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Research article

The effect of land use type on selected soil physicochemical properties in Shihatig watershed, Dabat district, Northwest Ethiopia

Tigist Kibret Asmare [a,*], Befkadu Abayneh [a], Melese Yigzaw [a], Tsegaye Adane Birhan [b]

[a] *Department of Natural Resource Management, College of Agriculture and Environmental Sciences, University of Gondar, Ethiopia*
[b] *Department of Environmental and Occupational Health and Safety, Institute of Public Health, College of Medicine and Health Sciences, University of Gondar, Ethiopia*

A R T I C L E I N F O

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A B S T R A C T

Different land use practices have a substantial influence on soil quality. An inappropriate land use system in Ethiopia leads to extensive deforestation which aggravates the loss of soil fertility. Even though there are various studies conducted on the effect of land use type on soil physicochemical properties, it is inadequate in the northern highlands of Ethiopia, in particular in the Dabat district. Thus, this study aimed to assess the effect of land use type and soil depth on selected soil physicochemical properties in the Shihatig watershed, Northwest Ethiopia. A total of 24 undisturbed core and disturbed composite soil samples were collected from the four land use types (natural forest, grazing, cultivated, and *Eucalyptus* lands) and two depths (0–20 cm and 20–40 cm) with three replications. The physicochemical properties of the soil were determined using standard operating procedures. The two-way analysis of variances was conducted using SAS software, Version 9.4. The result showed that the texture and soil organic carbon were affected by land use type, soil depth, and the interaction of the two factors; while bulk density, soil moisture content, total nitrogen, available phosphorus, cation exchange capacity, and level of Mg^{2+} were significantly affected by both land use and soil depth, whereas pH and electrical conductivity were affected by only the land use type. The highest clay, pH, electrical conductivity, total nitrogen, cation exchange capacity, and exchangeable cations (Ca^{2+} and Mg^{2+}) were recorded in the natural forest land, while the lowest values of the same parameters were found under cultivated land. The mean values of most of the soil properties were low in the cultivated and *Eucalyptus* lands. Therefore, adopting sustainable cropping systems such as crop rotation and the addition of organic manure, and minimizing planting the *Eucalyptus* tree is vital to improve the existing soil quality and enhance crop productivity.

1. Introduction

Land use is also defined as the arrangements, activities, and inputs people undertake in a certain land cover type to produce, change or maintain it [1]. Different land use practices have a considerable impact on the soil's physicochemical characteristics and

* Corresponding author.
E-mail address: tigk07@gmail.com (T.K. Asmare).

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agricultural productivity [2]. Land degradation has a serious effect on soil physical and chemical properties especially infiltration, bulk density, organic matter, porosity, and aggregate stability causing compaction and erosion. This has an attendant implication on food production, health hazards, and the ecosystem [3]. The rate of soil quality degradation depends on land use systems, soil types, topography, and climatic conditions [4].

Both soil depth and the types of land use have an impact on the geographical variation in soil fertility from field to larger area scale. Revealing spatial variability of soil fertility and its influencing factors are important to improve sustainable land use strategies [5]. Therefore maintaining soil fertility requires sustainable use of soil resources because soils can easily lose their quality and quantity within a short period for many reasons. It is known that soil physicochemical properties such as soil organic matter, total nitrogen, available phosphorous, and cation exchange capacity are some of the key indicators of soil fertility, therefore, management practices that increase those indicators can be expected to improve soil fertility [6].

Over the last decades, soil quality degradation becomes a major challenge in achieving food security and natural resource conservation in sub-Saharan Africa including Ethiopia [6,7]. For instance, in the past few decades, the global grain production growth rate has decreased from 3% in the 1970s to 1.3% in the early 1990s, which is one of the key indicators of declining soil fertility [8]. Therefore, the intensive degradation of land resources has increased the need to appraise the effect of land use on soil quality [9].

The quick expansion of cultivation and grazing practices is seriously degrading native forest ecosystems and leading to a serious problem of soil quality decline [10]. The deforestation, overgrazing, and continuous cultivation have triggered soil erosion losses at the rate of 130 tones/ha for cultivated fields and 35 tons/ha average for all land use classes in the highland areas of the country, which was estimated to be one of the highest in Africa [11]. Recently, the forest land was drastically degraded for firewood, shelter, and expansion of cultivated and grazing lands, which leads to reduce the nutrient status of the soil [12,13]. Moreover, *Eucalyptus* plantation has joined the land use system by rapidly expanding on grassland, cultivated land, and degraded land in the highlands of Ethiopia [14,15]. These factors may synergistically result in degraded soil physicochemical quality and lower productivity. Thus, it is beneficial to understand the effects of *Eucalyptus* plantations on soil properties to support generating land use management options [16].

Numerous studies have been carried out in Ethiopia to evaluate the impact of different land use types on the physical and chemical characteristics of soil [17–21]. However, the effect of land use type on selected soil physicochemical properties has not been adequately studied in the northern highlands of Ethiopia, in general, and in the Dabat district in particular. Thus, the finding may help different stakeholders to design proper land use planning aiming at replenishing soil fertility, protecting forests, and restoring the degraded ecosystem. Therefore, this study is designed to investigate the actual status of soil physicochemical properties in different land use types and soil depths in the Shihatig watershed, Dabat district, Northwest Ethiopia.

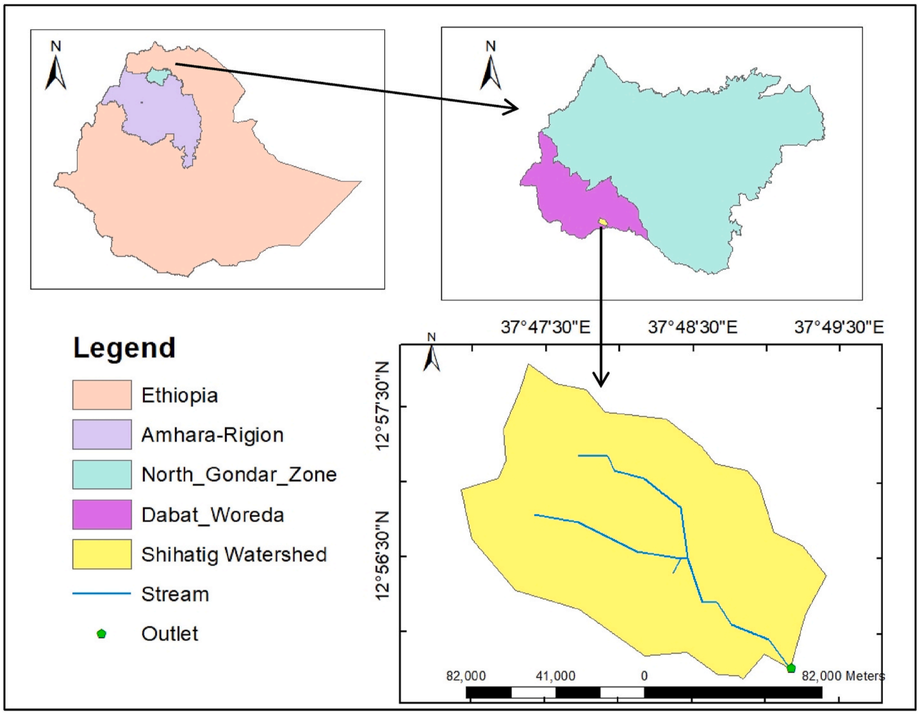

Fig. 1. Location maps of Shihatig Watershed.

2. Materials and methods

2.1. Description of study area

2.1.1. Location of the study area

The study was conducted in the Shihatig watershed which is located in Dabat district, which is 248 km far from Bahir Dar (the capital city of Amhara Regional State) and 809 km from Addis Ababa (the capital of Ethiopia) to the Northwest Ethiopia. It is located between 12° 55′ 40″–12° 57′ 45″ N and 37° 47′ 00″–37° 49′ 30″ E (Fig. 1). The watershed covers an area of 976.45ha. The average land holding size is 0.75ha per household for crop production. This watershed was selected purposively representing the northern highlands of Ethiopia because of its representativeness in land use types, soil type, and climate.

2.1.2. Climate

The study area has a mean annual rainfall and temperature ranging from 667.19 mm to 1077.40 mm and 13.80 °C to 28.54 °C respectively (Fig. 2). The altitude of Dabat is 2596 m above sea level. The pattern of rainfall distribution is unimodal and the rainy months extend from June to the end of September. The district has *Dega* (highland) (42.31%), *Weyna Dega* (midland) (11.59%), and *Kolla* (lowland) (46.10%) agroecological zones [22]. Thus, the Shihatig watershed is under the category of the Weyna Dega agro-ecological zone.

2.1.3. Soil, land use, and farming system of the study area

Based on the criteria established by the world reference base (WRB) [23], the soil of the study site is dominantly pellic vertisol [22, 24]. The study site is characterized by mixed farming systems, the farming system is both livestock and crop production. Major land use types include 1) Natural forest land containing Birbira (*Militia ferruginea*), Girar (*Acacia abyssinica*), Wanza (*Cordia africana*), Warka (*Ficus vasta*), Weira (*Olea africana*), and other tree species, 2) *Eucalyptus* plantation, 3) Cultivated land covered with wheat (*Triticum aestivum)*, barley *(Hordeum vulgare)*, beans (*Vicia faba*), peas (*Pisum sativum*), chickpea (*Cicer arietinum*), and Teff *(Eragrostis tef)* crops, 4) Grazing land. The district has a total area of 122,328ha, in which about 30,621ha is cultivated land, 14,243ha is occupied by grazing lands, and 456.75ha by natural forest.

2.2. Study design, soil sampling, and sample preparation

Primarily, a visual field survey of the area was carried out to have a general view of the variations in the study area. Sampling sites were selected as representative of land use systems in the watershed. Four major land-use types; natural forest, grazing, cultivated, and *Eucalyptus* plantation were identified in the watershed based on vegetation cover, grazing, and cultivation history. The sampling method was in the "X" position using a soil auger from each land use type with three blocks along the slope. Sampling points were situated on the same slope and topography. Soil samples were collected from representative sites of each of the four land use types with three replicates. The three representative plots (20 m × 20 m) for each land-use type were located adjacent and to a maximum distance of 200 m from the natural forest and within the natural forest. Then, each of the soil samples from the two depths consisted of five sub-samples to make a single composite soil sample collected from four corners and at the center of each plot. Before the collection of soil samples, gravel materials, roots, old manures, and areas near the trees were excluded from each sampling point.

Disturbed and Undisturbed soil samples were collected from each land use type at the two soil depths. Undisturbed soil samples were collected from the pits of the two depths using a core sampler to determine the bulk density (Db) and soil moisture content. Therefore, a total of 24 undisturbed and 24 composite soil samples (four land uses, in two soil depths (0–20 cm and 20–40 cm), with three replications) were collected. Then, the composite soil samples were thoroughly mixed in a bucket and packed in a labeled polyethylene bag, registered, and transported to the soil laboratory of the University of Gondar and Adet Agricultural Research Centers Soil Laboratory for the analysis of its characteristics.

The disturbed soil samples were crushed air-dried at room temperature and hand-sieved through a 2-mm mesh to remove' roots, stones, and other large debris to obtain a homogenized soil sample for the analysis of soil physical and chemical properties.

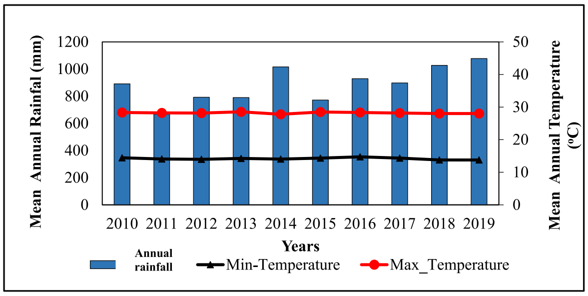

Fig. 2. Mean annual distribution of rainfall and maximum and minimum temperature of the study area from 2010 to 2019. (**Source:** KNMI climate explorer CRU TS-4.04 land (12.75–13.25° N and 37.5–38° E) from 2000 to 2019 (http://climexp.knmi.nl/start.cgi)).

2.3. Analysis of soil physical and chemical properties

The physical properties of soil were examined using standard protocols. The moisture content was determined using the gravimetric method, soil texture was determined using the hydrometer method [25], the textural class was determined using the USDA soil textural triangle classification system [26], soil bulk density and total porosity were measured using the core method [27].

The soil pH and electrical conductivity (EC) were determined using the potentiometric method [28], Soil Organic Carbon and soil organic matter were measured through the Walkley and Black method [29], Total Nitrogen was determined using the Kjeldahl digestion, distillation, and titration method [27], Available Phosphorous was determined using Olsen method [28]. Cation Exchange Capacity (CEC) was determined titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution [30]. Exchangeable bases (Ca^{2+} and Mg^{2+}) were determined after extracting the soil samples with ammonium acetate (1 N NH_4OAc) at pH 7.0. Exchangeable Ca^{2+} and Mg^{2+} in the extract were analyzed using a flame atomic absorption spectrophotometer [30].

2.4. Statistical analysis

The data were entered and analyzed using SAS software, Version 9.4, and a two-way analysis of variance was used to compare the effects of different land use types on selected soil physiochemical properties at the two soil depths separately. Means were compared by least significant difference (LSD) at $p < 0.05$ level.

3. Result and discussion

3.1. Effects of land use and soil depth on selected soil physical properties

The physical properties of the soil were affected by land use type and soil depth. The present study showed that the physical properties of the soils varied significantly across different land use types.

3.1.1. Soil texture

The results of the analysis of variance showed that the particle size distribution varied significantly ($P \leq 0.05$) as a result of the main effects of land use, soil depth, and the interaction effect of land use type with soil depth (Tables 1 and 2).

The highest clay content (51.57%) under the natural forest land might be due to the vegetation cover and reduced rate of soil erosion, thus the clay content would not be reduced and depleted [1]. The result was consistent with the studies conducted in Dawuro Zone, Southern Ethiopia [4], Agedit watershed, Northwest Ethiopia [19]. The lowest clay (32.37%) observed in the *Eucalyptus* plantation could be linked to the common trend in which farmers planted the *Eucalyptus* tree on too degraded lands. These degraded lands might be initially dominated by sand particles due to the selective removal of fine particles by erosion [16]. There was also a significant difference in the percentage of sand ($P \leq 0.01$) between E*ucalyptus* plantations and natural forests. The highest (49.37%) and the lowest (23.7%) sand fractions were recorded under the *Eucalyptus* plantation and the natural forest land, respectively. This might be due to the selective removal of clay particles by erosion and leaving the sand particles which ultimately increase the proportion of sand content under the E*ucalyptus* plantations. This finding is consistent with a study conducted in the Chemoga watershed, Blue Nile basin, Ethiopia [31].

The increment of clay content downward in the soil depth might be due to the migration of clay particles down the soil profile. The finding was consistent with the study conducted in the Maybar watershed, North Ethiopia [32]. The lower (14.73%) silt content recorded under the subsurface layer of grazing land might be due to high susceptibility to wind and water erosion.

Table 1
Main effect of land use types and soil depth on selected soil physical properties.

Treatments	Db	TP	SMC	Clay	Silt	sand	Textural class
Types of land use							
Cultivated	1.34^{a}	49.43^{c}	16.69b^{c}	42.95^{b}	26.00^{a}	31.05^{c}	Clay
Eucalyptus	1.26^{b}	52.45^{b}	16.03^{c}	32.36^{c}	18.27^{c}	49.37^{a}	SCL
Forest	1.13$_{c}$	57.36^{a}	17.70^{a}	51.57^{a}	24.73^{a}	23.70^{d}	Clay
Grazing	1.15^{c}	56.60^{a}	17.27^{a}	43.98^{b}	17.85^{c}	38.33^{b}	Clay
Soil Depth							
0–20 cm	1.19^{b}	55.09^{a}	16.60^{a}	37.42^{b}	22.78^{a}	39.50^{a}	
20–40 cm	1.25^{a}	52.99^{b}	17.24^{b}	47.68^{a}	20.64^{b}	31.67^{b}	
land use	**	**	*	**	**	**	
Depth	*	*	*	**	**	**	
land use*Depth	NS	NS	NS	**	**	**	
CV (%)	4.35	3.70	4.31	14.92	9.72	13.15	

Note: Mean values followed by different letters were significantly different at at $P \leq 0.05$; ** represents p-value ≤ 0.01, * represents p-value ≤ 0.05, “NS” represents p-value >0.05 or “not significant”; SCL= Silt clay loam; Db = Bulk density; TP = Total porosity; CL = cultivated land; EP = *Eucalyptus* plantation; FL = forest land; GL = grazing land; CV= Coefficient of variation.

Table 2
Interaction effects of land use types and soil depth on selected physical soil properties.

Land use	Db (g/cm³)		Tp (%)		SMC (%)		Clay (%)		Silt (%)		Sand (%)	
	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	20-40c
CL	1.31ᵃ	1.37ᵃ	50.69ᶜ	48.30ᵇ	16.63ᵃᵇ	16.86ᵃᵇ	42.97ᵃ	42.93ᵇ	25.13ᵃ	26.87ᵃ	31.90ᵇ	30.20ᵇ
EP	1.18ᵇ	1.33ᵃ	55.34ᵇ	49.81ᵇ	15.62ᵇ	16.44ᵇ	30.63ᵇ	34.10ᶜ	18.77ᵇ	17.77ᶜ	50.60ᵇ	48.13ᵃ
FL	1.12ᶜ	1.14ᵇ	57.74ᵃ	56.98ᵃ	17.14ᵃ	18.26ᵃ	44.93ᵃ	58.20ᵃ	26.27ᵃ	23.20ᵇ	28.80ᶜ	18.60ᶜ
GL	1.15ᵇᶜ	1.14ᵇ	56.60ᵃᵇ	56.98ᵃ	17.02ᵃ	17.52ᵃᵇ	32.47ᵇ	55.50ᵃ	20.97ᵇ	14.73ᵈ	46.90ᵃ	29.77ᵇ
CV (%)	2.51	5.52	2.04	4.90	3.75	4.82	13.76	6.21	6.33	7.07	11.26	5.00
p-value	**	**	**	**	**	NS	**	**	**	**	**	**

Note: Mean values followed by different letters were significantly different at at $P \leq 0.05$; ** represents p-value ≤0.01, * represents p-value ≤0.05, "NS" represents p-value >0.05 or "not significant"; Db = Bulk density; TP = Total porosity; CL = cultivated land; EP = *Eucalyptus* plantation; FL = forest land; GL = grazing land; CV= Coefficient of variation.

3.1.2. *Soil bulk density*

The effects of land use type and soil depth on soil bulk density are presented in Tables 1 and 2 The highest bulk density (Db) was recorded under the cultivated land (1.34 gcm^{-3}) followed by *Eucalyptus* plantation (1.26 gcm^{-3}), grazing (1.15 gcm^{-3}), and natural forest (1.13 gcm^{-3}). Considering the soil depth, the soil bulk density was increased from 1.19gcm^{-3} to 1.25gcm^{-3} as the downward soil depth increased from surface 1.19gcm^{-3} (0–20 cm) to subsurface 1.25gcm^{-3} (20–40 cm) soil layer (Table 1). The soil bulk density was significantly ($P \leq 0.05$) affected by the land use, and soil depth whereas it was insignificant ($p > 0.05$) within the interaction effect of both factors (Tables 1 and 2).

The highest recorded under the cultivated land might be linked to the result of low organic matter content, more disturbances of soils, and compaction from repeated cultivation [9,16,33]. The result was consistent with the previous studies conducted in Shenkolla Watershed, South Central Ethiopia [11], and the central highlands of Ethiopia [17]. The lowest bulk density found in the forest land might be due to the result of less disturbance of the soil and high plant residues input contributed by the natural forest litter relative to the other land use types [34]; and better soil aggregation and increased root growth with lower cone penetration resistance due to high organic matter content [35]. The result was consistent with the study conducted in the Achefer District, Northwest Ethiopia [18], and Central highlands of Ethiopia [33].

The downward increment of the soil bulk density might be explained by more compaction by overlying soil and less root penetration [36], and lower soil organic matter in the subsurface layer [37]. This finding is consistent with the studies conducted in Ethiopia [18,33].

The bulk density of this study area was within the expected values the aeration and water movement within the soil structure is in a good situation that supports plant growth and determines the numbers and diversity of soil microbes which may enhance agricultural productivity [20].

3.1.3. *Total porosity*

The result showed that total porosity was significantly ($p < 0.05$) affected by the land use type and soil depth whereas it was insignificant ($p > 0.05$) within the interaction effect of both factors (Tables 1 and 2).

The reason for the highest (57.36%) total porosity under natural forest land might be due to the litter falling from trees which increases the accumulation of SOM and higher root penetration that make the soil have a lower bulk density and high porosity which may result in the adequate flow of air and water through the soil [11,38]. The result was in line with the study conducted in Southern Ethiopia [4]. The lowest (49.43%) total porosity under cultivated land might be due to continuous tillage and low organic matter content in the cultivated land may lead to increased compactness and lower soil porosity. This finding is consistent with the previous findings [18,19,38,39]. The downward decrement of the total porosity could be due to the weight of overlying the soil and a decline in soil organic matter (SOM) as depth increases [19].

3.1.4. *Soil moisture content*

The result revealed that soil moisture content was significantly ($P \leq 0.05$) affected by land use type and soil depth whereas it was insignificant ($p > 0.05$) within the interaction effect of both factors (Tables 1 and 2). The highest soil moisture content (17.7%) recorded in natural forest land might be linked to the accumulation of organic matter to capture the moisture and less evaporation loss because of the shading effect [36,40]. The other reason might be higher clay contents which increased the water-holding capacity of the soil. The lowest soil moisture content (16.03%) recorded under the *Eucalyptus* plantation could be attributed to the competitive effect of the *Eucalyptus* plantation in terms of high water consumption during transpiration [41–43]. This finding was consistent with the study conducted in North West region of Cameroon [41]. The downward increment of the moisture content might be explained by the dominant composition of clay fractions at the subsurface layer of the soil which might result in the increased water-holding capacity of the soil [44]. The result was consistent with previous studies conducted in Ethiopia [36,37].

3.2. Effects of land use and soil depth on selected soil chemical properties

3.2.1. Soil pH

The results of the analysis of variance showed that the soil pH was affected by the land use types ($P \leq 0.05$) but not significantly ($p > 0.05$) affected by soil depth and the interaction effect of land use by soil depth (Tables 3 and 4).

The highest pH (6.55) recorded in the natural forest might be due to the accumulation of organic matter under the natural forest soil, which traps basic cations, this may lead to decreased H^+ concentration and increased pH of the soil [17]. The result was consistent with the previous study conducted in Northern Ethiopia [45]. On contrary, studies conducted in Bangladesh [9], Ethiopia [46], and India [47] have found the lowest pH of the natural forest land. Relatively lower pH (6.21) registered under the *Eucalyptus* plantation soil could be linked to the continuous uptake of basic cations by the tree and less return of organic residues to the soil, which also enhances the accumulation of Al^{3+} and H^+ in the soil [16,18] and immobilization of exchangeable bases by the *Eucalyptus* [43] and the possible release of phenolic acids from the leaves and roots of certain *Eucalyptus* species [48]. This finding was consistent with the previous studies conducted in northwest Ethiopia [14,48].

The pH value of soil varied from (6.21-6.55) across land uses, which showed that the four land use types were slightly acidic based on the previously proposed classification of soil pH [49].

3.2.2. Electrical conductivity

The result revealed that soil electrical conductivity was significantly affected only by land use type ($P \leq 0.05$), while it was not significantly affected by soil depth and the interaction effect of land use by soil depth (Tables 3 and 4).

The reason for the highest mean value of EC (0.09 ms/cm) under forest land could be due to the higher organic matter content in the forest soil, which could contribute to retaining more ions and increasing soil electrical conductivity [20]. The lowest EC value (0.06 ms/cm) detected under the *Eucalyptus* plantation might be due to the loss and uptake of basic cations by the Eucalyptus tree. The result was consistent with the study conducted in the Maybar watershed in Ethiopia [32], and southern Ethiopia [38], whereas it was inconsistent with a study conducted in Tejibara Watershed, Ethiopia [36].

According to the standard classification of EC values [50], the EC values measured under all land use categories in the study area revealed that the concentration of soluble salts is below the threshold that affects the growth and productivity of most crops and plants. Therefore, it may not pose a constraint on the growth of plants or agricultural production.

3.2.3. Soil organic carbon

Soil organic carbon was significantly ($P \leq 0.05$) affected by land use, soil depth, and the interaction of land use with soil depth (Tables 3 and 4).

The highest (1.79%) SOC recorded under the natural forest land may be due to the high biomass and plant litter fall returned to the soil [51], atmospheric carbon sequestration through photosynthesis, thus creating natural storage of carbon [52]. The lowest (1.20%) SOC under the cultivated land could also be attributed to continuous cultivation, which aggravated organic carbon oxidation and carbon dioxide emission [53]. The finding was consistent with the study conducted in Kabe Watershed, Ethiopia [44]. The downward decrement of the SOC could be linked to a higher return of biomass for a surface breakdown of plant litter and a decrease in organic matter content down the soil profile. This finding was also consistent with previous studies conducted in Ethiopia [11,44,54].

The SOC ranges from 1.79 to 1.2 in the four land use systems. As per the classification rating suggested by Ref. [49], the soil OC under natural forest land (1.79%) was medium, whereas the other land uses had a low content of soil organic carbon.

3.2.4. Total nitrogen (TN)

The mean values for TN were found to be highest in the natural forest land (0.15%), followed by grazing land (0.12%), *Eucalyptus* plantation (0.11%), and cultivated land (0.107%) (Table 4). The TN was significantly ($P \leq 0.05$) affected by land use and soil depth, but not significantly ($p > 0.05$) affected by the interaction of land use with soil depth (Tables 3 and 4).

Table 3
Main effect of land use types and soil depth on selected soil chemical properties.

Treatment	pH	EC (ms/cm)	SOC (%)	TN (%)	C:N	avail.P (ppm)
Types of land use						
Cultivated	6.36^{bc}	0.07^{ab}	1.20^{c}	0.107^{b}	11.11^{a}	15.84^{a}
Eucalyptus	6.21^{c}	0.06^{b}	1.35^{bc}	0.11^{b}	12.27^{a}	2.46^{c}
Forest	6.55^{a}	0.09^{a}	1.79^{a}	0.15^{a}	11.93^{a}	8.66^{b}
Grazing	6.44^{a}	0.08^{a}	1.46^{b}	0.12^{b}	12.16^{a}	2.35^{c}
Soil Depth						
0–20 cm	6.44^{a}	0.08^{a}	1.52^{a}	0.14^{a}	10.71^{a}	7.82^{a}
20–40 cm	6.33^{a}	0.07^{a}	1.36^{b}	0.10^{b}	14.77^{b}	6.8^{b}
land use	*	*	**	**	NS	**
Depth	NS	NS	*	**	*	**
land use*Depth	NS	NS	*	NS	NS	NS
CV (%)	2.44	21.80	8.63	17.11	33.40	9.10

Note: Mean values followed by different letters were significantly different at at $P \leq 0.05$; ** represents p-value ≤ 0.01, * represents p-value ≤ 0.05, "NS" represents p-value >0.05 or "not significant".

Table 4
Interaction effects of land use types and soil depth on selected soil chemical properties in Shihatig watershed, Dabat district.

Land use	PH		EC		SOC		TN		C:N		Avail. P	
	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
CL	6.35^{a}	6.37^{a}	0.08^{a}	0.06^{bc}	1.23^{b}	1.12^{c}	0.12^{a}	0.09^{a}	10.25^{a}	12.40^{a}	16.00^{a}	14.00^{a}
EP	6.25^{a}	6.17^{a}	0.06^{a}	0.05^{c}	1.37^{b}	1.32^{bc}	0.14^{a}	0.08^{a}	9.63^{a}	16.60^{a}	2.63^{c}	2.29^{c}
FL	6.66^{a}	6.43^{a}	0.09^{a}	0.10^{a}	2.01^{a}	1.57^{a}	0.17^{a}	0.13^{a}	11.85^{a}	12.16^{a}	9.70^{b}	7.57^{b}
GL	6.52^{a}	6.37^{a}	0.08^{a}	0.08^{ab}	1.49^{ab}	1.44^{ab}	0.13^{a}	0.11^{a}	11.43^{a}	13.07^{a}	2.93^{c}	1.76^{d}
CV (%)	2.46	2.41	20.06	23.62	8.01	9.32	13.05	22.73	15.01	39.07	7.21	11.07
p-value	NS	NS	NS	*	**	*	NS	NS	NS	NS	**	**

Note: Mean values followed by different letters were significantly different at at $P \leq 0.05$; ** represents p-value ≤ 0.01, * represents p-value ≤ 0.05, "NS" represents p-value >0.05 or "not significant"; CL = cultivated land; EP = *Eucalyptus* plantation; FL = forest land; GL = grazing land.

The highest (0.15%) amount of total nitrogen was found in natural forest land. The possible reason could be the high organic matter content which is the main source of soil total nitrogen due to the release of nitrogen during mineralization and ideal forest micro-climate conditions that tempered soil temperature and hence reduced TN loss through volatilization [45,51]. The lowest (0.107%) TN recorded in the cultivated land might be due to the continuous cultivation that leads to the depleted organic matter residue [35,38], surface runoff [55], and downward leaching of negatively charged nitrates [55]. The numerically comparable level of TN in the *Eucalyptus* plantation soils could also be attributed to the slow degradable and nutrient-poor litter (recalcitrant litter) of the *Eucalyptus* trees [43]. The downward decrement of TN could be because nitrogen supplies such as plant biomass, animal manure, and other debris may become decreased downward the soil depth. This finding was also consistent with the studies conducted in the Abobo area, western Ethiopia [56], Farta District, Northwest Ethiopia [19], and Chilga District, Northwestern Ethiopia [57].

According to the rating scale suggested by Ref. [49], the amount of TN in the Shihatig watershed was low in cultivated (0.107%) and *Eucalyptus* plantations (0.11%); and also medium in the forest (0.15%) and grazing (0.12%) lands. Thus, the content of TN could be rated as natural forest land > grazing land > *Eucalyptus* plantation > cultivated land in the Shihatig watershed. The result agreed with other studies conducted on different land use types in the Northwestern highlands of Ethiopia [8,18,19].

3.2.5. Carbon to nitrogen ratio (C:N ratio)

The soil C:N ratio was significantly ($p \leq 0.05$) affected by soil depth but not affected by land use type and the interaction effect of land use by soil depth (Tables 3 and 4). The higher (14.77) and the lower (10.71) C:N ratios were recorded at the subsurface (20–40 cm) and the surface (0–20 cm) layer, respectively (Table 3).

The C:N ratio was increased with increased soil depth, this could be attributed to the rate at which TN decreased with soil depth much higher than a carbon reduction [32]. This finding was consistent with a previous study [55]. When the C:N ratio is greater than 30:1, nitrogen is immobilized by soil microorganisms, whereas when the C:N ratio is less than 20:1, mineral nitrogen is released into the soil environment. As a result, the C:N ratio in the study area was less than 20:1. This indicates that mineral nutrients are released into the plant and soil environment [51].

3.2.6. Available phosphorus

The results of analysis of variance (ANOVA) showed that soil available phosphorus was significantly ($P \leq 0.05$) affected by land use types and soil depth, but not significantly ($p > 0.05$) affected by the interaction of land use by soil depth (Tables 3 and 4).

The highest amount of available phosphorus (15.84 ppm) recorded on cultivated land might be due to the residual continuous application of phosphorus-rich fertilizers, namely diammonium phosphate ($(NH_4)_2HPO_4$), and the addition of manure on cultivated

Table 5
Main effect of land use types and soil depth on cation exchange capacity and exchangeable base on Shihatig watershed, Dabat district.

Treatments	CEC (cmol$_{(+)}$kg^{-1})	Ca (cmol$_{(+)}$kg^{-1})	Mg (cmol$_{(+)}$kg^{-1})
Types of land use			
Cultivated	46.78^{c}	15.60^{ab}	2.77^{c}
Eucalyptus	50.75^{b}	16.09^{ab}	3.05^{bc}
Forest	54.52^{a}	16.81^{a}	3.84^{a}
Grazing	53.02^{ab}	16.48^{ab}	3.46^{ab}
Soil Depth			
0–20 cm	51.81^{b}	16.32^{a}	3.47^{a}
20–40 cm	50.72^{a}	16.17^{a}	3.09^{b}
land use	*	NS	**
Depth	*	NS	*
land use*Depth	NS	NS	NS
CV (%)	9.10	11.65	17.00

Note: Mean values followed by different letters were significantly different at at $P \leq 0.05$; ** represents p-value ≤ 0.01, * represents p-value ≤ 0.05, "NS" represents p-value >0.05 or "not significant".

land [5,35]. Despite the higher OM contents of the natural forest soils, its lower available phosphorus level implies that the significant source of available phosphorous was inorganic phosphorus [47]. The lowest available phosphorus (2.35 ppm) found under grazing land could be attributable to animal trampling and excessively overgrazed pastures [33,36]. This finding was consistent with previous studies conducted in Ethiopia [33,34,57]. The downward decrement of the available soil phosphorus could be due to the increased clay content of the subsurface layer of soil, which fixes more phosphorus [58]. This implies that a higher clay content in the soil may reduce the available phosphorus and make it non-bioavailable. Based on the classification suggested by Ref. [59], except for cultivated land which contains a sufficient level of available phosphorus; the other land use types were low in available phosphorus.

3.2.7. Cation exchange capacity

The cation exchange capacity (CEC) of the soils in the study area was significantly ($P \leq 0.05$) affected by land use types and soil depth but not significantly ($p > 0.05$) affected by the interaction of land use by soil depth (Tables 5 and 6).

The highest CEC level (54 $cmol_{(+)}kg^{-1}$) in natural forest land could be linked to the high amount of SOM and clay content in natural forest, both of which are negatively charged and can act as anions capable of holding cations [8,52]. The lowest CEC (46.78 $cmol_{(+)}kg^{-1}$) under cultivated land could be related to the organic matter depletion as a result of intensive cultivation [5]. This was in line with the studies conducted in Konso, Ethiopia [51] and Kashmir, India [47]. The downward decrement of CEC could be attributed to the decreased level of soil organic matter at the subsurface layer soil [31].

As per the ratings suggested by FAO (2006), the CEC of the studied soils qualified in the range of high to very high across the different land uses and soil depths. The finding was also consistent with the study conducted in Kashmir, India [47].

3.2.8. Exchangeable bases (Ca^{2+} and Mg^{2+})

The mean values of exchangeable Ca^{+2} under the natural forest, grazing, E*ucalyptus,* and cultivated lands were 16.81 $cmol_{(+)c}kg^{-1}$, 16.48 $cmol_{(+)}kg^{-1}$, 16.09 $cmol_{(+)}kg^{-1}$ and 15.60 $cmol_{(+)c}kg^{-1}$, respectively, whereas the level of exchangeable Mg^{2+} under the natural forest, grazing, E*ucalyptus,* and cultivated lands were also 3.84 $cmol_{(+)}kg^{-1}$, 3.46 $cmol_{(+)}kg^{-1}$, 3.05 $cmol_{(+)c}kg^{-1}$, and 2.77 $cmol_{(+)}kg^{-1}$, respectively. The higher exchangeable Ca^{+2} (6.32 $cmol_{(+)}kg^{-1}$) and exchangeable Mg^{+2} (3.47 $cmol_{(+)}kg^{-1}$) were found at the surface layer (0–20 cm) of the soil, the lower levels of exchangeable Ca^{+2} (6.17 $cmol_{(+)}kg^{-1}$) and exchangeable Mg^{+2} (3.09 $cmol_{(+)}kg^{-1}$) were found at the subsurface layer (20–40 cm) of the soil (Table 5). The analysis of variance (ANOVA) results revealed that exchangeable Ca^{2+} was not significantly affected by land use types, soil depth, and the interaction of land use by soil depth whereas exchangeable Mg was significantly ($P \leq 0.05$) affected by land use type and soil depth but not significantly ($p > 0.05$) affected by the interaction of the two factors (Tables 5 and 6).

The highest level of exchangeable bases (Ca^{2+} and Mg^{2+}) found under natural forest land might be due to high SOM, which has a greater capacity to bind with these exchangeable bases [37]. The lowest exchangeable bases observed on the cultivated land could be related to the influence of continuous cultivation, which leads to low SOM and uptake of basic cations such as Ca^{2+} and Mg^{2+} by crops during crop harvesting [51]. This result is consistent with the studies conducted in Kuyu District, Ethiopia [20], Gendeberet District, Ethiopia [37], and Maybar watershed, northwestern Ethiopia [32].

The significant reduction in the level of exchangeable Mg^{2+} downward in the soil depth could also be linked to the possibility of the high exchangeable Mg^{2+} available on the surface soil layer with an abundance of plant residues than the subsurface layer [20]. Exchangeable Mg^{2+} could also be added by outside sources attributed to human management such as through falls, plant and animal residues, animal manures, and wood ashes [60]. This finding was consistent with the study conducted in Gendeberet District, Ethiopia [37].

3.3. Limitations of the study

The data collection was done only in the dry season. Therefore, the study didn't show the temporal change in the physicochemical properties of soil. The study only looked at a few physicochemical parameters of soil. The levels of soil macro and micronutrients under different land uses should be investigated.

4. Conclusion

Almost all selected soil physicochemical properties were significantly ($p < 0.05$) affected by land use types. Most of the selected soil physicochemical properties, except soil pH and EC, were significantly ($p \leq 0.05$) affected by soil depth. Soil texture and SOC were significantly ($p \leq 0.05$) affected by the interaction of land use type with soil depth. Soils from the natural forest have a higher concentration of nutrients and better physical conditions when compared to the other land use types. In contrast, soil from the cultivated land and *Eucalyptus* plantation were a lower nutrient status than other land use types. Implementing integrated soil and water management strategies, reducing soil disturbance, reducing open grazing and adapting sustainable cropping systems, and shifting to indigenous tree plantation instead of *Eucalyptus* tree plantation are recommended to improve the fertility status of the soil. Further studies should be carried out on the other physical and chemical properties and the effect of different conservation methods on soil properties to improve the soil fertility level.

Author contribution statement

Tigist Kibret Asmare: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data;

Table 6
Interaction effects of land use types and soil depth on cation exchange capacity and exchangeable base.

Land use	CEC ($cmol_{(+)}kg^{-1}$)		Ca^{2+} ($cmol_{(+)}kg^{-1}$)		Mg^{2+} ($cmol_{(+)}kg^{-1}$)	
	Soil Depth (cm)		Soil Depth (cm)		Soil Depth (cm)	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm
Cultivated	49.41^{b}	43.47^{b}	16.06^{b}	15.15^{b}	3.06^{b}	2.48^{c}
Eucalyptus	52.63^{a}	49.20^{ab}	16.38^{ab}	15.80^{ab}	3.14^{b}	2.95^{bc}
Forest	53.54^{a}	49.05^{ab}	16.39^{ab}	17.23^{a}	4.05^{a}	3.62^{a}
Grazing	52.99^{a}	53.04^{a}	16.45^{b}	16.52^{ab}	3.61^{ab}	3.30^{ab}
CV (%)	4.21	8.34	4.70	7.65	12.84	9.66
p-value	*	NS	NS	NS	NS	*

Note: Mean values followed by different letters were significantly different at at $P \leq 0.05$; * represents p-value ≤ 0.05, "NS" represents p-value >0.05 or "not significant".

Contributed reagents, materials, analysis tools or data; Wrote the paper.

Befkadu Abayneh and Melese Yigzaw: Analyzed and interpreted the data; Wrote the paper.

Tsegaye Adane Birhan: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data included in article/supp. material/referenced in article.

Additional information

No additional information is available for this paper.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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