-0.75	0.00
Clay	0.38	0.21	-0.97**	-0.97	0.42	-0.47	0.01	-0.19	0.81	-0.07
Silt	-0.37	-0.31	0.79	0.79	-0.32	-0.22	0.13	0.27	-0.76	0.20

**significant at P=0.01 level; * significant at P =0.5 level; SOM = soil organic matter; Total N = total nitrogen; C/N = carbon to nitrogen ratio; AvP = available Phosphorous; EA = exchangeable acidity; CEC = cation exchange capacity

Table 5. "continued"

	Mg	CEC	Fe	Zn	Cu	Mn	BD	FC	PWP	AWHC	Sand	Clay	Silt
Mg	1.0												
CEC	0.63**	1.0											
Fe	-0.73**	-0.47*	1.0										
Zn	-0.45	0.24	0.52	1.0									
Cu	-0.68**	-0.44	0.85	0.58	1.0								
Mn	-0.46	-0.24	0.89	0.49	0.80	1.0							
BD	-0.74	-0.63**	0.03	0.15	0.48	0.28	1.0						
FC	0.52	-0.03	-0.30	-0.40	-0.10	-0.14	-0.21	1.0					
PWP	-0.26	-0.74**	0.37	-0.22	0.47	0.32	0.43	0.59*	1.0				
AWHC	0.81**	0.41	-0.61	-0.36	-0.41	-0.38	-0.53*	0.87**	0.11	1.0			
Sand	0.53	0.75	-0.08	0.39	-0.08	0.17	-0.47*	0.28	-0.27	0.52	1.0		
Clay	-0.57	-0.78**	0.07	-0.38	0.04	-0.24	0.47	-0.27	0.28	-0.51	-0.97	1.0	
Silt	0.53	0.70	-0.03	0.27	0.05	0.34	-0.36	0.19	-0.23	0.39	0.72	-0.86	1.0

**significant at P=0.01 level; * significant at P =0.5 level; BD = bulk density; FC = field capacity; PWP = permanent wilting point; AWHC = available water holding capacity.

4. SUMMARY AND CONCLUSIONS

In order to understand the fertility status of the soils of Warandhab area, a general visual field survey and appropriate sampling was carried out to have a general trend of the variations among and within land use and soil depth. Following this, three representative land uses were selected from each land use type (cultivated, forest and grass lands), and GPS and clinometers were used to identify the geographical locations and slopes of the sampling sites, respectively. Finally, eighteen total composite soil samples and separate soil

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core sample for bulk density determination were prepared for laboratory analysis of selected physicochemical parameters of the soils.

The mean sand and silt contents of grass and forest land were significantly greater than that of cultivated land; whereas the clay content of cultivated land was highly significantly greater than grass and forest lands. Considering the soil depths, the higher sand and silt content was observed in the surface layer than in the subsurface soil layers. Oppositely, the greater clay content was observed in the subsurface than surface soil layers. Moreover, the textural class of cultivated and grass land were clayey, whereas it was clay loam for forest land.

The mean bulk density value of cultivated land was significantly greater than the value in the forest and grass land, but it was not significantly affected by soil depth. Soil water content at FC, PWP and AWHC were highly significantly affected by land use and soil depth. On the other hand, the water content at FC, PWP and AWHC of the subsurface soil layers were significantly greater than the surface soil layers.

The mean value of pH in the cultivated land was significantly lower than the other two land use types and the mean pH value of the surface soil layer was lower than the subsurface soil layers. Besides, the mean SOM content value recorded in the cultivated land was lower than in the two remaining land uses. Further, the mean SOM content in the surface was greater than in the subsurface soil layers. The mean value of total N was greater in the surface forest land and lower in the surface layer of cultivated land. Moreover, the mean available P content was greater in the surface layer of cultivated land and lower in the subsurface grass land.

The mean exchangeable Mg and K content of the soil were highly significantly affected by land use but not by soil depth. On the other hand, Ca was not affected by both land use and soil depth. The mean value of exchangeable Na, K, Ca, and Mg were relatively lower in the surface and higher in the subsurface soil layers of cultivated and forest lands, respectively. Generally, the value of exchangeable bases relatively increases with soil depth. The mean CEC content of the soil were highly significantly affected by both land use and soil depth. However, it was greater in the surface grass land and lower in subsurface cultivated land.

The values of available Fe, Zn, and Cu observed were highly significantly affected by land use and soil depth while the mean value of available Mn was highly significantly affected by land use but not with soil depth. Besides, the mean available Fe, Mn, Zn, and Cu were higher in the surface layers of the cultivated land. Most of the soil parameters measured in this study indicates that there was some variation in soil fertility status which might lead to a decrease in soil productivity. Therefore, to maintain a decrease in soil nutrients and to increase sustainable agricultural outputs, reducing the intensity of cultivation, adopting integrated soil fertility managements and application of organic fertilizers could maintain the existing soil condition and replenish the degraded soil properties of the study area.

ABBREVIATIONS

AvP	Available Phosphorus
AWHC	Available Water Holding Capacity
BD	Bulk Density
C/N	Carbon to Nitrogen Ratio
CEC	Cation Exchange Capacity
CGS	Council of Graduate Studies
CL	Cultivated Land
CV	Cumulative Variance
EA	Exchangeable Acidity
FC	Field Capacity

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FAO	Food and Agriculture Organization
FL	Forest Land
GIS	Geographical Information System
GPS	Global Positioning System
GL	Grass Land
LSD	Least Significant Difference
MS	Mean Square
OC	Organic Carbon
PBS	Percentage Base Saturation
PWP	Permanent Wilting Point
SOM	Soil Organic Matter
SAS	Statistical Analysis System
SEM	Standard Error of Mean

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II. APPENDIX TABLES

Appendix Table 1. Main effects of land use and soil depth on selected physical properties of soils in Warandhab area

Treatments	Sand (%)	Silt (%)	Clay (%)	STC	BD (g/cm^3)	FC (%)	PWP (%)	AWHC (%)
Land use*								
Cultivated land	24.66c	23.66b	51.66a	c	1.41a	37.54b	27.87a	9.67c
Grass land	31.33b	25.66bb	43.00b	c	1.11b	37.99b	24.09b	13.89b
Forest land	42.00a	31.00a	27.00c	cl	1.12b	45.49a	27.52a	17.98a
LSD (0.05)	2.047	2.083	2.186		0.186	0.598	0.933	0.886
SEM (±)	2.516	1.312	3.477		0.060	1.185	0.650	0.645
CV (%)	4.872	6.047	4.190		11.956	1.152	2.738	4.976
Soil depths (cm)*								
0-20	38.11a	29.00a	32.89b	cl	1.16a	37.73b	25.19b	12.53b
20-40	27.22b	24.55b	48.22a	c	1.25a	42.96a	27.99a	15.16a
LSD (0.05)	1.672	1.701	1.785		0.152	0.488	0.762	0.723
SEM (±)	2.597	1.167	3.643		0.070	1.302	0.662	1.228

*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; STC = soil texture class; c = Clay; cl = Clay loam; BD = Bulk density; FC = Field capacity; PWP = Permanent wilting point; AWHC = Available water holding capacity; LSD = least significant difference; SEM = Standard error of the mean; CV = Coefficient of variation

Appendix Table 2. Main effects of land use and soil depth on some chemical properties of soils in Warandhab area

Treatments	pH (H_2O)	pH (KCl)	SOM (%)	Total N (%)	C/N ratio	AvP (mg /kg)	EA(cmol (+)/kg)
Land use*							
Cultivated land	5.50c	4.30c	2.71c	0.13c	11.62a	15.33a	0.23a
Grass land	6.23a	5.21a	4.75b	0.23b	11.59b	2.83c	0.15b
Forest land	5.59b	4.51b	6.55a	0.32a	11.60b	8.66b	0.16ab
LSD (0.05)	0.012	0.009	0.080	0.004	0.015	0.802	0.077
SEM (±)	0.103	0.089	0.619	0.031	0.008	1.227	0.025
CV (%)	0.172	0.151	1.343	1.376	0.102	6.972	33.028
Soil depths (cm)*							
0-20	5.54b	4.47b	6.06a	0.30a	11.59b	11.55a	0.21aa
20-40	6.01a	4.87a	3.29b	0.16b	11.61a	6.33b	0.15a
LSD (0.05)	0.010	0.007	0.066	0.003	0.012	0.655	0.064
SEM (±)	0.115	0.139	0.555	0.028	0.007	2.008	0.022

*Main effect means within a column followed by the same letter are not significantly different from each other at p ≤ 0.05; LSD = least significant difference; SEM = standard error of the mean; CV = coefficient of variation;

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SOM = soil organic matter; Total N = total nitrogen; C/N = carbon to nitrogen ratio; AvP = available phosphorous; EA = exchangeable acidity

Appendix Table 3. Main effects of land use and soil depth on exchangeable basic cations and CEC in Warandhab area

Treatments	Na(cmol(+)/kg)	K(cmol (+)/kg)	Ca(cmol(+)/kg)	Mg(cmol(+)/kg)	CEC(cmol (+)/kg)
	Land use*				
Cultivated land	0.14b	1.20c	10.90b	3.62b	28.33c
Grass land	0.18a	1.37b	14.92a	8.15a	37.20a
Forest land	0.21a	2.07a	14.03ab	8.51a	36.50b
LSD (0.05)	0.043	0.072	3.772	1.01	0.394
SEM (±)	0.015	0.131	0.958	0.369	1.254
CV (%)	18.900	3.632	22.066	11.612	0.903
	Soil depths (cm)*				
0-20	0.15b	1.27b	12.30a	6.42a	36.80a
20-40	0.20a	1.83a	14.28a	7.09a	31.22b
LSD (0.05)	0.035	0.059	3.080	0.824	0.322
SEM (±)	0.015	0.154	1.026	0.832	1.425

*Main effect means within a column followed by the same letter are not significantly different from each other at p ≤ 0.05; LSD = least significant difference; SEM = standard error of the mean; CV = coefficient of variation; CEC = cation exchange capacity

Appendix Table 4. Main effects of land use and soil depth on available micronutrients in Warandhab area

	Extractable micronutrients (mg/ kg)			
Treatments	Fe	Mn	Zn	Cu
Land use*				
Cultivated land	19.74a	84.04a	1.87a	3.03a
Grass land	15.53c	47.55c	1.38c	1.51c
Forest land	17.26b	75.29b	1.68b	2.42b
LSD (0.05)	0.850	1.934	0.189	0.237
SEM (±)	0.440	4.419	0.180	0.094
CV (%)	3.776	2.181	8.965	7.935
Soil depths (cm)*				
0-20	18.28a	78.75a	2.01a	2.47a
20-40	16.73b	59.18b	1.27b	2.17b
LSD (0.05)	0.694	1.580	0.154	0.193
SEM (±)	0.645	5.584	0.112	0.230

*Main effect means within a column followed by the same letter are not significantly different from each other at p ≤ 0.05 LSD = least significant difference; SEM = standard error of the mean; CV = coefficient of variation

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Appendix Table 5. Mean square (MS) estimates for two-way analysis of variance of soil physicochemical properties
under three land use and two soil depths in Warandhab area

Physical properties	Land use			Soil Depth			Land use X Soil depth		
	MS	F	P	MS	F	P	MS	F	P
Sand (%)	458.7	39.6	<.0001**	533.6	46.0	<.0001**	56.9	22.5	0.0002**
Silt (%)	86.2	14.6	0.0006**	88.9	15.1	0.0022**	22.2	8.5	0.0070**
Clay (%)	939.6	251.2	<.000**	1058.0	282.8	<.0001**	8.0	2.8	0.1104^{NS}
BD (g/cm^3)	0.2	8.8	0.0044**	0.0	0.7	0.4187^{NS}	0.0	0.7	0.5303^{NS}
FC (%)	119.8	123.2	<.0001**	122.8	126.3	<.0001**	4.8	22.0	0.0002**
PWP (%)	26.1	29.3	<.0001**	30.4	34.1	0.0001**	2.7	5.2	0.0287*
AWHC (%)	103.6	147.4	<.0001**	31.0	44.1	<.0001**	1.8	3.9	0.0564^{NS}
pH (H_2O)	0.9	3226.2	<.0001**	1.0	3244.1	<.0001**	0.0	12.8	0.0017**
pH (KCl)	1.4	55.3	<.0001**	0.7	28.9	0.0002**	0.1	2970.8	<.0001**
SOM (%)	22.2	99.5	<.0001**	34.5	154.7	<.0001**	1.3	333.2	<.0001**
Total N (%)	0.1	99.4	<.0001**	0.1	154.9	<.0001**	0.0	317.9	<.0001**
C/N ratio	0.0	4.0	0.0476*	0.0	3.4	0.0886^{NS}	0.0	10.9	0.0031**
AvP (mg/kg)	234.7	603.6	<.0001**	122.7	315.6	<.0001**	52.1	133.9	<.0001**
EA ($cmol_{(+)}/kg$)	0.0	3.2	0.0852^{NS}	0.0	3.8	0.0802^{NS}	0.0	1.1	0.3822^{NS}
Ca ($cmol_{(+)}/kg$)	26.7	3.1	0.0894^{NS}	17.6	2.1	0.1830^{NS}	6.5	0.8	0.4933^{NS}
Mg ($cmol_{(+)}/kg$)	44.6	72.4	<.0001**	2.0	3.3	0.0993^{NS}	2.2	3.5	0.0692^{NS}
K ($cmol_{(+)}/kg$)	1.3	15.5	0.0005**	0.1	0.1	0.7600^{NS}	0.5	150.7	<.0001**
Na ($cmol_{(+)}/kg$)	0.0	7.3	0.0083**	0.0	8.8	0.0118*	0.0	7.9	0.0086**
CEC ($cmol_{(+)}/kg$)	145.8	65.9	<.0001**	140.0	63.3	<.0001**	12.8	135.9	<.0001**
Fe (mg /kg)	26.8	61.3	<.0001**	10.8	24.7	0.0006**	1.3	3.0	0.0928^{NS}
Mn (mg/kg)	2177.0	962.5	<.0001**	751.2	4.6	0.0524^{NS}	961.6	425.1	<.0001**
Zn (mg/kg)	0.4	16.3	0.0007**	2.7	126.3	<.0001**	0.6	27.5	<.0001**
Cu (mg/kg)	3.5	102.7	<.0001**	0.4	12.4	0.0055**	0.3	7.8	0.0093**

*, ** Significant at $p \le 0.05$ and $P \le 0.01$, respectively; NS = not significant; F = calculated value; P = probability; BD = bulk density; FC = field capacity; PWP = permanent wilting point; AWHC = available water holding capacity;
SOM = soil organic matter; Total N = total nitrogen; C/N = carbon to nitrogen ratio; AvP = available Phosphorous; EA = exchangeable acidity