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Research Article

Fertility Status of Acid Soils under Different Land Use Types in Wolaita Zone, Southern Ethiopia

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Information on soil fertility status of acid soil of a particular area as affected by land use type is important for developing sound soil management systems for improved and sustainable agricultural productivity. The main objective of this study was to assess the fertility status and effect of land use change on soil physicochemical properties. In this study, adjacent three land use types, namely, enset-coffee, crop, and grazing land use were considered in four districts (i.e., Bolos Sore, Damot Gale, Damot Sore, and Sodo Zuria) of Wolaita Zone, southern Ethiopia. Soil samples were collected from a depth of 0–20 cm from each land use type of the respective districts for physicochemical analyses. The results showed that land use types significantly affected ($P \leq 0.05$) soil properties such as bulk density, available P, exchangeable potassium, exchangeable acidity, exchangeable bases (Na, K, Ca, Mg), exchangeable acidity, and CEC. Besides, soil pH, OC, and TN were influenced significantly ($P \leq 0.05$) both by districts and land use types. The very strongly acidic soils were found predominantly in the crop and grazing lands whereas a neutral acidity level was found in the enset-coffee land use type of four districts. In conclusion, the study proves that land use type change within the same geographic setting can affect the severity of soil acidity due to over cultivation and rapid organic matter decomposition. Finally, the study recommends an in-depth study and analysis on the root causes in aggravating soil acidity under crop and grazing land use types.

1. Introduction

Agricultural sustainability requires periodic evaluation of soil fertility status, which is important in understanding factors that impose serious constraints to crop production under different land use types and for adoption of suitable land management practices [1]. The land-use systems play a tremendous role in influencing nutrient availability and cycling and may also influence secondary succession and biomass production [2, 3]. Soil acidity and associated low nutrient availability are key constraints to crop production in acidic soils, mainly Nitisols of Ethiopian highlands [4]. Haile et al. [5] estimated that ~43% of the Ethiopian crop land is affected by soil acidity). The soil acidity in Ethiopia is dominated by strong acid soils (pH 4.1–5.5) [6]. The decline in soil fertility is caused by land use type changes [7]. The loss of soil fertility in Ethiopia is related mainly to cultural practices such as low fertilizer use, removal of vegetative cover, and burning plant residues or the annual burning of vegetation on grazing land. In addition to soils developed from parent materials low in carbonate minerals, soil acidification takes place in areas where mean rainfall exceeds evapotranspiration [5]. The existence of high exchangeable acidity in a soil usually demonstrates the occurrence of exchangeable hydrogen, exchangeable aluminum as either Al^{3+} or partially neutralized Al-OH compounds such as $Al(OH)^{3+}$, and weak organic acid ions held at the colloidal surfaces of the soil [8]. The specific adsorption of organic anions on hydrous iron and Al surfaces and the corresponding release of hydroxyl ions could also increase the pH and available P in the soil solution. Similar to the western, southern, and central highlands of Ethiopia, severe soil acidity problem has been reported recently in the highland areas of Wolaita Zone, southern Ethiopia. However, the degree, extent, and causes of the problem had not been yet examined. The major agricultural constraints in Wolaita area are shortage of land for crop cultivation and livestock grazing, decline of soil fertility, rainfall variability, and pests and diseases. Nowadays, due to increasing population pressure and shortage of land, deforestation and cultivation activities are being carried out on steep slopes, which accelerate soil erosion. Indeed, there are limited efforts in the study area to tackle soil acidity through the use of lime although the scale of operation is not commensurate with the problem. Knowledge on the distribution, degree, extent, and causes of severe soil acidity in the Wolaita can assist policy makers, researchers, extension workers, and farmers to improve the fertility and productivity of the acid. Thus, this study was conducted to determine the physicochemical properties of different land use types and extents of soil acidity of the Wolaita Zone, southern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Sites. The study was conducted in Sodo Zuria, Damot Gale, Damot Sore, and Boloso Sore districts of Wolaita Zone, southern Ethiopia (Figure 1) during 2015. This zone is located at 385 km to south west from Addis Ababa, capital city of the country. These districts were purposely selected because they have high population, land shortage, over grazing, and high agriculture potential from the 12 districts in Wolaita Zone. The sites are located between 037°35′30″–037°58′36″E and 06°57′20″–07°04′31″N with altitudinal range of 500 to 2950 m above sea level. As per the recent nine years (2007–2015) climatic data, the mean annual rainfall is about 1355 mm (Figure 2). The mean average monthly temperature for the last nine years is 20°C [9].

2.2. Soil Sampling Design and Procedure. A randomized complete block research design used for collecting soil samples in the three representative land use types and four districts (Sodo Zuria, Damot Gale, Damot Sore, and Boloso Sore) with three replications of each at three peasant association, which are similar in their agro ecology, altitude, and slope, were selected. After the selection of the three peasant association, the land use types were systematically selected on the basis of contour line, similarity in soil color by visual observation, slope and altitude to reduce their natural difference, and soil type diversity impacts on the soil acidity. A total of 108 soil samples were collected in triplicates from the three land use types of both sites. Each composite soil sample was prepared from 15 subsamples taken by inserting an auger to a depth of 20 cm from randomly marked sampling points of each land use types at both sites.

2.3. Soil Sampling and Preparation. Soil samples were air-dried, ground, and passed through 2 mm sieve at the Soil Laboratory of the Hawassa Research Center. The physicochemical analyses of the soil samples were conducted at Regional Soil Laboratory following standard laboratory procedures. The bulk density determinations were done at Soil Laboratory in Wolaita Sodo University, College of Agriculture. Triplicate soil samples from each sites and land use types were collected.

2.4. Soil Laboratory Analysis. The collected composite soil samples were air-dried, ground, and sieved to pass through a 2 mm sieve except for soil organic carbon (OC) and total N (TN) analysis which were passed through 0.5 mm sieve. Soil particle size distribution was determined by hydrometer using Bouycous method [10]. Soil pH in water was determined with a digital pH meter at soil: water ratio of 1 : 2.5 [11]. The reserve acidity was measured in 0.1 M $CaCl_2$ using the same pH meter at the soil: 0.1 M $CaCl_2$ ratio of 1 : 2.5 [12]. The ΔpH was calculated by subtracting soil pH (KCl) from soil pH (H_2O). Bulk density was determined using the core sampling method [13]. Total porosity of the soil was calculated from the soil bulk and the particle densities; where 2.65 $g\cdot cm^3$ was used as a standard value for soil particle density; soil moisture content was measured by gravimetric method [11]. Organic carbon content of the soils was determined following the wet combustion method of Walkley and Black as outlined by Sahlemedhin and Taye [14]. Soil total nitrogen was analyzed by wet-oxidation procedure of the Kjeldahl method [15]. Available phosphorus was measured by following Bray II extraction using spectrophotometer [16]. Exchangeable Ca and Mg were measured from the extract with atomic absorption spectrophotometer (AAS), while exchangeable K and Na were determined by flame photometer. Exchangeable acidity was analyzed by [17]. Aluminum saturation percentage was calculated as the ratio of the exchangeable Al to CEC of the respective soil samples random powder method, and calcium carbonate content was determined by rapid titration method as described by Black [18]. Available Fe, Mn, Zn, and Cu were extracted by diethylene triamine pentaacitic acid (DTPA) method by using AAS [19].

2.5. Statistical Analysis. Mean comparisons using the least significant difference (LSD) test at probability of 5% level were done for the different land uses systems and correlation analysis has been done for the different soil properties and land uses systems using the SAS software [20], to see the relationship between parameters.

3. Results and Discussion

3.1. Effect of Land Use Types and Locations on Physical Fertility of Acid Soils. The textural analysis results revealed that 75% of all the land use types considered in this study were found to be clay loam (Table 1). However, sand, silt, and clay content in these soils were varied significantly ($P < 0.05$) among the land use types. According to Hazelton and Murphy [21], who rated all sand, silt, and clay contents of soils into high (>40%), moderate (25–40%), and low (10–25%), the sand contents high in soils of enset-coffee land

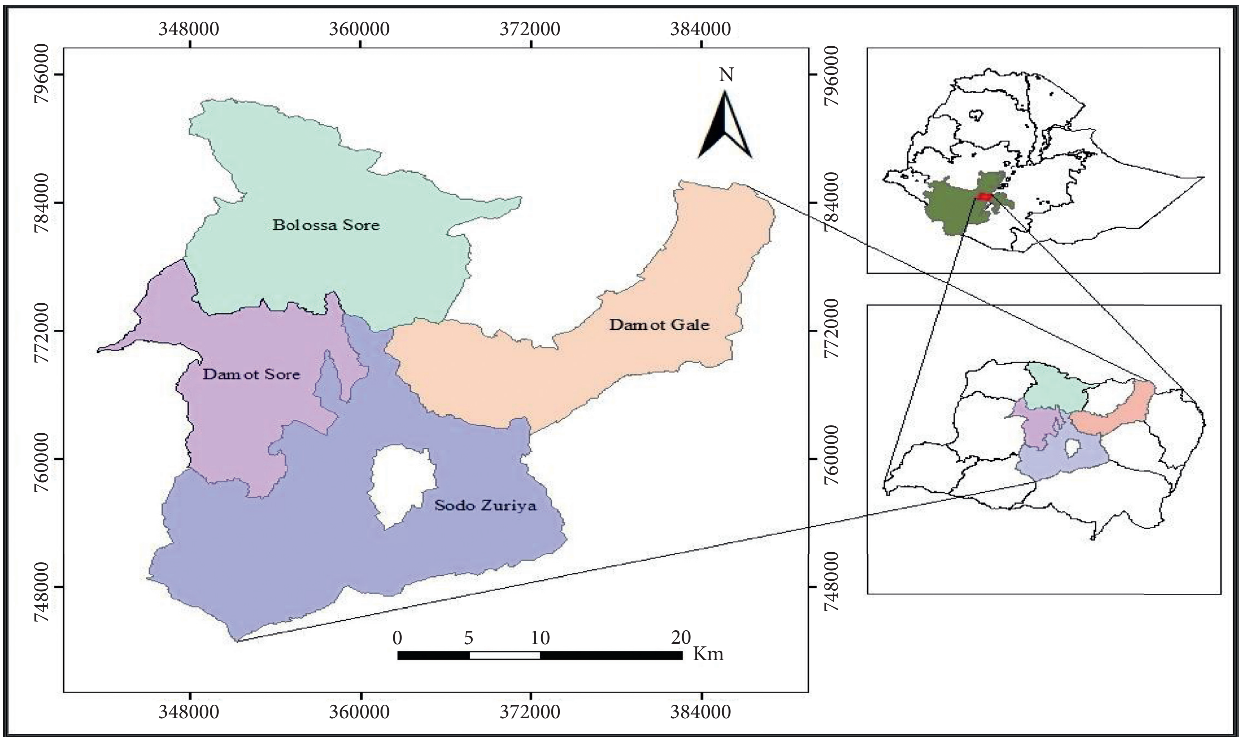

Figure 1: Location of the study sites, Wolaita districts, southern Ethiopia.

use of all locations and crop and grazing land uses were moderate (Table 1). The silt to clay ratio was 0.7, which is significantly lower than enset-coffee and crop land uses of Damot Gale district. Averaged over locations, values for Damot Sore crop land (0.8), grazing land (0.8), Sodo Zuria grazing land (0.9), Damot Gale grazing land (0.7), and Boloso Sore (0.8) grazing land uses showed similar trends due to the fact that the soils were might be of similar origin. It has been reported that silt/clay ratios less than unity indicate low values, signifying that the soils are pedogenically ferraltic in nature [22].

3.2. Soil Bulk Density and Total Porosity of Acid Soils. Bulk density value was not significantly ($P > 0.05$) affected by land uses and locations (Table 2). However, numerically the highest mean (1.39 g·cm^{-3}) value of bulk density was recorded on the Boloso Sore crop land and the lowest mean (0.98 g·cm^{-3}) value under Damot Gale enset-coffee land (Table 2), which might be resulted from compaction of soil due to intensive cultivation in all locations of the crop land. Soil bulk density was positively and significantly correlated with the silt and negatively ($r = -0.95$) with total porosity of the soil, respectively. This might be due to the reciprocal relationship between soil bulk density and total porosity, which shows the degree of soil compaction. Similar results were reported by Takele et al. [1]; Abad et al. [23] suggested that the bulk density of cultivated land was higher than that of adjacent grazing land.

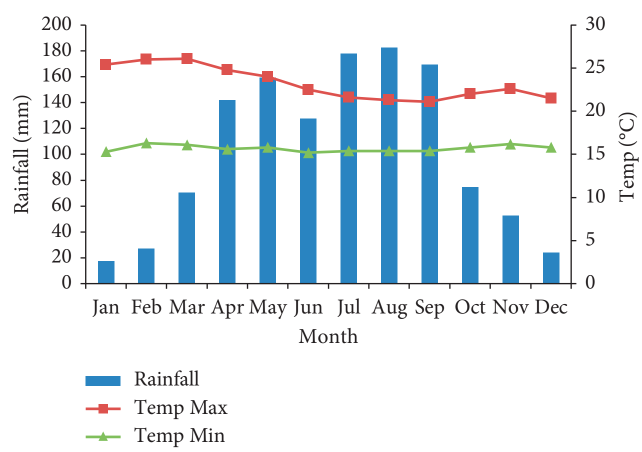

Figure 2: Nine years (2007–2015) mean monthly rainfall and mean maximum and minimum temperatures of the study areas [9].

3.3. Soil Moisture Content and Water Holding Capacity. Moisture content and WHC of the soils were significantly ($P \leq 0.05$) affected by land uses (Table 2). Considering the effects of land use, the highest (20.71%) in Damot Gale enset-coffee land and lowest (18.05%) crop land. Similarly, the highest moisture content was record (26.37%) and lowest was record from (21.43%) water holding capacity were recorded in the enset coffee and crop land, respectively. Similar results were reported by Mengistu et al. [24] that the water content at PWP was highest (19.71%) under the forest land and lowest in the grazing land (16.17%) and the cultivated land 16.56%.

Table 1: Mean values ($n = 108$) of particle size distribution and texture class of different locations and land use types of study areas.

Land use types	Sodo zuria: Particle size distribution Sand %	Clay %	Silt %	Silt/clay ratio	Texture class	Damot gale: Particle size distribution Sand %	Clay %	Silt %	Silt/clay ratio	Texture class
Enest-coffee	35a	33a	29a	1.0	Clay loam	22a	37a	25a	0.8	Sandy clay loam
Crop land	39b	29b	33b	1.1	Clay loam	40b	26b	50b	2.0	Clay loam
Grazing land	26c	38c	38c	0.9	Clay loam	38c	37a	25a	0.7	Clay loam
Mean	40	30	33	0.9		40	30	30	1.0	
CV (%)	12	12	11			10	13	10		
LSD $_{(0.05)}$	7	8	8			10	13	9		
	Damot sore					**Boloso sore**				
Enest-coffee	28a	24a	35	2.4	Silt loam	28a	39a	25a	1.3	Clay loam
Crop land	41b	39b	33	0.8	Clay loam	36b	26b	46b	1.8	Loam
Grazing land	31c	37c	32	0.8	Clay loam	36b	35c	29c	0.8	Clay loam
Mean	29	35	43	1.1		32	29	35	1.1	
CV (%)	10	13	10.1			8.6	7.8	9.4		
LSD $_{(0.05)}$	5	3	7			4	5	7		

CV = coefficient of variation, LSD = least significant difference.

Table 2: Mean valves of ($n = 108$) some selected physical properties of different locations and land use types of study areas.

Land use types	Sodo zuria: BD (g·cm^{-3})	TP (%)	MC (%)	WHC (%)	Damot gale: BD (g·cm^{-3})	TP (%)	MC (%)	WHC (%)
Enest-coffee	1.12a	59.02a	19.90a	24.95a	0.98a	64.36a	18.53a	22.78a
Crop land	1.33b	51.51b	18.14b	21.43b	1.16b	57.57b	18.05b	22.06a
Grazing land	1.28c	53.12c	19.95c	24.95c	1.20c	56.24c	20.59c	26.34b
Mean	1.24	54.55	19.33	23.78	1.11	59.39	19.09	23.72
CV (%)	12.05	10.03	7.83	10.47	8.58	5.86	8.63	10.07
LSD $_{(0.05)}$	0.15	5.47	1.51	2.49	0.09	3.46	1.64	2.38
	Damot sore				**Boloso sore**			
Enest-coffee	1.08a	59.38a	20.05a	26.15a	1.24a	54.73a	20.85a	26.37a
Crop land	1.18b	54.05b	19.70b	24.55b	1.39b	49.41b	18.52b	22.78b
Grazing land	1.14c	58.54c	20.71a	25.08b	1.35c	51.38c	18.44b	22.76b
Mean	1.13	57.32	20.71	25.26	1.33	51.84	19.27	23.97
CV (%)	4.89	2.47	2.31	2.86	8.85	7.75	6.64	7.86
LSD $_{(0.05)}$	0.05	1.41	0.46	0.72	0.11	4.01	1.27	1.88

BD = bulk density, TP = total porosity, MC = moisture content, and WHC = water holding capacity.

3.4. Effect of Land Use Types and Locations on Chemical Fertility of Acid Soils

3.4.1. Active and Exchangeable Acidity. The pH (H_2O, KCl and $CaCl_2$) values of the soils varied between 5.12 to 7.0, 4.21 to 6.31, and 4.3 to 6.50 in different locations with land use types, respectively. Based on the rating suggested by Hazelton and Murphy [21], the soils can be categorized as strongly acidic to neutral, very strongly acidic to slightly acidic, and extremely acidic to slightly acidic pH (H_2O, KCl and $CaCl_2$), respectively. It was lowest in soils of the Sodo Zuria grazing land use, and the highest soil pH value was also recorded in the Damot Gale enset-coffe land use compared to the crop and grazing land soils. Similarly, the lesser average soil pH in the crop and grazing lands is apparently due to the excessive removal of organic cations and associated cations by crop produce and over grazing, respectively, that they would not have a chance to return back and neutralizes the acid soil. In line with this, Mengistu et al. [24] pointed out that although acidity is naturally occurring, removal of plant residues carrying organic anions and excess cations from the farm or paddock is likely to accelerate soil acidification. The change in pH between [pH (H_2O) and pH (KCl, $CaCl_2$)] was greater than or equal to one across the soils sampling sites (Table 3). Soil pH (KCl) indicated the potential acidity and presence of weatherable minerals when the difference between pH (H_2O) and pH (KCl) is greater than unity [25]. Reserve acidity indication of the soil samples pH was found to range from 4.3 to 6.50 in different locations with land use types. The reserve acidity of soil was always higher than the active acidity. The difference between reserve and active acidity, ΔpH, of the studied soils was positive and found to range from 0.23 to 1.80 in different locations. This indicated that the studied of Damot Sore and Boloso Sore soil samples had considerable more reserve acidity in the soils. Tsehaye et al. [26] reported ΔpH values, which are to be in the range of 0.8 to 1.3 with a mean of 1.0. The reserve acidity values of the soils revealed that the reserve acidity

Table 3: Mean values of soil pH ($n = 108$) and change of soil pH across different locations and land use types of study areas.

	Sodo zuria					Damot gale				
Land use types	pH H_2O	pH KCl	pH $CaCl_2$	ΔpH KCl	ΔpH $CaCl_2$	pH H_2O	pH KCl	pH $CaCl_2$	ΔpH KCl	ΔpH $CaCl_2$
Enest-coffee	6.34a	5.85a	6.11a	0.49	0.23	7.01a	6.31a	6.50a	1.09	0.90
Crop land	5.30b	4.41b	4.71b	0.90	0.59	6.20b	4.80b	5.32b	1.40	0.90
Grazing	5.12c	4.37c	4.63c	0.75	0.75	6.10b	4.81b	5.10c	1.29	1.00
Mean	5.60	4.81	5.10	0.71	0.52	6.43	5.30	5.60	1.20	0.90
CV (%)	9.51	6.89	6.33	—	—	5.74	7.10	5.69	—	—
LSD $_{(0.05)}$	0.53	0.33	0.32	—	—	0.38	0.37	0.32	—	—
	Damot sore					Boloso sore				
Enest-coffee	6.70a	6.61a	5.72a	0.09	0.98	6.60a	5.30a	5.60a	1.30	1.00
Crop land	6.00b	5.80b	4.60b	0.20	1.40	6.00b	4.30b	4.70b	1.70	1.30
Grazing land	6.10b	5.72c	4.30c	0.38	1.80	5.60c	4.21b	4.61b	1.40	1.00
Mean	6.26	6.04	4.87	0.22	1.39	6.00	4.60	4.90	1.40	1.10
CV (%)	9.40	10.5	11.30	—	—	7.61	12.60	11.10	—	—
LSD $_{(0.05)}$	0.59	0.64	0.75	—	—	0.46	0.68	0.56		

value changes with different sites as well as with the land use types as observed for the case of active acidity.

3.5. Exchangeable Base. Average exchangeable Ca, Mg, K, and Na ions are presented in Table 4 which showed significant ($P \leq 0.01$) variation among difference locations within land use types. The exchangeable bases were low in both the soils of the crop and grazing land use types as compared to that of the enset-coffee land use. Hence, the low CEC and exchangeable cations in the crop land and grazing lands are clearly attributed to the presence of relatively low pH. The low-pH soil colloids are sites that adsorb hydroxy-aluminum and cease to function for cation exchange thereby could reduce the CEC of a soil. Exchangeable Ca was dominant in the exchange sites of the soil colloidal materials of the soil studied; this was followed by Mg, K, and Na ions in that order. However, Bore and Bedadi [27] reported that the highest and lowest exchangeable Ca were in the forest (25.4 Cmolc kg^{-1}) and grazing 15.2 Cmolc kg^{-1}) lands, respectively.

As per the ratings of FAO [28], the exchangeable Na in the soils of the sampling sites was low; the exchangeable Ca and Mg were medium to high in all sites which had high values while the exchangeable K was low except the enset-coffee land use in Sodo Zuria and Damot Gale sites which had high values, while the exchangeable K was low except the enset-coffee land use in Sodo Zuria and Damot Gale sites which had high values in contradiction with the generally held view that Ethiopia soils are rich in potassium [29]. The present studies are in line with Teshome et al. [30] who observed highest and lowest exchangeable Ca in forest and cultivated lands, respectively, in western Ethiopia of Ababo area.

Potassium to magnesium ratio of the studied soils varied from 0.05 : 1 to 0.26 : 1, which indicated Mg-induced K deficiency using the rating of Laekemariam [31]. This can be corrected by K application to bring the K to Mg ratio closer to one. If there is a high preferential K adsorption on the exchange sites of clay minerals, the amount of K desorbing may then decline, resulting in a reduced K uptake at low soil exchangeable K to Mg ratio. Therefore, attempts should be made to supply the plants with potassium in physiologically correct ratio and in a sustainable manner. Loide [32] suggested indicative K: Mg ratios of 0.7 : 1 and 1 : 1 for clay and loamy textured soils, respectively. In silt loam textured soils of Damot Gale, the K: Mg ratio varied from 0.2 to 1.6, while the ratio ranged between 0.1–1.5 in clay textured soils of Damot Sore and Sodo Zuria districts. Accordingly, to these, silt loam soils and clay soils had shown Mg induced K deficiency. Similar trends were obtained on K: Ca ratio in different land uses and sites.

The calcium to magnesium ratio across studied districts using the rating of Laekemariam [31] has shown the low level of Ca (1–4) on 35% and balanced (4–6) on 60% and low Mg (6–10) on 5% of the samples. These rates are lowest in Sodo Zuria crop land (1.99) and highest in Damot Sore crop land (3.55). This shows that soils under the land uses are of low fertility probably due to intense land use practice and excessive loss of Ca through leaching by the high tropical rainfall [33]. Addition of lime and organic manure can be used to supply Ca and improve soil fertility under the land use types [34].The observed order of cation in the exchange complex (Ca > Mg > K > Na) could also support the existence of Mg induced K deficiency (Table 5). Hence, K-containing fertilizer should be considered for soils of the study areas. It has been suggested that the proportions of the basic cations of the effective CEC are more relevant to plant performance than the actual levels [21]. According to Havlin et al. [35]; the range of critical values for optimum crop production for K, Ca, and Mg are from 0.28–0.51, 1.25–2.5, and 0.25–0.5 C mol·kg^{-1} soil, respectively. Accordingly, the exchangeable K, Ca, and Mg contents of the soils are above the critical values. However, this does not prove a balanced proportion of the exchangeable bases. Potassium uptake would be reduced as Ca and Mg are increased; conversely, uptake of these two cations would be reduced as the available supply of K is increased [35]. In addition, the ratio of exchangeable Ca: Mg should not exceed 10 : 1 to 15 : 1 to prevent Mg deficiency and also the recommended K: Mg is < 5/1 for field crops, < 3/1 for vegetables and sugar beets, and <2/1 for fruit and green house crops [35].

There was great variation in effective cation exchange capacity (ECEC) of the soils under the different land use

Table 4: Mean values ($n = 108$) of exchangeable base and percentage of base saturation in different location and land use types of study areas.

Land use types	Ex.Ca	Ex.Mg	Ex.K	Ex.Na	PBS	Ex.Ca	Ex.Mg	Ex.K	Ex.Na	PBS
	Sodo zuria					Damot gale				
		(C molc·kg^{-1})			(%)		(C molc·kg^{-1})			(%)
Enest-coffee	9.10a	4.50b	1.20a	0.34a	74.47a	11.44a	3.53a	0.75a	0.18a	85.02a
Crop lantd	8.76b	4.39a	0.24b	0.23b	70.80b	11.26b	3.22b	0.31b	0.14b	78.45b
Grazing	8.46c	4.10c	0.57c	0.34a	70.48a	11.08c	3.46c	0.68c	0.17a	80.25b
Mean	8.77	4.33	0.67	0.30	71.91	11.26	3.40	0.56	0.16	81.24
CV (%)	4.30	5.66	9.60	5.72	10.52	8.82	10.20	8.60	8.50	11.98
LSD (0.05)	0.47	0.35	0.20	0.15	0.56′	0.16	0.75	0.18	0.05	0.86
	Damot sore					Boloso sore				
Enest-coffee	11.40a	3.40a	0.37a	0.17a	72.35a	10.15a	3.85a	0.44a	0.33a	83.92a
Crop land	11.13b	3.13b	0.21b	0.16b	71.01a	10.43b	3.37b	0.26b	0.26b	81.36b
Grazing	9.93c	3.30c	0.29c	0.17a	70.20b	10.40b	3.84a	0.31a	0.31a	79.89c
Mean	7,95	3.27	0.29	0.16	71.21	10.32	3.68	0.33	0.30	81.72
CV (%)	4.94	5.36	8.80	7.40	10.67	4.33	8.03	6.36	7.60	12.34
LSD (0.05)	0.47	0.21	0.23	0.21	0.67	0.46	0.44	0.02	0.12	0.41

Table 5: Mean values ($n = 108$) of basic cation saturation ratio, K saturation percentage, and calcium carbonate in different locations and land use types.

Land use types	K : Mg	K : Ca	Ca : Mg	K-index %	$CaCo_3$ %	K : Mg	K : Ca	Ca : Mg	K-index %	$CaCo_3$ %
	Sodo zuria					Damot gale				
Enest-coffee	0.26a	0.13a	2.02a	0.06a	24.15a	0.21a	0.06a	3.24a	0.04a	23.70a
Crop land	0.05c	0.03b	1.99b	0.01b	23.92b	0.09c	0.03b	3.44b	0.02b	23.20b
Grazing	0.14b	0.07b	2.06a	0.03b	23.56b	0.19b	0.06a	3.25a	0.03b	22.70c
Mean	0.15	0,07	2.02	0.03	23.87	0.16	0.05	3.31	0.03	23.20
CV (%)	7.70	7.90	11.11	6.53	10.73	6.55	6.89	12.23	5.47	12.70
LSD (0.05)	0.02	0.04	0.13	0.04	1.56	0.21	0.02	0.14	0.01	1.95
	Damot sore					Boloso sore				
Enest-coffee	0.11a	0.03a	3.35a	0.02a	23.02a	0.11a	0.04a	2.63a	0.02a	23.17a
Crop land	0.07b	0.02b	3.5b	0.01b	22.64b	0.08b	0.02b	3.10b	0.01b	23.05b
Grazing	0.08b	0.03b	3.01b	0.01b	22.12b	0.08b	0.03b	2.70c	0.01a	21.10b
Mean	0.08	0.02	3.30	0.01	2259.	0.09	0.03	2.81	0.01	22.44
CV (%)	10.11	9.82	12.10	5.10	6.44	9.10	6.71	10.10	4.50	8.33
LSD (0.05)	0.01	0.06	0.25	0.01	1.38	0.10	0.02	0.32	0.01	1.87

systems (Table 6). The highest and lowest ECEC were recorded at Damot Gale enest coffee land and Sodo Zuria grass land, whilst the values (14.10 C molc·kg^{-1} and 15.02 C molc·kg^{-1}) were recorded in the crop land at Sodo Zuria and Boloso Sore respectively. In line with ECEC, the highest value of CEC (21.20 Cmolckg^{-1} was observed in Damot Sore enset-coffee land soil and the lowest (17.60) was recorded in Bolos Sore crop land, the CEC value was not consistent showing that there was no significance difference among different land use systems (Table 6). According to Mesfin et al. [36] in Wolaita soils showed that kaolinite is 29.8% for Damot Sore and 7.8% for Damot Pulasa Districts.

3.6. Organic Carbon, Total Nitrogen, Available Phosphorus, and Carbon to Nitrogen (C: N) Ratio. The data in Table 7 showed the OC, TN, and available P contents of the soils studied. According, to the rating suggested by Karltun et al. [37]; the soil OC content was low in range (1.30 to 1.71%). Moreover, the TN contents of all the soils studied were in the low ranges (0.13 to 0.19%). Hazelton and Murphy [21] classified soil organic carbon percentages of <1.0, 1.0–1.71, 1.72–3.0, 3.1–4.29, and >4.3 as very low, low, medium, high, and very high, respectively. The lowest amount of organic matter in the soil might be due to low addition of crop residue, and continuous cultivation and rapid oxidation of soil OM. In conformity to the present observation, complete removal of aboveground biomass [30, 38], intensive cultivation [39], insufficient application of organic inputs [38] and and Wolaita agricultural land [31].

The carbon to nitrogen (C: N) ratio of the soils also varied between 7.36 and 14.16. The carbon to nitrogen (C: N) ratios of the soils at Wolaita zone was significantly affected by soil land use types ($P \leq 0.05$) (Table 7). On the other hand, although slight numerical variation was observed among the location, C/N ratio was not significantly affected by locations. This indicates that the rate at which total N decreased with land use types was much higher than reduction in carbon. Therefore OM and TN content have direct relation to soil acidity. The present finding was in line with Yihenew and Getachew [40] who reported highest values of C: N contents under grazing land use in northwestern Ethiopian soils. Mesfin et al. [36] revealed that available P with both Olsen and Bray II extraction methods for Wolaita acidic soils

Table 6: Mean values ($n = 108$) of cation exchangeable capacity in different locations and land use types.

Land use types	Sodo zuria			Damot gale		
	ECEC	CEC soil (C molc·kg^{-1})	CECap	ECEC	CEC soil (C molc·kg^{-1})	CECap
Enest-coffee	15.56	20.33a	70.10	16.36	18.70a	93.50
Crop land	14.10	19.22b	66.27	15.36	18.80a	72.30
Grazing land	13.92	19.11b	50.28	16.07	19.40b	52.43
Mean	14.52	19.55	62.21	15.93	18.96	72.74
CV (%)		11.10			12.01	
LSD $_{(0.05)}$		1.56			2.09	
	Damot sore			Boloso sore		
Enest-coffee	15.72	21.20a	93.36	15.42	17.60a	67.69
Crop land	15.17	20.60b	52.82	15.02	17.60a	55.00
Grazing land	15.58	19.50b	52.70	15.35	18.60b	53.14
Mean	15.67	20.43	66.29	15.26	17.93	58.61
CV (%)		11.6			10.3	
LSD $_{(0.05)}$		1.79			1.85	

Table 7: Mean Values ($n = 108$) of organic carbon (OC), total nitrogen (TN), and available Phosphorus (Av.P) in different locations and land uses.

Land use types	Sodo zuria				Damot gale			
	TN (%)	Av.P (mg kg^{-1})	OC (%)	C : N	TN (mg kg^{-1})	Av.P (%)	OC	C : N
Enest-coffee	0.17a	18.70a	1.60a	9.41	0.14a	20.58a	1.70a	12.14
Crop land	0.16b	10.57b	1.50b	9.37	0.12b	11.74b	1.60b	13.33
Grazing	0.16b	12.00c	1.60c	10.00	0.12b	14.56c	1.70a	14.16
Mean	0.16	13.76	1.56		0.30	15.63	1.66	13.21
CV (%)	6.10	10.65	11.7		12.1	11.39	11.1	
LSD (0.05)	0.05	1.46	0.10		0.01	2.24	0.10	
	Damot sore				Boloso sore			
Enest-coffee	0.17a	17.72a	1.71a	10.05	0.19a	16.87a	1.41a	7.42
Crop land	0.13b	10.70b	1.40b	10.76	0.15b	7.44b	1.30b	8.66
Grazing	0.19c	13.87c	1.40b	7.36	0.16b	8.25b	1.51c	9.43
Mean	0.16	14.10	1.50	9.39	0.16	10.85	1.40	
CV (%)	5.70	11.88	8.55		8.63	11.59	8.62	
LSD (0.05)	0.05	2.23	0.14		0.04	2.34	0.14	

Table 8: Mean values of ($n = 108$) available micronutrients in different location with land use types.

Land use types	Sodo zuria				Damot gale			
	Fe	Cu (mg kg^{-1})	Zn	Mn	Fe	Cu (mg kg^{-1})	Zn	Mn
Enest-coffee	172.20a	6.33a	12.51a	143.67a	146.50a	3.62a	11.17a	142.40a
Crop land	182.20b	0.31b	12.77a	143.22b	157.70b	0.23b	11.84b	140.20a
Grazing	177.00c	6.15c	11.97b	136.39b	149.40c	0.80c	11.31b	137.80b
Mean	177.06	4.26	12.41	107.76	151.20	2.05	11.44	140.13
CV (%)	9.34	7.80	11.49	14.67	10.8	8.4	7.90	12.70
LSD (0.05)	1.64	3.32	0.42	0.47	7.10	1.88	0.40	0.78
	Damot sore				Boloso sore			
Enest-coffee	123.30a	2.86a	10.10a	132.50a	97.30a	3.93a	9.58a	116.50a
Crop land	129.40b	0.80b	10.70b	147.30b	101.70b	1.25b	8.98b	123.80b
Grazing	125.00c	2.50c	10.30c	139.00c	99.50c	2.20c	9.40a	122.60c
Mean	125.90	2.05	10.36	139.60	99.50	2.26	9.32	122.46
CV (%)	7.42	8.40	9.40	10.89	9.40	7.20	12.60	12.70
LSD (0.05)	1.30	1.74	0.48	0.52	4.30	1.89	0.17	0.68

were low. The lowest available P (7.44) was observed in strongly acidic soil (crop land of Boloso Sore District). This may be due to the P fixation with Fe and Al as indicated by the favorable acidic soil reactions indicated by the results of the present study.

3.7. Available Micronutrients. The contents of available micronutrients (Fe, Mn, Zn and Cu) were significantly ($P \leq 0.05$) affected by land use, location and their interaction of land use and location (Table 8).The range value of micronutrients for the entire districts in their order is indicated as follows Fe (97.30 to 182), Mn (116.50 to 147.30), Zn (8.98 to 12.77) and Cu (0.23 to 6.33 $mg{\cdot}kg^{-1}$) and considering the ratings proposed by FAO [28] across district had sufficient (Fe, Mn, Zn) and Cu low to optimal contents. The highest contents of Fe, Mn, Zn and Cu were recorded under the enset-coffee and grazing land uses of four sites (Table 8), while the lowest contents of Fe, Mn, Zn and Cu were observed under the crop lands of four sites. Likewise, EthioSIS [6] reported sufficient Mn levels in different soil types of Ethiopia including Vertisols. Znic deficiency is mostly not expected on acidic soil [41]. The results reported that Mehlich 3 extracts comparable amounts of micronutrients (Fe, Zn, and Mn) were the sufficiency for Wolaita soil [31].Generally, Cu content in all soil samples of study districts were found to be yield limiting nutrients, whereas Fe, Mn and Zn levels were sufficient for crop production. It was accounted to low level of soil OM. In line with this finding, the study in some Nitisols of Ethiopia indicated Cu deficiency [39].

4. Conclusions

The physical and chemical properties of soils in the study area vary from land use types and location. The enset coffe land system and grazing land were medium to higher in values, OC, total N and available P, CEC, exchangeable bases, and micronutrients content especially on the surface layer; this might be due to coarser texture of the soil, and the magnitudes of exchangeable Ca and Mg in land use types were rated as low to medium for Ca and medium to high for Mg. Although it is clayey in texture and relatively better in available P, crop land was lower in soil nutrients with lower pH which has become limiting for crop production in all locations. Therefore, it is suggested that besides physical and biology conservation practices, controlled grazing or cut and carry system and integrated soil fertility management techniques are recommended to improve productivity of acidic soils of the study area.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Mesfin Kassa, Fassil Kebede, and Wassie Haile contributed equally to this study.

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