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Research Article

Soil Fertility Status as Influenced by Slope Gradient and Land Use Types in Southern Ethiopia

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Understanding the effects of land use types and slope gradients on the physicochemical properties of soil is essential for sustainable soil management. Therefore, this study was conducted at the Azit subwatershed of Gedebano Gutazer Welene Woreda, Southern Ethiopia, with the objectives to evaluate the effect of land use types, examine the interaction of land use and slope gradient, and evaluate the effect of slope gradient on selected soil physicochemical properties. A total of 27 soil samples using a simple random sampling technique with randomized complete block design from 3 land use types (cultivated, eucalyptus, and grazing lands) ×3 slope gradients (upper 10–15%, middle 5–10%, and lower 2–5% slopes) ×3 replications and depth (0–20 cm) were collected. Results indicated that most of the physicochemical properties of soils were significantly ($P < 0.01$) affected by land use and slope gradient. Silt and sand particles did not vary significantly ($P > 0.05$) among the land use types. The interaction effect of land use and slope was not significant ($P > 0.05$) for most of the soil properties except for organic carbon (OC). Results of data analysis also showed that soil fertility was low under cultivated and eucalyptus lands coupled with the upper slope gradient. Therefore, based on the study's findings, it can be recommended that integrated soil fertility management practices, such as the addition of soil organic matter and appropriate use of inorganic fertilizers, need to be implemented to restore the lost soil fertility status on the cultivated land and ultimately increase agricultural productivity on a sustainable basis. Eucalyptus plantings should also gradually be replaced by those that assist the soil in restoring its fertility.

1. Introduction

The ability of soil to offer the necessary nutrients in the right amounts for the sustainable growth of crops and soil nutrient recycling throughout time is known as soil fertility [1]. It is also referred to as the combination of many biological, physical, and chemical characteristics of soil that impact nutrient dynamics and availability either directly or indirectly Food and Agriculture Organization [2]. The main obstacles to global food production are strategies for managing soil fertility [3].

In sub-Saharan Africa, soil fertility depletion has been cited as the fundamental biophysical root cause for declining per capita food production [3, 4]. The reasons behind this could be a negative nutrient balance that may occur in cultivated lands, loss of topsoil through erosion, and loss of inherent soil fertility levels of macronutrients (nitrogen, phosphorus, and potassium), which mainly due to crop harvest, leaching, and low inputs applied to the soils [4]. Similarly, in Ethiopia, low soil fertility has also been attributed to low inherent soil quality, loss of nutrients through erosion, crop harvests, and little addition of inputs (organic and inorganic inputs), which are evident in the intensively cultivated area [5]. Moreover, agricultural fields lose 42 tons ha^{-1} of valuable topsoil annually. Due to this, soil fertility has decreased and is thought to be widespread, especially in Ethiopia and other sub-Saharan countries in Africa [6].

In Ethiopia, agriculture, pasture, and eucalyptus lands have replaced natural forests due to environmental causes (climatic changes, forest fires, etc.) and the country's rapidly rising population [7]. These changes under poor management practices have contributed to declining soil fertility, land degradation, and low agricultural productivity [8]. In the Ethiopian highlands, intensive and persistent land cultivation without good management, ineffective soil and water conservation measures, and soil degradation have also contributed to low agricultural output and food insecurity [9].

Research findings indicated that low organic matter content under cultivated land might be caused by higher rates of organic matter decomposition exacerbated by intensive farming and/or by low rates of return of organic materials as crop residues due to many competing uses, including animal feed, fuel, and construction [10]. Arunrat et al. [11] also indicated that burning crop residue is a factor that reduces the input of organic matter, which could impact soil properties and bacterial communities.

Slope gradient is one of the most important and determinant factors of topography that influences the process of drainage, surface runoff, and soil erosion, thereby affecting soil properties [12]. Most soil nutrients are significantly reduced due to soil erosion from the landscape with increasing slope steepness and unwise utilization of land [13].

Regarding slope gradient, the average annual rate of topsoil loss in our country, Ethiopia, is estimated to be 137 tons/hectare/year and can be even higher on steep slopes [14]. Soil loss could be increased with increasing slope gradient because of the respective high amount of water runoff that could be generated and reduced infiltration rate [15]. According to Selassie et al. [16], total nitrogen, organic matter, and cation exchange capacity mean values were higher on the lower than upper slope gradients in Southern Ethiopia.

The success of management in maintaining soil property attributes depends on understanding the soil response to land use and management practice over time because soil fertility and productivity are easily affected by land use and management [17]. A similar study reported that investigating soil fertility status is essential to determine the potential of soil productivity, as the fertility of the soil is the component of soil productivity, whereby the soil productivity in Ethiopian highlands is decreasing at a rate of 2-3% annually [18]. Therefore, an overall understanding of soil physicochemical properties is essential for designing appropriate soil resource management, land management options, and agricultural production for sustainable development [19].

Azit subwatershed of Gedebano Gutazer Welene District, where this study was conducted, is characterized by high population pressure with steep slope gradient and more intensive cultivation, making it vulnerable to deforestation, soil erosion, and nutrient depletion, having profound effects and threatening the livelihoods of the farmers. In addition, poor soil management practices coupled with the steep slope, high precipitation, continuous and more intensive cultivation with low inputs, and overgrazing have been practiced at the Azit subwatershed of Gedebano Gutazer Welene District [20]. As a result of this, there is a decline in soil fertility and low productivity. Therefore, evaluating soil fertility status under different land use types and slope gradients is relevant to curve the aforementioned effects and enhance productivity through sustainable use of soil resources.

However, in the study area (Azit subwatershed), the extent, causes, and measures of the decline in soil fertility had not received adequate research attention. There is no information on soil fertility decline and low productivity under different land use types and slope gradients at the Azit subwatershed. Knowledge-based soil and land resources management across various land use systems and slope gradients are relevant. Therefore, this study was conducted to evaluate the effect of land use types, examine the interaction of land use and slope gradient, and evaluate the effect of slope gradient on selected soil physicochemical properties at the Azit subwatershed.

2. Materials and Methods

2.1. Description of the Study Area

2.1.1. Location. The study was conducted at the Azit subwatershed in the Gedebano Gutazer Welene District of Gurage Zone, Southern Ethiopia (Figure 1). The subwatershed is situated about 127 km from Addis Ababa. Geographically, the subwatershed lies between 11° 11′ 30″ 12° 12′ 30″ to N and 38° 0′ 15″ to 38° 20′15″ E with an altitude of 2709 to 2947 meters above sea level. It covers a total area of 500 hectares [21].

2.1.2. Population, Topography Climate, and Soil Type. Based on the information obtained from the Office of Zere Peasant Association, the total population of Azit subwatershed for the year 2017 was estimated to be 7952. The topography of the subwatershed is generally characterized by 5% flat plain, 45% steep slope, 40% rugged mountains, and 10% gentle slope. The agroclimatic zone of the study area falls into the highland. The duration and pattern of rainfall influence the farmers' cropping cycles and practices in the Azit subwatershed area. The average annual rainfall is 1001–1400 mm with a bimodal rainfall pattern, i.e., the main rainy season (Meher), which extends from June to September, and the short rainy season (Belg), which covers the months from February to April. The effective rainy season is the one which extends from June to the end of September. Temperature varies between the mean annual maximum of 17.5°C and the mean annual minimum of 10.1°C across the elevation gradients. The common type of soil in the watershed is Vertisols [21].

2.1.3. Description of Land Use Types at Azit Subwatershed

(1) Cultivated Land. Formerly, this land use was under the forest cover and evolved 32 years ago with continuous plowing, clearing, removal of above-ground biomass, disposing, and leveling of farming fields (information from local elders). For the last 32 years, urea (46-0-0) and

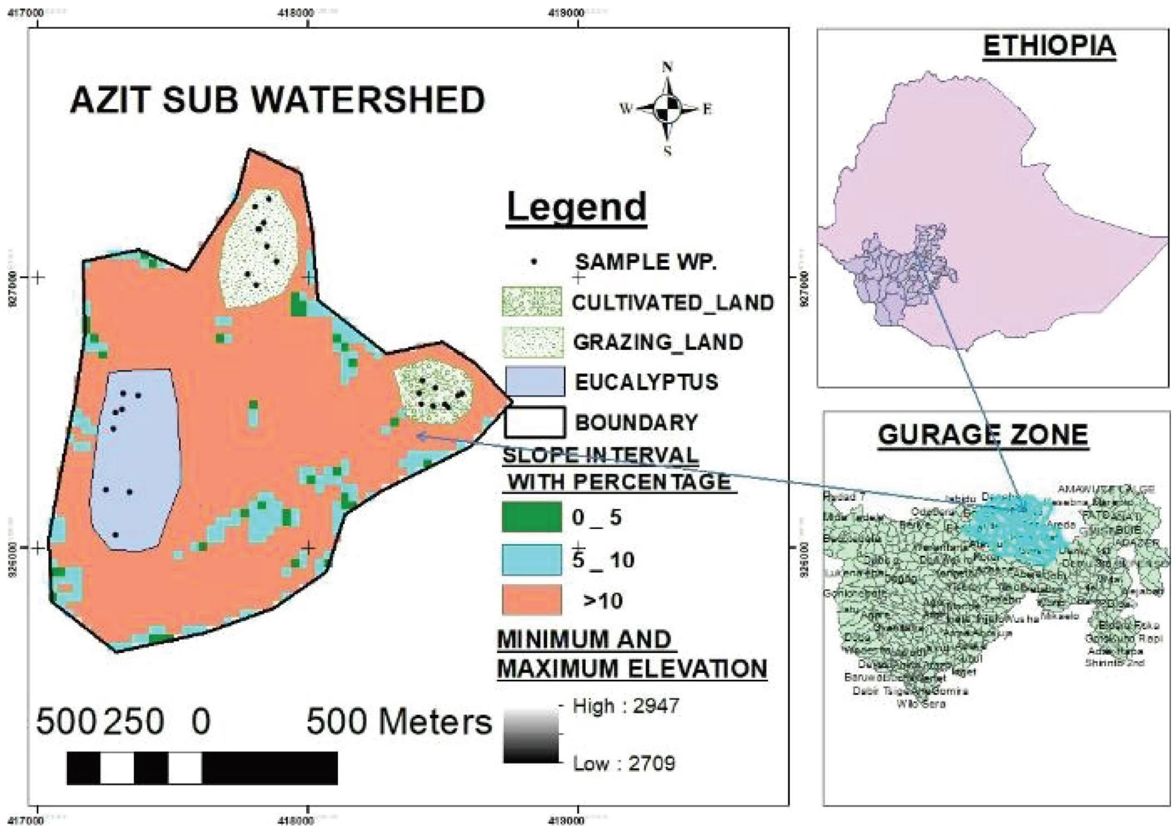

FIGURE 1: Location map of the study area.

diammonium (DAP) (18-46-0) (up to 100 kg ha^{-1} each) were used for rain-fed agriculture.

(2) Eucalyptus Land. This category of land consisted of exotic eucalyptus (*Eucalyptus globulus*) species in the study area. This tree stands indiscriminately planted in the watershed and gradually replaced the native tree species. The exotic eucalyptus species are planted by deforestation of the native tree species.

(3) Grazing Land. Land allocated for cattle grazing and short grass species dominated this land unit. In some places, rill and sheet erosions were observed. This land use evolved with permanent grass cover and has been with a continuous grazing system twenty years ago by clearing bushes and shrubs.

2.1.4. Farming System. The cultivated land accounts for an average of 67% of the subwatershed. It was dominated by traditional rain-fed subsistence peasant farming on individual holdings and grazing on communal land, and cut-and-carry systems [20]. The major development challenges of the area include lower productivity due to soil degradation, dependency on rainfed agriculture, and poor socioeconomic services. The major food crops produced in the area were ensete (*Ensete ventricosum*), wheat (*Triticum vulgare*), barley (*Hordeum vulgare*), haricot bean (*Phaseolus vulgaris* L.), and pea (*Pisumsativum*). The major vegetables in the area were potato (*Solanum tuberosum*), cabbage (*Brassicaoleracea* var. *capitata*), garlic (*Allium sativum*), and onion (*Allium cepa* L.). Livestock rearing was the area's second most important economic activity, where cattle and sheep rearing were common. Farming activities were commonly conducted using human and animal labor [20].

2.2. Site Selection and Field Survey. Before collecting soil samples, discussions were made with the district agricultural office expertise to get the prehistory and current information about the utilization of land use types and lifestyle of the local community in the study area. Subsequently, the Azit subwatershed was selected from the Zere Peasant Association due to the presence of different land use types under varying slopes, the prevalence of higher rates of soil erosion, and low productivity. Then, a reconnaissance field survey was carried out in order to have a general view of land use types in the study area. Using the global positioning system (GPS) with the 72H model, the geographic coordinates (latitudes and longitudes) and elevation of the research area were recorded through visual observation.

2.3. Research Design. The study consisted of two factors, i.e., land use types and slope gradient. The land use types, such as cultivated, eucalyptus, and grazing lands, were selected from the lower, middle, and upper slope gradients with three replicates. Randomized complete block design (RCBD) with a random sampling technique was employed for this study.

Slope gradients were measured by a clinometer, and each of them was also classified as upper (10–15%), middle (5–10%), and lower (2–5%) slope gradients based on the criteria set by FAO [22].

Land use types were selected based on the current utilization of land. Accordingly, disturbed and undisturbed soil samples were taken in three replicates from each land use category that included lower, middle, and upper slope gradients. That means a total of 27 soil samples (3 land use types ×3 slopes ×3 replications) were collected for the study.

2.4. Soil Sampling and Preparation and Sampling Techniques. From the different land use types and slope gradients, a total of 27 representative composite soil samples with three replications were collected at a depth of 0–20 cm (the plow depth) because this is the depth where most changes are expected to occur. Each composite sample was formed by bulking ten subsamples together. Undisturbed soil samples were taken by a core sampler to measure the soil bulk density, whereas the disturbed soil samples were taken using an auger to measure the other selected physicochemical properties of soils. Following these, the composite soil samples were air-dried, ground, and sieved by a 2 mm sieve. However, for organic carbon (OC) and total nitrogen (TN) analyses, the soil samples were ground to pass a 0.5 mm size sieve.

2.5. Laboratory Analysis

2.5.1. Analysis of Soil Physical Properties. Soil texture was analyzed by using the Bouyoucous hydrometer method [23]. After the distributions of particle size were determined in percent, the textural class of the soil was determined using the USDA soil textural triangle classification system [24]. The bulk density of the soil was measured from undisturbed soil samples collected using a core sampler after drying the core samples in an oven at 105°C [25]. The total porosity of the soil sample was estimated from the values of bulk density and particle density by assuming that the average particle density of mineral soil is 2.65 g cm^{-3}. Then, the total porosity was calculated as follows:

$$\mathrm{TP}\,(\%) = \left(\frac{1-\mathrm{BD}}{\mathrm{PD}}\right) \times 100, \tag{1}$$

where TP = total porosity of soil sample, BD = bulk density of an oven-dried sample of soil in g cm^{-3} at 105°C, and PD = average particle density of mineral soil in g cm^{-3}.

2.5.2. Analysis of Soil Chemical Properties. The pH of the soils was measured in water (H_2O) suspension in a 1 : 2.5 (soil : liquid) by pH meter. To determine OC, the Walkley and Black [26] method was used in which the carbon oxidized under standard conditions with potassium dichromate ($K_2Cr_2O_7$) in a sulphuric acid solution. Finally, the soil organic matter (SOM) content was calculated by multiplying the organic carbon percentage by 1.724 following the assumption that OM is composed of 58% carbon.

The total nitrogen content in the soil was determined using the Kjeldahl digestion, distillation, and titration method by oxidizing the OM in concentrated sulphuric acid solution (0.1N H_2SO_4) described by Black [25]. Then, C: N was calculated by dividing organic carbon by total nitrogen. The average *P* value was determined by the Bray and Kurtz method [27]. Exchangeable bases (Na, K, Mg, and Ca) were determined after extracting the soil samples by ammonium acetate (1N NH_4OAc). Exchangeable Na and K contents were analyzed by flame photometer, while Ca and Mg contents in the extracts were analyzed using the atomic absorption spectrophotometer (AAS) described by Rowell [28]. CEC was estimated titrimetrically by distillation of ammonium that could be displaced by sodium from NaCl solution [29]. Percent base saturation (PBS) was calculated by dividing the sum of the charge equivalents of the base-forming cations (Na, K, Mg, and Ca) by the total CEC of the soil and multiplying by 100.

2.6. Statistical Analysis. The data collected on the physicochemical properties of soil were subjected to two-way analysis of variance (ANOVA) following the general linear model (GLM) procedure using statistical analysis system (SAS) version 9.2 [30]. The mean comparison was done using Fisher's least significant difference (LSD) test at a 5% probability level. In addition, a Pearson correlation test was performed for selected soil parameters.

3. Results and Discussion

3.1. Effect of Land Use Types and Slope Gradient on Soil Physical Properties

3.1.1. Soil Particle Size Distribution. Results indicated that the land use highly significantly ($P < 0.01$) affected the proportion of clay although its effect was not significant ($P > 0.05$) on the concentration of sand. The results also showed that slope gradients very highly significantly ($P < 0.001$) affected the mean values of the sand. However, the interaction of land use and slope gradient did not significantly ($P > 0.05$) affect the sand, silt, and clay particles. Besides, the results also revealed that the land uses, slope gradients, and the interaction between land uses and slope gradient had no significant ($P > 0.05$) effect on silt particle concentration (Table 1).

Regarding the effect of different land uses, grazing land had the highest mean clay proportion (35.20%), while eucalyptus land had the lowest (32.30%) (Table 2). The cause for reduced clay content under eucalyptus and cultivated fields might be the selective removal of clay from the surface by erosion. The present findings are consistent with Teshome et al. [31] who reported low clay content in surface layers of cultivated lands as a result of the removal of particles through erosion. Significantly influenced texture of soil by land use types is also reported by Jobira et al. [32].

Concerning the effect of slope gradient, the maximum (40.23%) and the minimum (27.29%) of clay fractions were recorded from the lower and upper slope gradients, respectively. On the other hand, the highest (40.48%) and the

Table 1: Two-way analysis of variance (ANOVA) results of mean square estimates, slope gradient, land use, and interaction effect of land use types and slope gradients on physicochemical properties of soils at Azit subwatershed.

Source variation	Mean square of source of variation					
	Replication (2)	LU (2)	SG (2)	SGx LU (4)	Error 16	CV (%)
Sand	4.90^{ns}	2.48^{ns}	509.50^{***}	17.70^{ns}	13.98	10.79
Silt	9.30^{ns}	14.78^{ns}	10.00^{ns}	15.20^{ns}	9.45	9.35
Clay	0.70^{ns}	23.30^{*}	378.30^{***}	0.59^{ns}	6.25	7.69
Bulk density (BD)	0.01^{ns}	0.21^{**}	0.10^{**}	0.01^{ns}	0.01	12.59
Total porosity (f)	27.34^{*}	334.90^{**}	150.28^{**}	23.76^{ns}	20.66	7.02
pH	0.17^{**}	6.87^{**}	3.06^{**}	0.28^{ns}	0.43	11.87
OC	0.06^{*}	1.11^{***}	1.59^{***}	0.21^{***}	0.01	5.30
Total nitrogen (TN)	0.0015^{**}	0.03^{**}	0.02^{**}	0.0009^{ns}	0.001	8.75
Av. P (mg kg^{-1})	0.10^{**}	27.24^{**}	6.61^{**}	11.80^{ns}	0.02	6.63
CEC (cmol (+) kg^{-1})	0.81^{**}	21.53^{***}	41.70^{***}	1.38^{ns}	1.04	3.90
C:N	12.59^{**}	205.09^{**}	8.30^{ns}	14.00^{ns}	13.58	6.59
Exc. Ca (cmol (+) kg^{-1})	2.33^{**}	19.11^{***}	12.33^{***}	1.11^{ns}	0.41	10.54
Exc. Mg (cmol (+) kg^{-1})	6.33^{**}	8.78^{**}	23.00^{**}	0.72^{ns}	0.58	15.00
Exc. K (cmol (+) kg^{-1})	0.40^{**}	4.42^{**}	2.40^{**}	0.26^{ns}	0.27	12.50
Exc. Na (cmol (+) kg^{-1})	0.02^{*}	0.03^{**}	2.24^{**}	0.15^{ns}	0.10	11.00
PBS (%)	187.14^{*}	947.79^{***}	437.00^{***}	31.04^{ns}	25.60	8.67

DF = degrees of freedom, * = significant at (P = 0.05), ** = high significant at P = 0.01, *** = highly significant at P = 0.001, ns = Nonsignificant, SG = slope gradient, LU = land uses.

Table 2: Mean value of selected soil physical properties under different land uses and slope gradients at Azit subwatershed.

Land use	Sand (%)	Silt (%)	Clay (%)	BD (g cm^3)	TP (%)	Textural class
Cultivated	33.44	34.34	32.51^b	1.11^a	58.02^b	Clay loam
Grazing	32.20	32.60	35.20^a	0.82^b	69.88^a	Clay loam
Eucalyptus	34.40	33.30	32.30^b	0.89^b	66.44^a	Clay loam
LSD (0.05)	NS	NS	2.50	0.12	4.50	
CV (%)	10.79	9.35	7.69	12.59	7.02	
Slope gradient						
US (10–15%)	40.48^a	32.23	27.29^c	1.01^a	62.40^b	Clay loam
MS (5–10%)	34.04^b	33.45	32.51^b	0.97^a	62.42^b	Clay loam
LS (2–5%)	25.48^c	34.29	40.23^a	0.81^b	69.50^a	Clay loam
LSD (0.05)	3.73	NS	2.49	4.54	0.11	
CV (%)	10.79	9.35	7.69	7.02	12.59	

Means in the same column followed by the same letter(s) are not significantly different at 5% level of significance. LSD = least significant difference, CV = coefficient of variation, NS = nonsignificant, BD = bulk density, TP = total porosity.

lowest (25.48%) mean values of sand particles were recorded in the upper and lower slope gradients, respectively (Table 2).

The fact that a relatively higher proportion of sand fractions was recorded in the upper slope than in the other slope gradients could be due to the high mean annual precipitation across the research area that might have selectively transported the fine soil fractions by runoff in the form of erosion while leaving the coarser fraction behind. The conclusion that can be drawn from this finding is that the clay content was rising as the slope gradient decreased, whereas the sand content showed declining tendencies as the slope gradient decreased. Similar findings were reported by Luizão et al. [33], who noted that when the slope gradient increases, the most visible changes on the steep slope were a drop in clay content and a matching increase in the sand and silt fractions. In contrast, a higher percentage of clay is found in the lower slope gradient because water erosion deposited it from the upper slope. The findings of this study correspond with those of [34], who claimed that the finer soil materials deposition is at the lower slope position where they are coming from the top position.

The correlation matrix revealed a considerable and strong positive association between clay particles and OM ($r = 0.74^{**}$), CEC ($r = 0.78^{**}$), as well as a moderately favorable relationship between calcium and potassium ($r = 0.64^{*}$) and magnesium ($r = 0.69^{*}$), respectively (Table 3). The finding showed that clay contents significantly impacted organic matter, CEC, and plant nutrients. In addition, soils with high clay contents likely have higher soil CEC and soil organic matter contents. This agrees with the findings by Nath [35], who showed that clay content had a substantial and positive association with the majority of soil attributes.

Regarding the effects of the land uses, slope gradients, and the interaction between land uses and slope gradient on silt particle concentration, although the effects were not significant, there exist some numerical variations in silt particles. Grazing areas had the highest (34.34%), and the

Table 3: Pearson's correlation(r) matrix for various soil physicochemical parameters of Azit subwatershed.

	BD	Sand	Clay	Silt	pH	OM	TN	CEC	PBS	Ca	Mg	K	Na
BD	1.00												
Sand	0.44*	1.00											
Clay	−0.49*	−0.89**	1.00										
Silt	−0.08ns	−0.06ns	0.14ns	1.00									
pH	−0.34ns	−0.48*	0.51*	0.12ns	1.00								
OM	−0.68*	−0.60*	0.74**	−0.02ns	0.59*	1.00							
TN	−0.03ns	−0.46*	0.45*	0.18ns	0.45*	0.46*	1.00						
CEC	−0.46*	−0.70**	0.78**	0.12ns	0.53*	0.79**	0.41*	1.00					
PBS	−0.37ns	−0.46*	0.55*	0.01ns	0.83**	0.73**	0.58*	0.62*	1.00				
Ca	−0.47*	−0.57*	0.64*	0.09ns	0.81**	0.76**	0.41*	0.73**	0.89**	1.00			
Mg	−0.36ns	−0.67*	0.69*	0.23ns	0.58*	0.74**	0.68*	0.81**	0.77**	0.67*	1.00		
K	−0.37ns	−0.49*	0.64*	−0.65*	0.77**	0.75**	0.53*	0.67*	0.86**	0.73**	0.71**	1.00	
Na	−0.17ns	0.37ns	0.19ns	−0.45*	0.34ns	0.08ns	−0.22ns	0.08NS	0.38ns	0.37ns	−0.72**	−0.27ns	1.00

* at $P < 0.05$, ** = at $P < 0.01$. ns = nonsignificant, OM = organic matter, pH = soil reaction, TN = total nitrogen, CEC = cation exchangeable capacity.

cultivated fields had the lowest (32.60%) mean values of silt fractions. The results also showed that the silt fractions were obtained from the lower and upper slope gradients, respectively, with the highest (34.29%) and lowest (32.23%) values (Table 2). Due to its greater susceptibility to erosion than the eucalyptus and grazing areas in the study area, cultivated land might have contained a relatively high amount of silt content. This might be the consequence of continuing land cultivation, which exposed the surface of the soil to the removal of soil organic material and smaller soil particles from the upper to lower slope gradient, leading to the deposition of soil particles in a specific location by erosion, particularly at the lower part. This indicates an increase in erosive processes through the reduction of organic carbon from the upper and middle slopes (Table 4) and inputs from vegetation and an increase in silt contents after a fire [11]. Ostovari et al. [36], and Arunrat et al. [37] also reported that as the silt content increases, the soil erodibility also increases.

Generally, the silt particles in the study area did not vary according to the types of land uses, the gradient of the slopes, or the interactions between the two. This might be due to the fact that the weathering of soil happens gradually, the texture stays largely constant, and the management practices do not change it. This is consistent with the findings of [38], who reported that soil texture is the natural soil properties less altered by management and which also determines nutrient status.

3.1.2. Soil Bulk Density and Total Porosity. Results of data analysis indicated that the slope gradients and land use types highly significantly ($P < 0.01$) influenced the mean value of bulk density (BD) and total porosity (TP). However, the interactions between the land use types and slope gradient had no statistically significant ($P > 0.05$) effect on BD and TP (Table 1).

Considering the BD, the lowest value (0.82 g cm^{-3}) was observed under grazing land, which was statistically identical to that of eucalyptus land (0.89 g cm^{-3}), while the highest value (1.11 g cm^{-3}) was seen under cultivated land (Table 2). The loss of OC through oxidation due to intensive cultivation and erosion, which deplete soil OC, is one potential explanation for why the greatest BD value was recorded under cultivated land. This finding is consistent with the finding by Lemenih et al. [39], who found a gradual increase in bulk density as the result of deforestation and prolonged cultivation in the top plow layers as the result of the reduction of soil organic matter content and tillage-induced compaction.

With respect to the effect of slope gradient, the higher slope recorded the highest (1.01 g cm^{-3}) mean BD value, preceded by the middle slope (0.97 g cm^{-3}), and the lower slope recorded the lowest (0.81 g cm^{-3}) BD value (Table 2). The relatively lowest value of bulk density registered from the lower slope gradient could be due to the high clay content, total porosity, and reduced soil disturbance by the erosion process, as this area has a comparatively level land position. In contrast, the higher mean value of BD, which was recorded from the middle and upper slopes (Table 2), could be the result of the high rate of soil erosion from the steeper slope that might have resulted in reduced soil OM, TP, and increased soil compaction. This result is in line with findings by Gupta [40], who found that soil bulk densities under different topographies are inversely related to pore space and soil OM.

Regarding TP, the soils of grazing land had the highest mean TP (69.88%) value followed by those of eucalyptus land, while the soils of cultivated land had the lowest mean TP (58.02%) value (Table 2). The result obtained might be due to the highest clay fraction and the lowest BD content of grazing land. Relatively, the lower clay content and the high BD of soils under cultivated land might be the reason for lower TP. The result recorded is contrary to that was reported by Habtamu et al. [9], who indicated that compaction through grazing increased BD, thereby lowering the TP of soil.

Comparatively, the lower mean value of TP recorded under cultivated land was caused by the possibility that when BD increases, the soil pore space may decrease, and the soil particles may compact together, obstructing air and water flow between soil pore spaces, resulting in a fall in TP of the soil. The percentage of total porosity values in all land use types could be rated as very high (more than 40%) based on the rating of total porosity by FAO [41].

Table 4: Interaction effect of land use and slope gradient on selected chemical properties of soils at Azit subwatershed.

Soil property	Land use	Slope gradient US 10–15%	MS 5–10%	LS 2–5%	LSD (0.05)	CV (%)
OC	Cultivated	1.50[a]	1.67[ac]	2.77[a]	0.20	5.30
	Grazing	2.43[b]	2.50[b]	2.73[a]		
	Eucalyptus	1.63[ac]	1.73[c]	2.40[b]		

Means within columns followed by the same letter are not significantly different from each other at $P < 0.05$. CV = coefficient of variance, LSD = list significant difference, OC = organic carbon, US = upper slope, MS = middle slope, LS = lower slope.

Considering the effect of slope gradient on TP, the lower slope gradient resulted in the highest mean TP value (69.50%), while the upper and middle slopes resulted in the lowest (62.40%) values (Table 2). Increased soil bulk density might be related to the declining trend in organic matter seen in different land use types from the upper to lower topographic positions. The findings obtained in this study are consistent with those of Gupta [40], who found that bulk densities are inversely related to the pore spaces and soil OM. The decreasing trend of organic matter from the upper to the lower topographic position of different land use types could be credited to the increased soil bulk density.

The correlation matrix indicated that there was a moderately negative correlation between bulk density and OM ($r = -0.68^*$), calcium ($r = -0.47^*$), CEC ($r = -0.46^*$), and clay ($r = -0.49^*$), respectively (Table 3). This correlation further suggests that soil bulk density was decreased by the presence of clay and OM content. The outcome agrees with the findings by Achalu et al. [42], who found that organic matter reduces bulk density through its favorable influence on soil aggregation.

3.2. *Effect of Land Use Types and Slope Gradient on Soil Chemical Properties*

3.2.1. Organic Carbon. When the data on the organic carbon (OC) were analyzed, it became clear that land use and slope interactions had a very highly significant ($P < 0.001$) influence on OC (Table 1).

The upper slope recorded the lowest OC (1.50%), whereas the lower slope recorded the highest OC (2.77%) from the cultivated land (Table 4). The cause for the higher mean value of OC that was detected from the lower slope of cultivated land might be linked to the removal (movement) of organic matter from the upper slope to the lower slope. This is consistent with the findings of [15], who indicated that the quantity of soil organic matter (SOM) was higher at the midslope and lower slopes compared to the upper slope.

Except for its (OC) content in the lower slope gradient of cultivated land, the OC values were generally lower under cultivated land than in eucalyptus and grazing lands, which could be related to intensive cultivation and erosion, which could deplete organic matter. This result is consistent with the finding by Yihenew [43], who concluded that the majority of the farmed soils of Ethiopia had low OM contents since there were not many organic materials supplied to the soil, and the biomass was completely removed from the field. In addition, the low OC content in cultivated land could be attributed to the fact that cultivation increases soil aeration which enhances the decomposition of OC by soil microorganisms. On the other hand, less soil disturbance in the grazing land might have apparently led to the observed better content of OC. This result is consistent with the result that was reported by Berhanu [44], which stated that under the cultivated land use type, losses of OC were not fully compensated by organic matter inputs from the crop residues. These effects in such tropical soils could also be due to the effects of frequent tillage practices coupled with reduced OC inputs and almost complete removal of crop residues from the cultivated fields for various uses. Tekalign [45] rated soil with OC content (<0.86%) as very low, (0.86–2.59%) as low, (2.59–5.17%) as medium, and >(5.17%) as high. As a result, the OC contents of the study area could be rated as low for all land uses and slope gradients except the medium contents of OC in lower slopes of cultivated and grazing lands. The correlation matrix also revealed that OM showed a significant and strong positive correlation ($r = 0.73^{**}$, 0.74^{**}, 0.75^{**}, 0.79^{**}, and 0.76^{**}) with PBS, Mg, K, CEC, and Ca, respectively (Table 3). From this result, as the availability of OM increased, the content of clay particles, pH, exchangeable bases (Ca, Mg, K), CEC, and PBS could also be increased.

3.2.2. Soil pH. Soil pH was highly significantly ($P < 0.01$) affected by the land use types and slope gradient. However, it did not show significant variations due to the interaction of land use with slope ($P > 0.05$) (Table 1). According to the Ethiopia soil information system [46], the soil pH of the research area which typically ranged from 4.60 to 6.30, could be classified as strongly acidic to moderately acidic. The highest pH value (6.30) was found in grazing land, while the lowest pH value (4.60) was found under eucalyptus land (Table 5). Comparatively, the lower pH value recorded in the soil of eucalyptus land as compared to those of cultivated and grazing lands might be attributed to the fast-growing tree plantation species that could be associated with a more intense uptake of basic cations from the soil and loss of organic matters by rotational harvesting and took away from the site. This finding is in line with the discovery by Aweto and Moleele [47], who found that the low soil pH might cause a reduction in base saturation, eventually leading to the depletion of soil exchangeable bases. Due to the influence of slope gradient, the lowest mean soil pH value (4.88) was recorded on the upper slope, and the highest mean soil pH value (5.90) was reported on the lower slope (Table 5).

Table 5: Effect of land use types and slope gradient on selected soil chemical properties at Azit subwatershed.

	Av. P (mg kg^{-1})	pH (1 : 2.5 H_2O)	TN (%)	C: N	PBS (%)	CEC (cmol (+) kg^{-1})
Land use						
Cultivated	4.14^{b}	5.70^{a}	0.17^{b}	8.35^{b}	59.45^{b}	25.67^{b}
Grazing	5.30^{a}	6.30^{a}	0.23a	16.83^{a}	68.00^{a}	27.81^{a}
Eucalyptus	2.98^{c}	4.60^{b}	0.12^{c}	16.39^{a}	47.67^{c}	24.89^{b}
LSD (0.05)	0.56	0.66	0.03	3.68	5.06	1.11
CV (%)	13.63	11.87	8.75	6.59	8.67	3.90
Slope gradient						
US (10–15%)	3.52^{b}	4.88^{b}	0.14^{b}	14.67	50.89^{c}	24.47^{b}
MS (5–10%)	4.07^{b}	5.80^{a}	0.15^{b}	14.10	59.67^{b}	25.3^{b}
LS (2–5%)	4.83^{a}	5.90^{a}	0.22^{a}	12.80	64.67^{a}	28.56^{a}
LSD (0.05)	0.56	0.65	0.03	NS	5.06	1.11
CV (%)	13.63	11.87	8.75	6.59	8.67	3.90

Means in the same column followed by the same letter(s) are not significantly different at 5% level of significance, LSD = least significant difference, CV = coefficient variation, US = upper slope, MS = middle slope, LS = lower slope, OC = organic carbon, TN = total nitrogen, Av. P = available phosphorus, PBS = percentage base saturation.

Since pH and basic cations of soils typically have a strong and positive relationship with one another, the reason for the higher mean pH value obtained in the lower slope might be related to an increase in the basic cations along that slope. The findings from this study are consistent with those of [48], who noted that the accumulation of bases that are thought to have been moved laterally by erosion could be responsible for the rise in the pH value of soil at the lower slope. The pH of the soil showed a moderately positive correlation with TN ($r = 0.45^{*}$), clay ($r = 0.51^{*}$), CEC ($r = 0.53^{*}$), OM ($r = 0.59^{*}$), and a strong positive relationship with Ca ($r = 0.81^{**}$) (Table 3). This indicated that these soil properties could vary together with the soil pH, and it examines the availability of other physicochemical properties of the soil and vice versa.

3.2.3. Total Nitrogen. The results revealed that the total nitrogen (TN) was highly significantly ($P < 0.01$) influenced by the land use types and slope gradient, although it was insignificantly ($P > 0.05$) influenced by the interaction of land use types with slope gradient (Table 1). Grazing land had the highest mean value of TN (0.23%), which was followed by cultivated land (0.17%), while eucalyptus land had the lowest mean value (0.12%) (Table 5). Eucalyptus and cultivated land were found to contain less TN, which might be related to the high rainfall of the area which caused nitrates to be lost from the cropped fields. Nitrate ions, which were not adsorbed by the negatively charged colloidal particles that dominate most soils, thus moved with the drainage water as they are mobile in soils and lost from the soil. In addition, the rapid mineralization of OC could also be responsible for the low content of TN since there is reduced input of plant residues in cultivated land. The finding obtained in this study is consistent with that of [49], who found that in the central part of Ethiopia, lower TN concentrations were seen under cultivated land and eucalyptus plantations than under the other land use systems. Berhanu [44] also noted that fluctuation in TN content paralleled with that of the change in organic carbon content in the soils of Girar Jarso, North Shoa Zone of Oromia, Ethiopia.

The upper slope of the soil provided the lowest TN value (0.14%), whereas the lower slope provided the highest TN value (0.22%) (Table 5). The soil erosion brought on by heavy rainfall, inadequate input application, crop residue removal, continuous cultivation, and the steepness of the slope in the research area might be the cause of the upper slope's markedly lower TN content when compared to the middle and lower slope gradients. This result is in line with the findings of [50–52], who indicated that the loss of nitrogen was caused by the total clearance of crop residue from the field and continued cultivation, which aggravates the quick rate of mineralization. According to Barber [53], soils having TN < 0.1%, 0.1–0.2%, 0.2–0.3%, 0.3–0.4%, and >0.4% are rated as very low, low, medium, high, and very high, respectively. Therefore, the TN content of the study area could be classified as low except for the medium TN content in the grazing lands and on the lower slope gradient.

3.2.4. Available Phosphorous. The results indicated that the soil available phosphorus (Av. *P*) was highly significantly ($P < 0.01$) influenced by the land use types and slope gradient, although it was not significantly ($P > 0.05$) influenced by the interaction of land use types with slope gradient (Table 1). Among different land use types, the highest value of Av. *P* was found in grazing land (5.30 mg kg^{-1}), preceded by cultivated land (4.14 mg kg^{-1}), and the lowest value was found under eucalyptus (2.98 mg kg^{-1}) (Table 5). Comparatively, the lower level of Av. *P* content recorded under the eucalyptus land might be due to the drop in the pH of the soil, which might have caused a significant quantity of Av. *P* to be fixed or absorbed. Aweto and Moleele [47] obtained a similar result, indicating that eucalyptus is more capable of immobilizing phosphorus and making it inaccessible for plant utilization. The maximum mean value of Av. *P* (4.83 mg kg^{-1}) was recorded from the lower slope, while the lowest value (3.52 mg kg^{-1}) was obtained under the upper slope area, taking into account the effects of slope gradients

(Table 5). The lower value of Av. P on the upper slope compared to the lower and middle slopes might be caused by the low pH of soils, continuing crop absorption, losses through erosive processes and acidic soil fixation, and the lack of external input in the study area. This result is consistent with those of [51, 52, 54], who found that most Ethiopian soils have low concentrations of Av. P as a result of low pH (acidic), an intensive cropping system, variable fertilizer application, and nutrient mining. Landon [55] classified Av. P content <15 mg kg^{-1}, 15–50 mg kg^{-1}, and more than 50 mg kg^{-1} as low, medium, and high, respectively. As a result, the Av. P content of soils in the study area might be categorized as low.

3.2.5. Carbon to Nitrogen Ratio. The carbon to nitrogen ratio (C: N) was highly significantly ($P < 0.01$) affected by land use type. However, C: N was not significantly ($P > 0.05$) affected by the slope gradient as well as by the interaction of slope gradient and land uses (Table 1). The grazing land had the highest mean C: N ratio (16.83), followed by the eucalyptus land (16.39), while the cultivated land had the lowest mean C: N ratio (8.35) (Table 5). The lower mean value of the C: N seen on cultivated land compared to grazing and eucalyptus land might be due to the higher rates of organic carbon mineralization compared to organic nitrogen because of the addition of extra oxygen during plowing, which raised soil temperature. This finding is consistent with the findings of [31, 42], who suggested that a narrow C: N at the surface of the soil may be caused by increased microbial activity, increased CO_2 evolution, and loss of the environment.

On the other hand, the greater amount of C: N found in grazing and eucalyptus lands could be due to the soil microorganisms' immobilization of N. This demonstrated that the soil was not provided with enough nitrogen. The current outcome is consistent with the finding of Yihenew [43], who found that even though the soil may have a high organic carbon content, a high C: N ratio could be a sign of nitrogen immobilization or low nitrogen content in the area.

Soils on the upper, middle, and lower slopes of grazing, eucalyptus, and cultivated lands did not differ in their mean C: N ratios from the soils on lower slopes. Hazelton and Murphy [56] rated the C: N as very low (<10), low (10–15), medium (15–25), high (25–70), and very high (70–100). Based on this rating, all other land use types might be categorized as medium, with the exception of cultivated land, which is very low.

3.2.6. Cation Exchange Capacity. The soil cation exchange capacity (CEC) was very highly significantly ($P < 0.001$) affected by the land uses and slope gradients, although it did not show a significant ($P > 0.05$) effect on the interaction of land uses with slope gradients (Table 1). In light of the effects of land uses, grazing and eucalyptus lands, respectively, recorded the highest (27.81 cmol (+) kg^{-1}) and the lowest (24.89 cmol (+) kg^{-1}) values of CEC (Table 5). Substantially, the lower mean value of soil pH might be the cause of the lower mean value of CEC found under eucalyptus land compared to other land use types. This finding is in line with the observation by Mulugeta [15], who indicated that pH is an important soil parameter that is positively associated with CEC; thereby, high pH values increase the number of negative charges on the colloids and CEC.

According to Hazelton and Murphy [56], the top soils having CEC 25–40, 12–25, 6–12, and <6 cmol (+) kg^{-1} are categorized as high, moderate, low, and very low, respectively. Based on this, the CEC values of the study area could be categorized as moderate for eucalyptus while high for cultivated and grazing lands.

The highest and lowest soil CEC values 28.56 cmol (+) kg^{-1} and 24.47 cmol (+) kg^{-1} were measured from the lower and upper slopes, respectively (Table 5), due to the influence of slope gradient on CEC values. Compared to the middle and upper slopes, the lower slope had a higher mean value of CEC. The lowest CEC values at the upper slope might be a consequence of erosion and landscape positions removing fine particles, basic cations, and organic matter from topsoil. This finding indicates that the basic cations and organic matter content were dropping as the slope gradient increased, and as a result, the CEC content also fell. The result is consistent with the findings by Alemayehu [57], who reported the effect of slope position on nutrient status, where it was found that upper slope areas had lower nutrient concentrations than the lower areas as the result of erosion of topsoil and subsequent deposition on the lower slope positions in the study conducted in the Southern part of Ethiopia. The CEC had a strong positive relationship with OM ($r = 0.79^{**}$) and clay content ($r = 0.78^{**}$) (Table 3). Based on this finding, it could be concluded that as clay and SOM contents increased, the CEC content also increased. This conclusion is in line with that made by Jobira et al. [32], and Fassil and Charles [58], who found that the amount and type of clay minerals present in soils affect CEC.

3.2.7. Percentage Base Saturation. Data analysis (Table 1) revealed that percentage base saturation (PBS) was very highly significantly affected ($P < 0.001$) by the land use categories and slope gradients but not by the interaction of land use types and slope gradients ($P > 0.05$). The PBS of soil under grazing land was highest (68.00%), followed by the PBS value of 59.45%, which was recorded under the cultivated land, and the lowest mean value of PBS was recorded under the eucalyptus land (47.67%), according to the mean comparison test of PBS among different land use types (Table 5). The addition of cattle dung to grazing fields might have increased the mean value of the PBS under grazing land, which in turn might have enhanced the level of OM content. As a result, an increase in OM content might have helped to improve the concentrations of basic cations and PBS in grazing land. Pearson's correlation matrix, which showed a positive association between PBS and pH at $r = 0.83^{**}$, OM at $r = 0.73^{**}$, and Ca at $r = 0.89^{**}$ (Table 3), has also validated this.

The existence of lower pH values under eucalyptus land might have contributed to the reduction of basic cationic soil nutrients, which might have contributed to the very low mean values of PBS. Similar findings were also reported by Cao et al. [59] and Demessie et al. [60], who showed that eucalyptus plants produce litter with low nutrient concentrations, which decomposes slowly to release low amounts of nutrients. According to the ratings by Tekalign [45], PBS is rated as low (20–40%), medium (40–60%), and high (60–80%). Based on this rating, the PBS of the study area could be categorized as medium for eucalyptus land and cultivated land, while high for grazing land.

The maximum PBS value (64.67%) was found in the lower slope class, while the lowest value (50.89%) was found in the upper slope class when considering the influence of slope gradient on PBS (Table 5). A heavy rainfall pattern might have contributed to the lowest PBS value in the upper slope by increasing the loss of basic cations from the top of the landscape and the buildup of sand particles in the study area. This result is consistent with the findings by Guzman and Al-Kaisi [61], who noted progressive organic carbon losses in upper slope shoulder positions. In contrast, lower slope positions and level depressions experience organic carbon accumulation, which may be attributed to the erosion and depositional processes.

Table 6: Effects of land uses and slope gradients on exchangeable bases at Azit subwatershed.

	Exchangeable bases (cmol (+) kg^{-1})			
	Ca	Mg	Na	K
Land use				
Cultivated	6.67^{b}	5.00^{a}	1.20^{b}	2.32^{b}
Grazing	8.40^{a}	5.56^{a}	2.07^{a}	2.96^{a}
Eucalyptus	5.56^{c}	3.67^{b}	1.18^{b}	1.56^{c}
LSD (0.05)	0.64	0.76	0.33	0.31
CV (%)	10.40	15.00	11.00	13.00
Slope gradient				
US (10–14%)	5.67^{c}	3.44^{c}	1.20^{b}	1.77^{c}
MS (5–10%)	7.00^{b}	4.33^{b}	1.58^{a}	2.67^{b}
LS (2–5%)	8.00^{a}	6.56^{a}	1.67^{a}	2.80^{a}
LSD (0.05)	0.64	0.76	0.31	0.52
CV (%)	10.40	15.00	11.00	13.00

Means within columns followed by different letters are significantly different ($P < 0.05$) with respect to land types and slope gradients. LSD = least significant difference, CV = coefficient variation, US = upper slope, MS = middle slope, LS = lower slope, Ca = calcium, Mg = magnesium, Na = sodium, and K = potassium.

3.2.8. Exchangeable Bases. Exchangeable calcium (Ca) was very highly significantly ($P < 0.001$) affected by land uses and slope gradients. In addition, other exchangeable bases (Mg, K, and Na) were also significantly ($P < 0.01$) affected by land uses and slope gradients. However, the exchangeable bases (Ca, Mg, K, and Na) did not show a significant ($P > 0.05$) effect on the interaction between land uses and slope gradients (Table 1). The highest mean values of exchangeable Ca (8.40 cmol (+) kg^{-1}) and Mg (5.56 cmol (+) kg^{-1}) were recorded under grazing land. In addition, the highest mean values of exchangeable Na (2.07) and K (2.96 cmol (+) kg^{-1}) were also registered under grazing land. On the other hand, the lowest mean values of exchangeable bases Ca (5.56 cmol (+) kg^{-1}) and Mg (3.67 cmol (+) kg^{-1}) were recorded under eucalyptus land. Besides, the lowest exchangeable Na (1.18 cmol (+) kg^{-1}) and K (1.56 cmol (+) kg^{-1}) were also registered under eucalyptus lands (Table 6).

The addition of cattle dung to grazing fields during open (free) grazing by cattle might have helped to increase soil pH, reduce the danger of soil erosion, and improve soil nutrients, which might have led to the highest mean values of exchangeable Ca and Mg that were observed under the soils of grazing land. Contrarily, the lower mean value of exchangeable Ca and Mg that were found beneath the soils of eucalyptus fields might be related to the low soil pH that enhanced losses of the soil base cations by replacing the basic cations with acidic cations at the exchange site. The results found in this study are in line with the finding by Aweto and Moleele [47], who found that low soil pH causes low soil base saturation.

Compared to cultivated and eucalyptus lands, relatively higher mean values of exchangeable K and Na were recorded under grazing land (Table 6). This might be because there is less long-term following and animal manure recycling under grazing land, which might have improved K and Na nutrients more than that of cultivated and eucalyptus lands. The current finding concurs with those made by Mesfin [62], who showed that in the central highlands of Ethiopia, virgin/grazing lands retain greater amounts of basic cations than cultivated lands.

Contrarily, the lower mean exchangeable K and Na values found under the soils of cultivated and eucalyptus lands might be due to the reason that these nutrients are susceptible to being washed away easily and the continuous harvesting of crops. This finding is analogous to that found by Foth [63], who noted that because K and Na adsorption requires little energy, they are more likely to remain in soil solutions than colloidal sites and could be easily removed from soil through leaching. The highest mean values of exchangeable Ca (8.00 cmol (+) kg^{-1}), Mg (6.56 cmol (+) kg^{-1}), Na (1.67 cmol (+) kg^{-1}), and K (2.80 cmol (+) kg^{-1}) were registered from the lower slope, whereas the lowest mean values of exchangeable Ca (5.67 cmol (+) kg^{-1}), Mg (3.44 cmol (+) kg^{-1}), Na (1.20 cmol (+) kg^{-1}), and K (1.77 cmol (+) kg^{-1}) were registered from the upper slope class (Table 6). The highest mean values of exchangeable Ca, Mg, K, and Na that were found from the lower slope could be due to the soil's relatively high amount of clay accumulation and CEC content. The correlation matrix also revealed that clay showed a significant and positive correlation ($r = 0.64^{*}$, 0.69^{*}, and 0.64^{*}) with Ca, Mg, and K, respectively. CEC also showed a significant and positive correlation ($r = 0.73^{**}$, 0.81^{**}, and 0.67^{*}) with Ca, Mg, and K, respectively (Table 3). Here, from this result, it could also be concluded that as the content of clay and CEC increased, exchangeable bases (Ca, Mg, and K) could also be increased.

On the other hand, the decreasing mean values of exchangeable Ca, Mg, K, and Na seen in the upper slope gradient might have been caused by the loss of vegetation covers, continuous crop harvesting, and soil erosion that led to the loss of these soil nutrients. The present finding is consistent with the observations made by Jobira et al. [32] and Yared [64], who noted an overall rise in organic matter content and essential nutrients as topography decreased.

4. Conclusion and Recommendation

The soil studied in the Azit subwatershed of Gedebano Gutazer Welene Woreda, Southern Ethiopia, revealed that land use types and slope gradients had significantly influenced most of the soil's physicochemical parameters. However, aside from OC, none of the soil properties were significantly affected by the interactions between land uses and slope gradients. In conclusion, based on the evaluated soil fertility under land use types and slope gradients, the study area varies as grazing land use and the lower slope gradient was better than the other land uses (cultivated and eucalyptus) and slope gradients (middle and upper slope gradients). This demonstrated that cultivated and eucalyptus areas along the higher slope gradient suffered from a lack of available nutrients. As a result, the soils urgently need to accumulate these nutrients. Thus, based on the findings of the study, it can be recommended that integrated soil fertility management practices, such as the addition of soil organic matter and appropriate use of inorganic fertilizers, need to be undertaken to improve the lost soil fertility status on the cultivated land and eventually improve agricultural productivity on a sustainable basis. In addition, eucalyptus plantations should be gradually replaced by those that help to restore the soil fertility status of eucalyptus land.

Data Availability

The data used to support the findings of this research are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

The authors collected, analyzed, interpreted, and prepared the manuscript of the study.

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