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Research Article

Status of Soil Acidity under Different Land Use Types and Soil Depths: The Case of Hojje Watershed of Gomibora District, Hadiya Zone, Southern Ethiopia

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In the humid regions of Ethiopia, soil productivity and fertility are significantly affected by soil acidity, which is connected to infertility and mineral toxicity. The study aimed to assess the status of soil acidity under different land use types and soil depths in Hojje watershed of Gomibora district, Hadiya Zone, Southern Ethiopia, in November 1, 2020. Soil samples (24 nos.) were collected using X-design format from four different land use typeshome garden, cultivated land, grazing land, and *Eucalyptus* plantation at two soil depths (0–20 cm and 20–40 cm). The soil samples were prepared, their physiochemical characteristics were examined, and statistical analysis was performed. The results indicated that the soil under cultivated land and *Eucalyptus* plantation were strongly acidic (pH 5.15 and 5.32) with mean values of exchangeable acidity (4.6, 4.59 $cmol_{(+)}$ kg^{-1}) and acid saturation percentage (47.85, 46.96%), respectively. The grazing land was moderately acidic (pH 5.63) and home garden soil was slightly acidic (pH 6.67). The home garden soils had statistically significant ($p < 0.01$) lower exchangeable acidity (0.64 $cmol_{(+)}$ kg^{-1}) and acid saturation percentage (2.61%). Although, soil pH (H_2O and KCl), exchangeable acidity, acid saturation percentage, exchangeable base, CEC, and base saturation are significantly ($p < 0.01$) affected by both the main effect and interaction effects of the two factors. As a result, it is advised to apply lime to the cultivated land to reduce the acidity of the soil for profitable crop production as the amount of acidity is above the tolerance limit for the area's locally produced crops.

1. Background

Significant obstacles to agricultural production in many parts of the world include soil acidity, which is linked to infertility and mineral toxicity [1]. Additionally, it affects a variety of chemical and biological reactions that control plant nutrient availability and element toxicity [2]. Aluminum (Al), manganese (Mn), and hydrogen (H), the elements most directly linked to soil acidity, gradually replace soluble nutrients as rainwater percolates downward from the top layers of the soil [3]. Aluminum (Al) is one of the predominant elements of the Earth's crust and in soils with normal pH; it is present in insoluble form and hence causes no harm to plants.

The solubility of Al in neutral and alkaline soils is too low to be toxic to plants. In acidic soils, it becomes soluble and enters the root where it hinders the growth and development of the root and interacts with soluble phosphorus to produce insoluble aluminum phosphate, which is unavailable to plants [4]. In general, a pH of less than 7 is considered acidic. pH is defined as the negative logarithm (base 10) of the molar concentration of H-ions in soil solution.

However, soils with a pH of less than 5.5 are viewed as acidic from an agricultural perspective because Al is soluble in water and becomes the dominant ion in the soil solution, which is hazardous to plant growth and production [5], stated that approximately 43% of the world's tropical land area is classified as acidic, most acid soils are found in tropical America (about 68%), tropical Asia (38%), and tropical Africa (27%). Moreover, the effect of toxicity of the tropics and subtropics accounts for 60% of the acid soils in the world [6].

To get sustainable crop production, acidic soils have to be managed by different management techniques, including selection of acid tolerant species, an agroforestry system, and organic materials like compost, crop residues, farmyard manure, and chicken manure. The optimum method also involves adding agricultural lime to a pH range that is ideal for higher crop output and to prevent soil acidification [7]. According to the world reference base for the soil resources [8] classification system, acid soils included under Andosols, Podzols, Plinthosols, Nitisols, Ferralsols, and Acrisol. According to [9], acid soils include Alfisols, Ultisols, and Oxisols. Soil acidity affects the growth of crops because acidic soils contain toxic levels of Al and Mn ions and are characterized by deficiency of essential plant nutrients such as P, N, K, Ca, Mg, and Mo [10].

The major causes of soil acidity include both natural and anthropogenic factors that cause soil acidity. However, anthropogenic activities speed up the rate of acidification. Causes include the type of parent materials used to create the soils, which include silica-rich acidic (felsic) parent materials such as granite and rhyolite, leaching of base cations, continuous of acid-forming fertilizers such as urea and diammonium phosphate (DAP), and continuous removal of basic cations through crop harvesting [11]. In Ethiopia, about 40.9% of the agricultural land area is covered by strong to weak acid soils found in western, southwestern, northwestern, and central high lands of Ethiopia. Of these, 27.7% account for moderately to slightly acid (pH 5.8–6.7) and 13.2% covered by strong to moderately acidic soils with a pH 5.5–6 [12, 13]. The soil in areas such as Chencha, Sodo, Sidam, Dawro, Kambate, and Gurage in SNNP are severely affected by soil acidity and limit the crop production owing to very strong acid reaction 4.81 [14, 15].

The district experiences high annual rainfall of between 1500 and 1896 millimeters, which contributes to soil erosion and the leaching of basic cations [16]. The removal of basic cations occurs during crop harvest even though farmers in the district use urea and DAP fertilizers for a long time without proper management, prolonged intensive cultivation, or complete removal of crops. Instead, residues are used for things like firewood, livestock feed, fence construction, and thatching on houses' roofs. Studies on the status of soil acidity under different land use in the study area are scarce, and hence, the present study was undertaken so that a more effective land management strategy is to be implemented by the local farmers and similar agroecological areas of the country.

2. Materials and Methods

The study was conducted in Gomibora district of Hadiya Zone, Southern Nations, Nationalities, and Peoples' Region state (SNNPRS) of Ethiopia. Gomibora district is located at about 259 km south of Addis Ababa and 27 km away from Hossana, the capital of Hadiya Zone, and it is one of the 13 districts of Hadiya Zone. It is geographically located between 7° 43′ 27″ to 7° 57′ 7″ N latitude and 37° 42′ 35″up to 37° 54′ 47″ E longitudes (Figure 1) [16].

2.1. Topography and Climate. Topographic feature of the district is mostly characterized by moderately gentle and steep land. The altitude ranges between 1972 and 2214 m.a.s.l and about 74% of the land mass of the district is classified as Woina-Dega according to the traditional agroecology classification system of Ethiopia. The rainfall distribution is bimodal, which occurs in two main rainy seasons (*Belg* and *Maher*). *Belg* is a short rainy season that starts from the beginning of January up to April, and *Maher* is a longer rainy season that extends from May to the end of September. The annual precipitation varies between 1500 mm and 1896 mm. The minimum and maximum temperatures (Figure 2) are 13.2 and 26.85°C, respectively [16].

2.2. Soil Type. The majority of the rocks in the study region are relatively soft weathered rocks that are particularly prone to erosion. The volcanic parts of the landscape are dominantly composed of acid to basic lava with ash and tuff. Soils of the area are derived from highly weathered rocks (granite and basalts) as Humic-Nitisols (60%), Eutric-Vertisol (20%), Eutric-Leptosol (10%), and Lithic-Leptosol (10%) cover extensive area. Soil covering an extensive area is deep, well drained with more than 50–150 cm rooting depth. Nitisols dominate the district and they support highly intensive land uses [17].

2.3. Site Selection. Field observation and a reconnaissance soil assessment were done prior to collecting soil samples. Evidently, a purposive sample technique was used to identify subwatersheds linked to issues with soil acidity. The following factors were taken into consideration when choosing a subwatershed (1) area associated with soil acidity from the previous report; (2) crop response to fertilizer application (information from farmers); (3) similar topography and soil types taken into consideration to lessen the heterogeneity of land use types and its detrimental effects on the soil acidity; and (4) similar climatic conditions to minimize agroecological influence, i.e., Woina-Dega based on the traditional agroecology classification system. Based on these information areas, one soil sampling subwatershed, i.e., Hojje watershed was selected from Gombora district to assess soil acidity.

2.4. Soil Sampling Techniques. Soil samples (24 composites) were collected from four land use types with three replications of each at two depths (0–20 cm and 20–40 cm). The land use types were home garden, cultivated land, grazing land, and *Eucalyptus* plantation land. Home gardens that have been planted with permanent crops for over 37 years, including enset (*Ensete ventricosum*), chat (*Catha edulis*), and bananas, also receive special care and applications of farmyard manure and compost. According to farmers' responses, cultivated land has been under intensive cultivation for over 35 years and has received urea and diammonium phosphate (DAP) fertilizer most of the time under wheat (*Triticum vulgare*), barley (*Hordeum vulgare*), and teff (*Eragrostis tef*) production. Grazing land, particularly

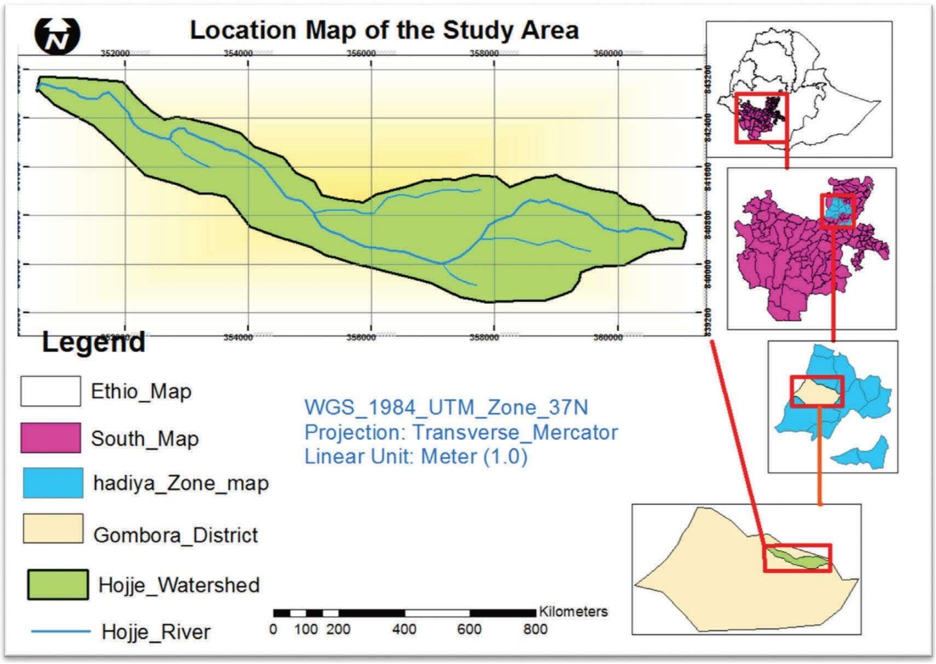

Figure 1: Location map of study area.

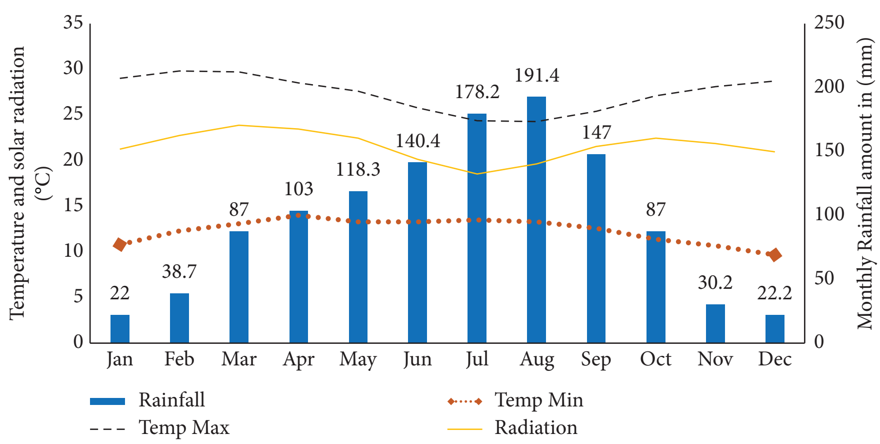

Figure 2: Mean monthly rainfall, temperature, and solar radiation of the study area.

communal grazing land, was used for the long-term grazing of livestock. *Eucalyptus* plantations, particularly those on private properties, are economically noticeable but environmentally unacceptable, despite the fact that they were first planted over 22 years ago. The composite soil samples were taken from two soil depths 0–20 cm and 20–40 cm from each type of land use in accordance with EthioSIS sampling guidelines [18], from 20 m × 20 m = (400 m^2) size plots. After that, the composite soil samples were taken from the four corners and the center of the square plots using the X-design format.

2.5. Laboratory Analysis. For the purpose of determining the physicochemical characteristics of the soil, soil samples from each type of land use were collected at depth, air dried, and passed through 2 mm sieves; however, samples for organic carbon were ground to pass 0.5 mm size sieves. From undisturbed soil samples obtained using core samples and the procedures, the bulk density of the soil was estimated [19]. The particle size distribution was determined according to the procedure outlined by [20]. The pH of the soil was measured potentiometrically with a digital pH meter in the supernatant suspension of 1 : 2.5 soil water 1M KCl solution [21].

In the study by Walkley and Black [22], the wet digestion method was used to determine the soil organic carbon content and percent soil organic matter was obtained by multiplying percent soil organic carbon by a factor of 1.724. Total nitrogen was determined using the micro-Kjeldahl digestion, distillation, and titration method as described by [9] by oxidizing the organic matter in concentrated sulfuric acid solution (0.1 NH_2SO_4). Available soils P was extracted by [23], the method quantified using a spectrophotometer (wavelength of 880 m) calorimetrically using vanadomolybdate acid as an indicator. Cation exchange capacity and exchangeable bases (Ca, Mg, K, and Na) were determined after extracting the soil samples by ammonium acetate (1N, NH_4OAc) at pH 7.0. Exchangeable Ca and Mg in the extracts were determined using an atomic absorption spectrophotometer, while Na and K were determined using a flame photometer [24]. Cation exchange capacity was thereafter estimated titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution [24]. Exchangeable acidities (Al and H) were determined from a neutral 1M KCl extracted solution through titration with standard NaOH solution based on the procedure described by [25]. Percent base saturation (PBS) was calculated by dividing the sum of the charge = equivalents of the base-forming cations (Ca, Mg, Na, and K) by the ECEC of the soil and multiplying by 100 and percent acid saturation (PAS) was calculated by dividing the sum of the charge = equivalents of the acid-forming cations (Al^{+3} and H^{+}) by the ECEC of the soil and multiplying by 100.

2.6. Data Analysis and Statistical Procedures. The use of descriptive statistics and two-way analysis of variance (ANOVA) allowed researchers to determine whether or not variations in soil parameters and soil depths were statistically significant within and among different types of land use, as well as within and between them. Statistical Analysis System (SAS) version 9.3 was used to execute the LSD mean separation method in order to identify the means that were significantly different at 5% levels [26].

3. Results and Discussion

3.1. Soil Acidity under Various Land Use Types and Soil Depths

3.1.1. Soil pH. All land use types and two soil depths had soil pH values that were between 0.8 and 1.35 units higher than those of the corresponding KCl solution measurements (Table 1). The release of significant amounts of exchangeable hydrogen (H^{+}) and aluminum ions (Al^{+3}) into the soil solution is indicated by the low soil pH in KCl. This is connected to the presence of exchangeable Al^{+3} and H^{+} in clay lattice or colloidal surfaces, which suggested high potential acidity [27, 28].

The mean values of pH-H_2O and pH-KCl were significantly ($p < 0.01$, $P \leq 0.05$) affected by all land use types, soil depths, and interaction (Tables 1 and 2). The highest mean values 6.67 and 5.88 and the lowest mean values 5.15 and 3.80 of soil pH using H_2O and pH-KCl were recorded under the home garden land and cultivated land, respectively, compared to other land use types (Table 1). The contribution of organic matter through the addition of manure, compost, mulching of its residue, adding of wood ash, and crop residue from outfield garbage may be the reason for the highest value of soil pH (H_2O) and KCl under the home garden. The pH of the soil has been reported to rise when manure is used [29, 30]. Similar to this, adding animal manure to a weathered Nigerian Ultisol raised the pH from 4.6 to 6.7 and increased the amount of exchangeable calcium in the soil from 1.6 to 6.6 $cmol_{(+)}\ kg^{-1}$ [31].

Contrarily, the lowest pH-H_2O and pH-KCl values were found under cultivated land, *Eucalyptus* plantations, and grazing land. This may be because crops continuously remove basic cations from the soil through photosynthesis, intensive farming practices increased the leaching of basic cations, exchangeable bases are washed away by rill and sheet erosion, acid-forming inorganic fertilizers are continuously applied to acid soils, and there is a risk that excessive precipitation [28, 32]; they reported that there has been a significant change in the chemical properties of the soil as a result of land use and management practices. Contrarily, because the trees in *Eucalyptus* plantations absorbed more basic cations and the soil did not receive them back as quickly, the soils there were acidic. The oblong-shaped canopy of *Eucalyptus* plantations may also cause big raindrops, which enhance the leaching of basic cations and the release of organic acids related to the mineralization of organic matter, contributing to the relative decline in soil pH [32]. Generally, the pH values (H_2O and KCl) observed in the area were within the range of extremely acidic to slightly acidic soil reactions as indicated by [33].

The higher mean values of pH-H_2O (5.86) and pH-KCl (4.86) were observed in subsurface soils (20–40 cm). In general, soil pH increased with soil depth (Table 1). Mean value of subsurface [34] reported that soil pH increased with the depth of soil profile and relatively high pH was observed in subsoil horizons in Nitisols of Bako area. The variability in soil pH suggested the increase in base accumulation with an increase in depth that could be attributed to the downward movement of solutes by leaching within a profile [32, 35] and also reported that the increase in pH with soil depth could be associated with enhanced carbonate levels and less weathering rates.

3.1.2. Exchangeable Acidity and Acid Saturation Percentage. The soil exchangeable acidity and acid saturation percentage were significantly ($p < 0.01$) affected by land use type, soil depth, and their interaction ($p < 0.01$), whereas exchangeable acidity values were significantly affected by the interaction effect of land use type by soil depth ($p < 0.05$) (Tables 1 and 2).

The mean exchangeable acidity values were 0.64, 2.65, 4.60, and 4.59 $cmol_{(+)}\ kg^{-1}$) for home garden, grazing land, cultivated land, and *Eucalyptus* plantation land, respectively (Table 1). The highest (4.60 $cmol_{(+)}\ kg^{-1}$) and the lowest (0.64 $cmol_{(+)}\ kg^{-1}$) exchangeable acidity was recorded under the cultivated lands and home garden soil, respectively (Table 1). The home garden land (mean value) showed that the reduction of exchangeable acidity by about (−86.1%) compared to its cultivated land. The different management techniques and applications of wood ash farm yard manure may be to blame for these outcomes. The exchangeable acidity of a Nigerian weathered Ultisol was reduced by applying animal manure, going from 3.00 $cmol_{(+)}\ kg^{-1}$ to 0.1 $cmol_{(+)}\ kg^{-1}$ [31].

Table 1: Main effects of land use and soil depth on soil pH (H_2O), pH(KCl), Ex. acidity, acid saturation percentage, SOM, TN, and aval P of the soils in the Hojje watershed ($N = 24$).

	pH (H_2O), 1 : 2.5	pH (KCl), 1 : 2.5	ΔpH	EA, $cmol_c\ kg^{-1}$	AS %	SOM, mg/kg	TN, mg/kg	Av. P, mg kg^{-1}
				Land use types				
HG	6.67^a	5.88^a	0.80	0.64^c	2.61^c	7.07^a	0.27^a	12.73^a
GL	5.63^b	4.78^b	0.85	2.65^b	24.86^b	3.86^b	0.17^b	3.48^b
CL	5.15^d	3.80^d	1.35	4.60^a	47.85^a	2.34^c	0.12^c	2.83^c
EP	5.32^c	4.16^c	1.16	4.59^a	46.96^a	2.39^c	0.13^c	2.98^c
LSD (0.05)	0.09	0.14		0.25	1.61	0.82	0.012	0.49
				Soil depth				
0–20 cm	5.52^b	4.45^b	1.07	3.33^a	34.05^a	4.49^a	0.21^a	6.42^a
20–40 cm	5.86^a	4.86^a	1.00	2.91^b	27.09^b	3.34^b	0.13^b	4.59^b
LSD	**0.07**	**0.10**		**0.18**	**1.14**	**0.58**	**0.01**	**0.35**
CV	**1.31**	**2.39**		**6.57**	**4.26**	**5.21**	**5.61**	**7.22**

Main effect means within a column followed by the same letter are not significantly different from each other at $P \leq 0.05$; CL, cultivated land; HG, home garden; GL, grazing land; EP, *Eucalyptus* plantation; KCl, potassium chloride; AS, acid saturation percentage; LSD, least significance difference; CV, coefficient of variation; EA, exchangeable acidity; SOM, soil organic matter; TN, total nitrogen; Av. P, available phosphorus; *N*, number of samples.

Table 2: The interaction effects of land use and soil depth on soil pH (H_2O), pH (KCl), Ex. acidity and acid saturation percentage of the soils in the Hojje watershed ($N = 24$).

Land use types	pH (H_2O), 1 : 2.5		pH (KCl),1 : 2.5		EA., $cmol_{(+)}\ kg^{-1}$		Acid saturation (%)	
	Soil depth (cm)							
	0–20	20–40	0–20	20–40	0–20	20–40	0–20	20–40
HG	6.53^b	6.80^a	5.63^b	6.13^a	0.83^d	0.46^e	3.49^e	1.72^e
GL	5.4^d	5.87^c	4.50^d	5.06^c	3.12^b	2.18^c	30.81^c	18.90^d
CL	4.93^f	5.36^d	3.56^g	4.03^f	4.70^a	4.49^a	51.29^a	44.41^b
EP	5.2^e	5.43^d	4.10^{fe}	4.23^e	4.69^a	4.50^a	50.59^a	43.33^b
LSD (0.05)	**0.132**		**0.18**		**0.36**		**2.34**	
CV	**1.31**		**2.39**		**6.57**		**4.26**	

The interaction effects within a column followed by the same letter are not significantly different from each other at $P \leq 0.05$. CL, cultivated land; HG, home garden; GL, grazing land; EP, *Eucalyptus* plantation; KCl, potassium chloride; AS, acid saturation percentage; LSD, least significance difference; CV, coefficient of variation; EA, exchangeable acidity; *N*, number of samples.

Changes in soil pH, soil organic matter, soil texture, and cropping history may be the cause of this variation in exchangeable acidity. According to [36, 37], in all land use types and two soil depths, with the exception of home gardens, the mean exchangeable acidity is categorized as being very high. The findings of this investigation corroborated those of other authors [34, 38–40] and reported that inorganic fertilizer application is the root cause of soil exchangeable acidity.

The acidity saturation (mean values) of soil were 2.61%, 24.85%, 47.85%, and 46.98% in home garden, grazing land, cultivated land, and *Eucalyptus* plantation land, respectively (Table 1 and Figure 3). The highest mean value (47.85%) of acid saturation was observed under the cultivated land, whereas the lowest mean value of (2.61%) was observed under the home garden soil. The home garden (mean value) indicates the reduction of acid saturation by 94.5% cultivated land. Similar trends were observed in acid saturation percentage than that of exchangeable acidity.

The significant differences between the home garden land and the cultivated land were likely caused by the different management techniques and application of wood ash, farm yard manure, and household waste, as well as the lack of application of chemical fertilizer. Hence, the cultivated fields, *Eucalyptus* plantation, and grazing land had very high levels of acid saturation. According to the acid saturation described in soil acidity management and lime application guidelines prepared by Genenew and Kuma Megersa [32, 41], the acceptable acid saturation tolerance limit for crops is 1% for cabbage, 1% for carrots, 5% for onions, 5% for field beans, 10% for wheat and barley, 20% for potatoes, and 40% for teff. However, the acid saturation in cultivated land exceeded the area's local crops' saturation tolerance limit (>40%). When comparing the two soil depths, the subsurface soils (20–40 cm) had the lower mean values of exchangeable acidity (2.91) and acid saturation percentage (27.09%), respectively (Table 1). From the surface to the subsurface soil, the exchangeable acidity and acid saturation percentage of the soil generally decreased. In comparison to surface soils, subsurface soils displayed a reduction in exchangeable acidity and acid saturation percentage of about 12.6% and 20.4%, respectively. This condition of fluctuating exchangeable acidity and acid saturation percentage suggested an increase in base accumulation with depth that could be explained by the leaching of solutes that cause downward movement of solutes within a profile [32].

The interaction effects (mean value) of soil pH-H_2O and pH-KCl were significantly ($P < 0.05$) affected by the land use types and soil depth (Table 2). The highest (6.80) pH-H_2O was recorded at 20–40 cm from the home garden soil; the lowest (4.93) was recorded at the surface layer of the cultivated land soil. The highest pH in the subsurface layer of the home garden soil could be the result of high clay content and high accumulation of basic cations and the lowest pH in the surface layer of the cultivated land could be due to leaching of basic cations.

The pH variation at the two depths may be caused by ongoing agricultural practices, excessive precipitation, and the use of inorganic fertilizers [42], and we found that the pH of the soil were affected by the interactions of land use

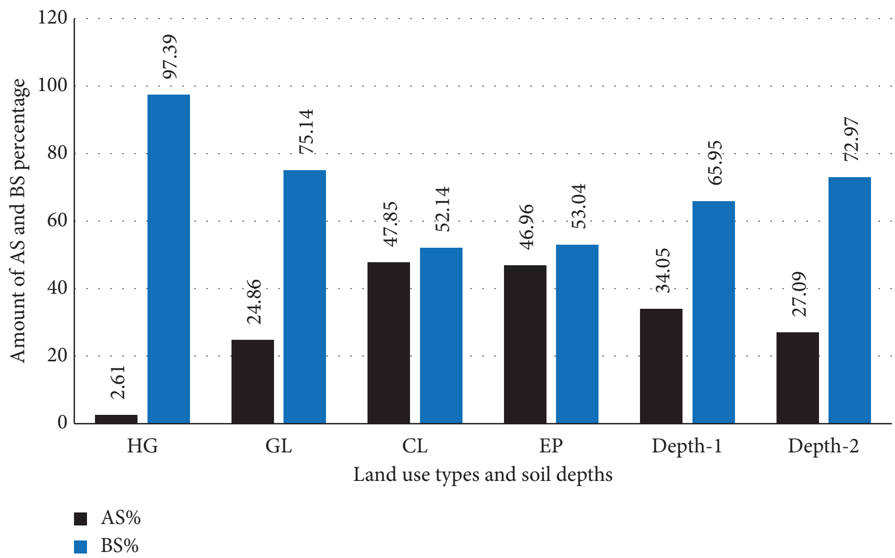

Figure 3: Comparison of acid saturation percentage with base saturation percentage under different land use types and depths.

changes and soil depth in Western Ethiopia [43]. According to [33], the soil pH range of the study area (4.93–6.80) indicated strongly acidic to slightly acidic soil under all land use types.

Results show that the highest mean (6.13) pH-KCl was recorded at the 20–40 cm soil depth of the home garden soil, whereas the lowest (3.56) was recorded at the surface layer 0–20 cm of the cultivated land compared to the three land uses (Table 2). The higher pH-KCl observed at the subsurface layer of the home garden land might be attributed to the accumulation of soluble cations, translocation of clay, and soil erosion through tillage [44, 45]. Generally, the pH-KCl ranged from very strongly acidic to moderately acidic (3.56–6.13) [43].

The exchangeable acidity and acid saturation percentage were significantly ($P < 0.05$) affected by the interaction effects of land use types by soil depth (Table 2). The highest mean (4.7) and lowest mean value (0.46) and exchangeable acidity and corresponding values (51.29 and 1.72%) for acid saturation percentage were recorded at the surface soil depth (0–20 cm) of cultivated land and subsurface soil depth (20–40 cm) of home garden soil, respectively (Table 2). These results show that intensive cultivation and application of inorganic fertilizers lead to the higher exchangeable acidity and acid saturation percentage content of the surface layer of cultivated land, whereas the lowest exchangeable acidity and PAS indicate better soil management for subsurface of home garden soil.

3.2. Soil Acidity and Plant Nutrient

3.2.1. Soil Organic Matter. Soil organic matter (SOM) content was significantly ($P \leq 0.01$) affected by land use, soil depth, and their interaction (Tables 1 and 3). Soil OM content was the highest (7.07 mg/kg) under the home garden; whereas, the lowest (2.33 mg/kg) was on cultivated land, but no significant difference between the cultivated land and *Eucalyptus* plantation at both soil depths (Table 1).

The low levels of organic matter applied to the soils and the complete removal of crop residue from the cultivated land may be to blame for the lowest SOM contents [46] and severe deforestation, steep relief conditions, intensive cultivation, and excessive erosion problem [47].

Higher mean value (4.49 mg/kg) of SOM was observed in the surface soil (0–20 cm), whereas the lowest mean value (3.34 mg/kg) was observed in subsoil (20–40 cm). The higher SOM in soil at surface depth in all land use types might be due to better return of biomass for decomposition at the surface [39, 48], reported surface soil to be more biologically active in soil systems.

According to the rating of soil organic matter as per the ranges suggested by [49], the soils of cultivated land and *Eucalyptus* plantations are rated as low, medium for grazing land, and high for home gardens at both soil depths (Table 1). Previous studies [7, 50] reported that less biomass return results in less SOM and total nitrogen content in the cultivated lands.

Soil organic matter (SOM) content was significantly ($P \leq 0.01$) affected by the interaction of land use type with soil depth (Table 3). SOM was significantly higher (8.46 mg/kg) at surface soil depth of the home garden soil. This might be related to a better canopy of plants in home gardens which results in reduced erosion and in turn low loss of basic cations.

The lower mean values of SOM (2.21 and 2.22 mg/kg) were recorded at subsurface soil of cultivated land and *Eucalyptus* plantation compared to other land use (Table 3). The lowest SOM in the cultivated land might be due to intensive cultivation of the land, fast decomposition SOM, and the removal of crop residues for animal feed, income generation, and source of energy [7, 32, 50], also who reported less biomass return and total nitrogen content in the cultivated and grazing lands.

Table 3: The interaction effects of land use and soil depth on soil SOM, TN, Ava. P, and CEC of the soils in the Hojje watershed ($N = 24$).

Land use types	SOM, mg/kg		TN, mg/kg		Ava. P (mg kg^{-1})		CEC, $cmol_{(+)}$ kg^{-1}	
	Soil depth (cm)							
	0–20	20–40	0–20	20–40	0–20	20–40	0–20	20–40
HG	8.46^{a}	5.68^{b}	0.32^{a}	0.23^{b}	14.49^{a}	10.97^{b}	26.63^{b}	28.47^{a}
GL	4.45^{c}	3.28^{dc}	0.22^{b}	0.12^{c}	4.45^{c}	2.51^{e}	12.91^{d}	13.89^{c}
CL	2.46^{d}	2.21^{d}	0.12^{c}	0.09^{d}	3.33^{d}	2.26^{ed}	12.56^{d}	12.71^{d}
EP	2.57^{d}	2.22^{d}	0.13^{c}	0.10^{d}	3.39^{d}	2.60^{e}	12.73^{d}	12.95^{d}
LSD (0.05)	**1.19**		**0.02**		**0.76**		**0.76**	
CV	**5.21**		**5.61**		**7.22**		**2.61**	

The interaction effect means within a column followed by the same letter are not significantly different from each other at $P \leq 0.05$. HG, home garden; GL, grazing land; CL, cultivated land; EP, *Eucalyptus* plantation; LSD, least significance difference; CV, coefficient of variation; SOM, soil organic matter; TN, total nitrogen; Av. P, available phosphorus; CEC, cation exchange capacity; BS, base saturation percentage; *N*, number of samples.

3.2.2. Total Nitrogen. The total nitrogen (TN) content was significantly $P \leq 0.01$) affected by land use types, soil depth, and their interaction effects of land use by soil depth (Tables 1 and 3).

The home garden soil had the highest mean TN value (0.27 mg/kg), while cultivated land and *Eucalyptus* plantation soil had the lowest (0.12 and 0.13 mg/kg), respectively. From 0.21 mg/kg in the surface (0–20 cm) to 0.13 mg/kg in the subsurface (20–40 cm) soil depth, the mean TN content significantly decreased (Table 1) [51], the considerable reduction of total *N* in the continuously cultivated fields owing to the rapid turnover (mineralization) of the organic substrates derived from crop residue or root biomass.

The highest mean value of TN (0.32 mg/kg) was recorded under the soil of a home garden at a depth of 0–20 cm, whereas the lowest mean value of TN (0.09 mg/kg) was recorded under the soil of cultivated land at a depth of 20–40 cm. However, at both depths, there was no distinction between the cultivated land and the *Eucalyptus* plantation (Table 3). The addition of organic matter, compost, easily degradable household waste, and dense vegetation cover, which reduced soil erosion and subsequently losses of nutrients, resulted in the home garden soil having the highest TN [5].

The lower TN in the cultivated land may be caused by continuous cropping without nutrient replacement, increased soil disturbance from tillage, a lack of soil organic matter management, and the use of crop residues as a source of energy, income, and animal feed [46], also reported similar findings. Total nitrogen decreased consistently with increasing depth of soil in all land uses, which corroborated the findings of [52, 53]. As per the rating of soil TN, the soils of cultivated land and *Eucalyptus* plantation were low, but grazing land and two soil depths were medium. Home garden soil was placed under the high rating class (Table 1).

3.2.3. Available Phosphorus. The available phosphorus (Av. P) content was significantly ($P \leq 0.01$) affected by land use type, soil depth, and their interaction (Tables 1 and 3). The content of available *P* in the home garden soil performed was found to be significantly higher than that of other land uses. The data also revealed that the available *P* was higher (6.42) in the surface soil (0–20 cm) than those in the subsurface (4.59) soil, which indicates a reduction of 28.5% compared to surface soil (Table 2).

The highest mean available *P* (14.49 mg kg^{-1}) was found in the surface soil of a home garden due to the interaction effect of land use and soil depth, while the lowest mean available *P* (2.26 mg kg^{-1}) was found in the subsurface soil of undercultivated land, followed by grazing land and *Eucalyptus* plantation soils, respectively (Table 3). By forming more readily assimilated organophosphate complexes and anion replacement of H_2PO_4 at adsorption sites, soil organic matter was found to have a positive impact on the amount of available *P* [42, 46, 54]. Similarly, the result is also in agreement with that of the result by Boke and Beyene [15]. Enset plant (*Ventricosum*) soils were found to have high available *P* in the Kokate and Adilo regions. Due to intensive farming and low organic matter content, cultivated land has the lowest available *P* [55], reported low *P* availability in most Ethiopian soils as a result of multiple crop harvests, erosion, fixation, and low soil organic matter content accumulation. Under all land uses, the amount of readily available phosphorus consistently decreased with soil depth. According to Landon [49], the mean available P content of the soils was within the range of medium in soils of home garden soil and low in soils of cultivated land, *Eucalyptus* plantation, and grazing land, respectively.

3.2.4. Exchangeable Basic Cations. The exchangeable calcium (Ca), magnesium (Mg), and potassium (K) were significantly ($P < 0.01$) affected by land use, soil depth, and their interaction (Tables 4 and 5). The exchangeable sodium (Na) was a significant ($P < 0.01$) variation with soil depth (Table 5).

The mean values of exchangeable calcium ($cmol_+$ kg^{-1}) recorded under the home garden, grazing land, cultivated land, and *Eucalyptus* plantation were 10.86, 3.63, 2.23, and 2.28 $cmol_c kg^{-1}$ soil, respectively (Table 4). The highest mean value of calcium (10.86) was recorded under home garden followed by grazing land. Compared to other land uses, cultivated land had the lowest mean value (2.23). There was no difference between the cultivated land and the *Eucalyptus* plantation. The highest mean exchangeable Ca^{+2}, Mg^{+2}, and K^{+} obtained in home garden soils, probably related to the high amount of organic matter, clay content, and

Table 4: Main effects of land use and soil depth on soil exchangeable cations and base saturation percentage of the soils in the Hojje watershed ($N = 24$).

	Ex. Ca^{+2} ($cmol_+ kg^{-1}$)	Ex. Mg^{+2} ($cmol_+ kg^{-1}$)	Ex. K^{+1} ($cmol_+ kg^{-1}$)	Ex. Na^{+1} ($cmol_+ kg^{-1}$)	ECEC ($cmol_+ kg^{-1}$)	CEC ($cmol_+ kg^{-1}$)	BS%
Land use types							
HG	10.86^a	10.84^a	2.49^a	0.3	25.13^a	27.55^a	97.39^a
GL	3.63^b	2.76^b	1.55^b	0.25	10.84^b	13.40^b	75.14^b
CL	2.23^c	1.75^c	0.86^c	0.2	9.63^c	12.64^c	52.14^c
EP	2.28^c	1.85^c	0.87^c	0.23	9.83^c	12.84^c	53.04^c
LSD (0.05)	0.098	0.093	0.022	NS	0.308	0.53	1.61
Soil depth							
0–20 cm	4.47^b	3.79^b	1.25^b	0.19^b	13.04^b	17.01^b	65.95^b
20–40 cm	5.03^a	4.81^c	1.63^a	0.3^a	14.68^a	16.21^a	72.91^a
LSD (0.05)	0.69	0.065	0.015	0.07	0.22	0.38	1.14
CV	1.66	1.73	1.21	33.17	1.79	2.61	1.87

Main effect means within a column followed by the same letter are not significantly different from each other at $P \leq 0.05$. HG, home garden; GL, grazing land; CL, cultivated land; EP, *Eucalyptus* plantation; LSD, least significance difference; CV, coefficient of variation; CEC, cation exchange capacity; Ex., exchangeable; BS%, base saturation percentage; $cmol_c$, cent mole charge; ECEC, effective cation exchange capacity; N, number of samples.

Table 5: The interaction effects of land use and soil depth on soil exchangeable cations, effective cation exchange capacity, and base saturation percentage of the soils in the Hojje watershed ($N = 24$).

Land uses type	Ex.Ca^{+2} ($cmol_+ kg^{-1}$)		Ex. Mg^{+2} ($cmol_+ kg^{-1}$)		Ex.K^+ ($cmol_+ kg^{-1}$)		ECEC ($cmol_+ kg^{-1}$)		BS%	
	Soil depths (cm)									
	0–20	20–40	0–20	20–40	0–20	20–40	0–20	20–40	0–20	20–40
HG	10.2^b	11.4^a	10.12^b	11.57^a	2.24^b	2.75^a	23.60^a	26.66^b	96.50^a	98.27^a
GL	3.36^d	3.90^b	2.13^d	3.39^c	1.33^d	1.77^c	10.12^b	11.55^c	69.18^c	81.09^c
CL	2.12^f	2.34^e	1.41^e	2.1^d	0.72^f	0.99^e	9.13^e	10.13^d	48.71^e	55.58^d
EP	2.16^f	2.41^e	1.50^e	2.19^d	0.73^f	1.01^e	9.28^e	10.38^d	49.41^e	56.67^d
LSD (0.05)	0.15		0.13		0.029		0.43		2.33	
CV	1.66		1.73		1.21		1.79		1.81	

The interaction effect means within a column followed by the same letter are not significantly different from each other at $P \leq 0.05$. HG, home garden; GL, grazing land; CL, cultivated land; EP, *Eucalyptus* plantation; LSD, least significance difference; CV, coefficient of variation; N, number of samples.

managements, observed that the chemical composition of applied farmyard manure had considerable amounts of macronutrients and small amounts of micronutrients [39, 56]; they discovered that nutrients like nitrate, calcium, magnesium, and other elements were being lost from crop root zones to subhorizons, where they could be absorbed by species with deep roots and returned to the surface through litter. The difference in exchangeable calcium between cultivated land and a backyard garden was likely due to significant acidification processes brought on by the removal of basic cations (Na, Ca, Mg, and K) by crop uptake, leaching, and erosion. In soil with a high acidity level, aluminum and manganese are more readily available, whereas calcium, phosphorus, and magnesium are less readily available to the plant at a lower pH [57].

The average amounts of magnesium (Mg) found in the home garden, grazing lands, cultivated lands, and *Eucalyptus* plantations were 10.75, 2.76, 1.75, and 1.85, respectively (Table 4). In contrast to other land uses, cultivated land had a lower mean magnesium value than uncultivated land (1.75), with the highest mean magnesium value (10.76) being found in home garden soil. There was no significant variation between cultivated land and *Eucalyptus* plantation for mean exchangeable Mg [58]. The mean of exchangeable potassium (K^+) under the home garden, grazing land, cultivated lands, and *Eucalyptus* plantation were 2.49, 1.55, 0.86, and 0.87 $cmol_+ kg^{-1}$, respectively (Table 2). The highest mean value of potassium (2.49) was under the home garden soil; whereas, the lowest mean value of potassium (0.86) was recorded under the cultivated land compared due to other land uses. There was no significant variation between cultivated land and *Eucalyptus* plantations. The result is in line with [59], continuous cultivation and inorganic fertilizer application resulted in the decline of soil pH and caused a loss of basic cations, in inherently poorly cultivated land. The means of exchangeable calcium, magnesium, potassium, and sodium were higher (5.03 4.81, 1.63, and 0.3 $cmol_+ kg^{-1}$ soil) in the subsurface soil than those in the surface soil depth (Table 4). The exchangeable Ca^{+2}, Mg^{+2}, K^{+1}, and Na^{+1} increased with soil depth due to higher clay content and accumulation of basic cations in subsurface layer.

The lowest exchangeable Ca, Mg, and K recorded in cultivated land (0–20 cm) depth might be due to the leaching effect due to intensive cultivation, crop residue removal, low clay content, and organic matter degradation as planting of pines and *Eucalyptus* species invariably alters many soil properties. Soils under *Eucalyptus* plantations become more acidic, the effect usually being attributed to the uptake of basic cations into the forest biomass [60]. Moreover, soil erosion, overgrazing, and removal of these cations by vegetation contributed to the depletion of Ca, Mg, and K in the cultivated and grazing lands [35]. Previous research studies [7, 28, 50, 61] observed that continuous cultivation and use of acid-forming inorganic fertilizers affected the distribution of Ca, Mg, and K in the soil and enhanced acidification.

According to [17, 49], the soils were rated as high for exchangeable Ca^{+2} in the home garden and low in grazing land, cultivated land, and *Eucalyptus* plantation. Exchangeable Mg^{+2} and k^{+} were high in home garden soil and low in grazing land, cultivated land, and *Eucalyptus* plantation. Exchangeable Na^{+1} was medium in the home garden soil but low in the grazing land, cultivated land, and *Eucalyptus* plantation. The exchangeable Ca^{+2}, Mg^{+2}, K^{+}, and Na^{+} were rated as low, medium, medium, and low in surface soil, respectively, but medium, high, high, and medium in subsurface soil, respectively.

3.2.5. Effective Cation Exchange Capacity. By land use type, soil depth, and their interaction, the mean of effective cation exchange capacity (ECEC) was significantly ($P < 0.01$) impacted (Table 4). The mean values of ECEC measured under the home garden, grazing land, cultivated land, and *Eucalyptus* plantation, respectively, were 25.13, 10.84, 9.63, and 9.83 $cmol_+ kg^{-1}$ (Table 4). Home garden soil had the highest average ECEC value, whereas soil from *Eucalyptus* plantations and cultivated land had the lowest averages. The soil on cultivated land and that on a *Eucalyptus* plantation did not differ significantly from one another. This may be explained by low basic cations brought on by soil erosion and leaching, as well as by the cultivated land's low proportion of clay content, which led to a lower ECEC value than the other land uses [62]. It was argued that agricultural practices like the use of nitrogen fertilizers accelerate the natural rate of acidification. The mean of effective cation exchange capacity (ECEC) was significantly ($P < 0.01$) affected by their interaction (Table 5).

3.2.6. Cation Exchange Capacity. Land use types, soil depths, and their interactions all had an impact on the mean cation exchange capacity (CEC), which was significant ($P < 0.01$) (Tables 1 and 4). The average (CEC) values measured under the *Eucalyptus* plantations, grazing land, and cultivated land were 27.55, 13.40, 12.64, and 12.84 $cmol_+ kg^{-1}$, respectively (Table 4). Grazing land had the highest mean CEC value, followed by home garden soil, while cultivated land and *Eucalyptus* plantation soil had the lowest mean values. The soil from *Eucalyptus* plantations and cultivated land did not differ significantly for CEC.

The intensive cultivation and application of acid-forming inorganic may have reduced the amount of exchangeable bases, which may be the cause of the lowest mean of CEC. The highest CEC in home garden land, however, might be the result of various management techniques that boost soil organic matter. This study is consistent with findings from the study by Bahilu [63].

Due to higher clay or OM than sandy soils, the subsurface layer of soil under the home garden had the highest mean CEC (28.46 $cmol_+ kg^{-1}$), while the surface layer of soil under cultivated land use had the lowest mean (12.56 $cmol_+ kg^{-1}$) [15]. The highest CEC in the subsurface layers of soil under all land use types could be the result of the high clay content and accumulation of basic cations [58, 64, 65]. As per the ratings suggested by [17, 49], the CEC of the soils qualified in the range of high in home garden and low in the cultivated land and medium under *Eucalyptus* plantation and grazing land, respectively.

3.2.7. Base Saturation Percentage. Land use types, soil depths, and their interactions had a significant ($P < 0.01$) impact on base saturation percentage (BS%) (Tables 4 and 5). The cultivated lands and home gardens, respectively, recorded the highest mean (97.39%) and the lowest mean (52.14%) of BS% (Table 4). The cultivated and *Eucalyptus* plantation land, however, did not significantly differ from one another. Thus, it shows that *Eucalyptus* significantly accelerated soil weathering and acidification, resulting in the formation of Spodosol and low base saturation. The higher clay content and better management may be to blame for the highest base saturation percentage under the home garden soil. In comparison to the surface layer, the subsurface layer had higher base saturation (72.91%).

Percentage base saturation (BS%) was significantly ($P \leq 0.01$) affected by their interaction effects of land use types and soil depths (Tables 5). Interaction effects of land use types with soil depths, highest base saturation percentage (98.27%) was recorded in sub-surface layer of the home garden land whereas the lowest mean value (48.71%) was recorded on surface layer of the cultivated land. As the percent base saturation ratings suggested by [37], the base saturation content of the soils qualified in the range of high to low across different land use types and soil depths.

3.3. Relationships of Soil Acidity and Selected Soil Physicochemical Properties. There was a close relationship between soil acidity and soil properties of different land use types. The correlation analysis showed that soil pH (H_2O; KCl) was highly significantly ($P < 0.01$) and positively correlated with total exchangeable bases (Ca^{+2}, Mg^{+2}, and K^{+}) ($r = 0.96^{**}$ 0.96^{**} 0.97^{**}; $r = 0.93^{**}$ 0.92^{**} 0.98^{**}), CEC ($r = 0.93^{**}$; $r = 0.89^{**}$). Base saturation had a significant positive relationship with ECEC but negatively correlated with exchangeable acidity ($r = -0.94^{**}$; $r = -0.96^{**}$) and acid saturation ($r = -0.96^{**}$; $r = -0.97^{**}$) for water and KCl, respectively (Table 6).

This result is consistent with the findings of [46], who found that in the soil of the Injibara area, pH is highly

Table 6: Pearson correlation coefficient (r) between soil acidity and other soil properties ($N = 24$).

	H_2O	KCl	Ex. Ac	AS	OM	TN	P	ECEC	Ca^{+2}	Mg^{+2}	K^+	Na^+	BS	CEC
pH (KCl)	0.97**	1.00												
Ex. acidity	0.94**	0.96**	1.00											
AS%	0.96**	0.97**	0.99**	1.00										
Om%	0.80**	0.80**	0.87**	0.87**	1.00									
TN	0.67**	0.66**	0.75**	0.74**	0.95**	1.00								
Aval. P	0.83**	0.79**	0.82**	0.82**	0.90**	0.91**	1.00							
ECEC	0.95**	0.90**	0.89**	0.89**	0.82**	0.76**	0.93**	1.00						
Ca^{+2}	0.96**	0.93**	0.93**	0.92**	0.86**	0.79**	0.93**	0.99**	1.00					
Mg^{+2}	0.96**	0.92**	0.91**	0.91**	0.82**	0.75**	0.92**	0.89**	0.94**	1.00				
K^+	0.97**	0.98**	0.98**	0.98**	0.81**	0.67**	0.80**	0.92**	0.94**	0.94**	1.00			
BS%	0.96**	0.97**	0.99**	0.99**	0.87**	0.74**	0.82**	0.89**	0.92**	0.91**	0.98**	0.38 ns	1.00	
CEC	0.93**	0.89**	0.88**	0.88**	0.82**	0.77**	0.94**	1.00**	0.99**	0.99**	0.90**	0.32 ns	0.88*	1.00

**Correlation is significant at the 0.01 level ($p < 0.01$), *correlation is significant at the 0.05 level ($p < 0.05$), and (ns) indicates there was no significant difference at 0.05 level. $n = 24$; Ex. acidity, exchangeable acidity; Av.P, available phosphorous; AS%, acid saturation percentage; ECEC, effective cation exchange capacity; CEC, cation exchange capacity; OM, organic matter; TN, total nitrogen; BS, base saturation percentage.

significantly and negatively correlated with exchangeable acidity ($r = -0.612^{**}$) while highly significantly and positively correlated with Ca and Mg ($r = 0.886$ and 0.775, respectively). McDonald [66] elaborated that basic cations (Ca^{+2}, Mg^{+2}, K^+, and Na^+) are usually found only in low amounts in acidic soil as they have been displaced from cation exchange sites by H^+ and Al^{+3} ions and subsequently leached from the soil.

The exchangeable acidity and acid saturation were negatively correlated with the available phosphorus ($r = -0.82^{**}$ and $r = -0.82^{**}$, respectively), and the correlation was highly significant ($P < 0.01$) (Table 6). But they were strongly ($P < 0.01$) and positively ($r = 0.83^{**}$, $r = 0.79^{**}$) correlated with soil pH (H_2O) and pH of KCl, respectively (Table 6).

According to [66], high concentrations of soluble iron, aluminum, and manganese cause insoluble phosphate compounds to precipitate when the environment is acidic. Additionally, certain silicate clays and hydrous oxides of aluminum and iron can fix phosphate, which can also decrease its availability. On the other hand, total nitrogen content and organic matter were both highly significant ($p < 0.01$) and negatively correlated with exchangeable acidity and acid saturation ($r = -0.87^{**}$, -0.87^{**} and $r = -0.75^{**}$, -0.74^{**}) (Table 6).

4. Conclusion

It has been determined that soil depth and type of land use had an impact on soil acidity. All land uses had strongly acidic soils, with the exception of soils used for home gardens. In contrast, cultivated land, *Eucalyptus* plantations, and grazing lands beneath the soil had poor nutrient availability. Home garden soils, on the other hand, have higher soil pH, lower exchangeable acidity, and lower acid saturation percentage. Exchangeable bases, CEC, BS, OM, TN, available phosphorous, and proportional clay content showed the lowest mean in cultivated land, *Eucalyptus* plantation, and grazing lands but relatively higher mean value in home garden land. The mean sand, silt content, OM, TN, and available phosphorous decreased with soil depth, while the mean values of Ca, Mg, K, Na, CEC, BS, and clay content increased with increasing of soil depth.

Based on finding, soil acidity in cultivated land poses a serious threat to crop production, so lime application should be encouraged for logistical and financial reasons. For farmers with limited resources, applying high rates of lime in acidic soils is frequently not an option. On cultivated land, it should be preferable to use farmyard manure and crops that can withstand acidity. To improve the production and productivity of acidic soils of cultivated land, site-specific fertilizer and lime application should be used. To understand the limitations in the resource base limiting the growth of crops or vegetation, the study on horizon layer-wise distribution of micronutrients should also be conducted.

Abbreviations

ANOVA: Analysis of variance
CEC: Cation exchange capacity
DAP: Diammonium phosphate
ECEC: Effective cation exchange capacity
FAO: Food and Agricultural Organization
PAS: Percentage acid saturation
PBS: Percentage base saturation
SNNP: South Nation Nationalities People
SOM: Soil organic matter
SPSS: Statistical Package for Social Science
TN: Total nitrogen
USDA: United States Department of Agriculture
WRB: World reference base soil resources.

Data Availability

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

Consent

Prior oral informed consent was obtained from the local community and from all individual participants.

Conflicts of Interest

The author declares that there are no conflicts of interest.

Authors' Contributions

The author made a valuable and unreserved contribution as well as read and approved the final article. The author agreed to submit the manuscript for publication.

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