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Research Article

Soil Physicochemical Properties Variation under Annual Crop and Coffee Landuse in the Chentale Watershed, Upper Blue Nile Basin, Ethiopia

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A detrimental decline in soil fertility has been attributed to losses in arable land productivity in Ethiopia. In this line, several studies were conducted to enable informed decisions; however, monitoring soil property dynamics in different biophysical, climatic, and cropping systems is yet to be adequate to support and influence decision and policymakers. To this end, this study evaluated soil physicochemical properties on land managed for annual crops and coffee land use in the Chentale watershed, the upper Blue Nile basin, Ethiopia. About 24 soil samples were collected from the two land uses and soil depths (topsoil: 0–15 cm and subsoil: 15–30 cm) with 6 replications for soil properties analysis. The result showed that most of the soil parameters varied significantly with land uses and were higher with coffee landuse ($p < 0.01$) than with cropland. Furthermore, a neutral pH range, clay loam texture, medium level of organic matter (3.93%) and nitrogen (0.18%), high level of available phosphorus (23.35 PPM), and high to very high level of exchangeable base were recorded from coffee landuse than from cropland. Whereas the mean values of organic matter (OM) and total nitrogen (TN) decreased significantly ($p < 0.05$) decreased in the subsoil. However, most of the physical and chemical properties of the soil did not vary significantly with depth. Moreover, low pH, low OM content, and low TN are the main properties of soil considered constraints of soil fertility in cropland at both depths. Therefore, it is recommended to maintain agroforestry practices, reduce the intensity of tilling, and supply organic materials to sustain the productivity of cropland.

1. Introduction

The rapid depletion of plant nutrients is one of the most prominent threats to food production in Africa [1]. Hence, soil erosion by water is the major challenge in Africa, which causes an estimated annual loss of cereal crops of about 2.67 million tons per hectare of croplands, which accounts $127 billion/year (at 2011 constant dollar) [2]. This is largely aggravated by land degradation associated with inappropriate land use [3]. Indeed, Ethiopia contributed about half of the estimated annual gross soil loss (4 billion tons per year) estimated for East Africa [4]. Therefore, approximately 23% of the country's land mass exhibits chronic degradation and therefore costs approximately $4.3 billion per year due to soil erosion resulting from inappropriate land use changes [5]. Typically, soil erosion not only removes soil particles but also washes important soil nutrients, further requiring the increased costs of replenishment and inorganic fertilization [6].

In recent studies conducted in Ethiopia, it has been well established that variations in soil physicochemical properties and fertility correspond to land use management practices [7–12]. For example, a higher concentration of organic carbon/matter in soil, total N, cation exchange capacity

(CEC), electrical conductivity (EC), pH, available P, and exchangeable K were recorded in Enset-based homegarden agroforestry than in croplands in central, south-central, and southeastern Ethiopia [9, 13–15]; lower bulk density and higher total porosity were revealed in grasslands than in bareland of northern Ethiopia [16]. Furthermore, the highest clay, pH, organic carbon, EC, total N, available P, CEC, and exchangeable cations were recorded in natural forests compared to cultivated land in the western and northwestern highlands of Ethiopia [7, 8, 11, 17]. Almost all of the studies mentioned above reported disparities in soil properties over varying levels of soil depth. These variations are commonly associated, among others, with soil disturbance levels, the availability of crop residues, the intensity of cultivation, the cropping system, and land management practices [11, 18].

The study area is part of the Blue Nile basin, situated in the hydrologically important regions of the Great Ethiopian Renaissance Dam (GERD). In the upper Blue Nile basin, the deterioration of agricultural productivity (i.e., soil fertility) remains a chronic threat to food security and environmental sustainability [19]. In this watershed, devastating gully erosion has expanded nearly double (from 1.84 to 3.43 ha) by consuming cultivated lands in less than a decade [20]. The authors also proved that gully erosion remains the main contributor to soil erosion in the watershed. In the nearby area, soil quality indicators revealed a 19.7% decline in the choke mountain agroecosystem [21]. In fact, soil fertility management and replenishment of nutrient losses need a long-term intervention plan, whereby interventions could have antagonistic short-term responses to soil fertility and crop yield [18]. Therefore, soil physicochemical evaluation should establish an inclusive intervention plan and maintain instantaneous responses.

Despite exhaustive studies conducted in different parts of the country, overwhelming levels of land degradation and increasing costs of production are still alarming for context-specific information and appropriate decisions [5, 22]. Indeed, agriculture is one of the oldest forms of subsistence in the Ethiopian highlands. The overwhelming deterioration of croplands demands counter-interventions. Therefore, evaluating the soil nutrient status of locally practiced land uses is pertinent to supporting sustainable land uses. Further, all investigations in varying biophysical and climatic contexts will eventually be an input to devising a sound land use policy, which is lacking in Ethiopia. Therefore, this study was conducted to evaluate the effect of agricultural land managed with annual crops (cultivated land) and perennial coffee-based agroforestry (coffee landuse) on soil physicochemical properties in the Chentale watershed, the upper Blue Nile basin, Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area. The study was carried out in the Chentale watershed, located in the Bure district of the West Gojam Zone in the Amhara National and Regional State of Northwestern Ethiopia. Hydrologically, the Chentale watershed is located in the upper Blue Nile basin. The watershed is approximately located between 10°19′41″ to 10°58′38″ north latitude and 37°1′31″ to 37°18′27″ east longitude (Figure 1). Elevations gradually increase from 2,232 m above sea level at the outlet of the watershed to 2637 m above sea level at the mountain peaks. The area has a consistent gradient, with 90% of the area having a slope less than 5% and the rest extending up to 10% at the upper part of the watershed (Bure District Office of Agriculture, 2017; unpublished).

According to the Ethiopian traditional climate classification system [23], the Woina Dega (temperate) agroclimatic system characterizes the study area that receives a unimodal rainfall pattern with a long rainy season (*Kiremt* extends from June to September) where most agricultural activities are carried out. The mean annual rainfall in the area ranges from 1400 mm to 1700 mm, and the average monthly temperature ranges from 18°C to 225°C [20].

Most soils in the study area are Vertisol. Approximately 90% of the area is covered by cropland and Eucalyptus-dominated vegetation and scattered indigenous trees are common in the area. The main livelihood source of the study area is predominantly subsistence agriculture based on a mixed crop-livestock production system. Therefore, intensive and continuous cultivation and overgrazing are the usual farming practices in the area. Cereal crop production is the dominant livelihood strategy of all members of the farming community in the watershed, and coffee is the main perennial crop in the study area. Many farmers have been using traditional, rain-fed, subsistence-oriented farming systems. The main production constraints identified among many are the shortage of agricultural land (cultivable and grazing) and the deterioration of soil fertility and productivity from year to year (Bure District Office of Agriculture, 2017; unpublished).

2.2. Study Design, Soil Sampling, Sample Preparation, and Analysis. The general view of landscape heterogeneity was captured through a preliminary survey, and then representative sample sites were selected based on vegetation cover, cultivated land use, history, and management practice. Subsequently, two representative fields were selected, that is, cultivated land with annual crops (hereafter called cropland) and a coffee-based perennial cropping site (coffee landuse) (Table 1). According to local farmers, annual crop production has a long history, while the use of coffee land has been planted in recent years.

A 20 × 20 m rectangular sampling plots [7] were laid on similar topographic attributes on the two land uses. Disturbed composite soil samples were collected in plots from two land uses and two depths (topsoil: 0–15 and subsoil: 15–30 cm) with six (6) replications using the Auger sampler (a total of 24 samples = 2 land use × 2 depth × 6 replications). Separate undisturbed soil samples were taken simultaneously at each land use and depth using the core sampler. In doing so, dead plants, gravels, burrows, old manures, wet spots, areas near trees, etc. were excluded during sampling.

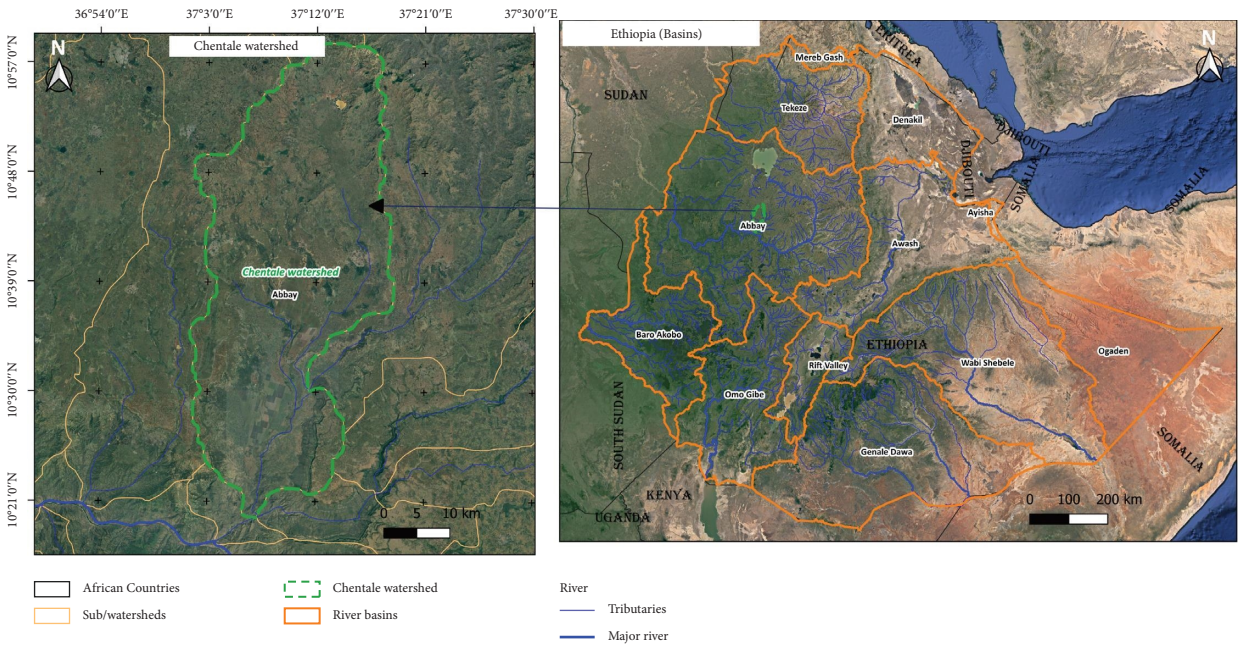

Figure 1: Location map of the study area.

Table 1: Description of the types of land use studied in the Chentale watershed.

Land use	Description
Coffee landuse	(i) The coffee landuse consists of fruit crops (avocado), evergreen *C. africana,* and *Croton macrostachyus* trees (ii) It receives crop residues in October and November, is dug once a year using hand hoeing in the same months for residue application, and is irrigated 4 to 6 times a year
Cropland	(i) The cropland is cultivated annually for wheat and/or teff crop. The cropland is traditionally (by "Maresha" powered by oxen force) tilled 7–10 times a year, from February to July to a depth of 20 cm, with harrowing ridge tillage and seeding by hand (ii) In this practice of rain-fed cultivation, mineral fertilizers (urea and DAP) and pesticides are applied while sowing grains (iii) Crop residues are buried in the soil during plowing and straws are burned in situ, used as fuel or as livestock forage (iv) Due to the limited shortage of farmland, fallowing is rarely practiced

Alongside the field, the composite soil samples were mixed, labeled, and packed in a polyethylene bag, registered, and transported to the Bahir Dar Soil Testing Laboratory of the Amhara National Regional State.

All soil samples were handled and prepared for physicochemical analysis according to standard operating procedures [24]. Standard laboratory procedures were followed in the analysis of the physicochemical properties considered in this study.

2.2.1. Analysis of Soil Physical Properties. The soil texture (particle size distribution) was determined by the hydrometer method [25]. Soil moisture was determined using the gravimetric method [26], and soil textural classes were determined following the textural triangle of the USDA system [27]. The percentage moisture content was then calculated on an oven-dry basis using the following formula [28]:

$$\text{Percentage Soil Moistur} = \frac{\text{Weight of moist soil} - \text{Weight of oven dried soil}}{\text{Wt. of oven dried soil}} \times 100. \quad (1)$$

The bulk density and porosity of the soil was determined using the core method prescribed for undisturbed soils [29]. Consequently, the total porosity was estimated using the formula:

$$\text{Total Porosity (\%)} = 100 - \frac{\text{Soil bulk density}}{\text{Particle density}} \times 100. \quad (2)$$

2.2.2. Analysis of Soil Chemical Properties. The pH of the soil was measured potentiometrically measured using the pH meter [30]. Soil organic carbon (OC) and the percentage of soil organic matter (OM) were determined using the Walkley-Black wet oxidation method [31]. Total nitrogen was determined using the micro-Kjeldahl digestion, distillation and titration method [32]. The available phosphorus was determined using the standard Olsen extraction method [33]. Electrical conductivity was measured using a soil/water suspension and an EC meter [34]. The total exchangeable bases were determined after leaching the soils with ammonium acetate while the extractable micronutrients (Fe, Cu, Zn, and Mn) were extracted with diethylene triamine penta acetic acid (DTPA); then the amounts of all of these micronutrients were measured using an atomic absorption spectrophotometer at their respective wavelengths [35].

2.3. Statistical Analysis. Statistical Analysis System software (SAS® 9.4) was used to organize and analyze the data. In fact, descriptive statistics and bidirectional analysis of variance (ANOVA) were used to compare soil parameters between land use and soil depth. Means of significance levels were compared using the least significant difference (LSD) at $p < 0.05$ level. The reporting standard cheklist of the study is in supplemental file. (available here).

3. Results and Discussions

3.1. Soil Physical Properties under Land Uses and Soil Depth

3.1.1. Soil Texture. The three soil particle distributions were significantly ($P < 0.01$) affected by land use and the interaction of land use with soil depth, but not by soil depth (Tables 2 and 3). The coffee landuse indicated significantly higher sand (34%) and silt (31%) content than cropland. While the clay fraction was significantly higher in cropland (61.3%) and the least in coffee landuse (35%) (Table 4). Similarly, higher sand content was reported in Enset-based agroforestry than cropland in southern Ethiopia [9, 10]. Farming practices, such as continuous tillage or long periods of intensive cultivation, may indirectly contribute to the changes. A similar report shows that continuous tillage and intensive land use affect the distribution of particle size and are related to cultivation time [8, 17]. The higher clay fraction in cropland soil than in other types of land use could be due to the fact that cultivation promotes further weathering processes, as it shears and pulverizes the soil and changes the moisture and temperature regimes [36].

The texture of the soil did not show a significant difference ($p > 0.05$) between the two layers of the soil (Tables 2 and 3). But there were slight mean variations between the surface and subsoil layers. Consequently, the clay content showed an increase with increasing depth, while the sand and silt content showed a decrease with increasing depth in both land uses. This indicates that clay fractions are likely to be lost through selective erosion and migration processes along the soil profile, which ultimately increase the proportion of sand and silt contents in the surface layers [37].

According to the USDA soil texture classification system, two soil textural classes were observed in the study area. The soils of cropland have a clay textural class, while the soils of coffee landuse have clay loam (Table 2). Over a very long period of time, pedogenesis processes such as erosion, deposition, eluviation, and weathering can change the soil texture [38]. Another study reported that a high clay content is an indication of a complete alteration of weatherable minerals into secondary clays and oxides [39].

3.1.2. Moisture Content. The soil moisture content (MC %) was significantly affected by the depth of the soil and its interaction with land use ($P < 0.05$), whereas there was no significant variation between land uses. The relatively lower MC value in the surface layer of coffee landuse might be due to a relatively lower clay content than the subsoil, and the topsoil might also be affected by evapotranspiration more than the subsoil. In fact, a higher clay content revealed a higher moisture content in cropland, while the moisture content did not show variation with the Enset-based system [10]. On the other hand, the moisture of the surface layer soil is usually greatly influenced by rainfall infiltration or evapotranspiration and is a regular water source for crop growth, while the moisture in the subtopsoil layer functions as a soil reservoir [40].

3.1.3. Bulk Density (BD). BD was significantly ($P < 0.01$) affected by land use and the interaction of land use with soil depth, but not by soil depth (Tables 2 and 3). Indeed, the mean values of BD cropland (1.21 g/cm^3) and topsoil (1.06 g/cm^3) were higher than coffee landuse (1.01 g/cm^3) and subsoil (1.09 g/cm^3), respectively (Table 2). The reason for the low BD in coffee landuse could be due to a higher organic matter (OM) content and less disturbance of the soil, and the reverse is true for intensively cultivated land. Similarly, variation in BD has been reported to be attributed to variation in soil OM, soil texture, and intensity of cultivation [7, 11, 41].

The depth of the soil did not significantly affect the value of BD. However, numerically, the BD was higher and lower in the subsoil and topsoil, respectively. The increase in the bulk density of the subsoil could be attributed to the effect of weight excreted by the overlying soil, the increase in clay content, and the corresponding decrease in the content of organic matter in the soil with increasing depths. Similarly, studies reported that lower BD in the topsoil is due to higher OM and higher biotic activities that make soils loose, porous, and well aggregated [7, 10]. According to the rating suggested for BD [42], soils on cropland (1.21 g/cm^3) and coffee landuse (1.01 g/cm^3) were rated as moderate and low, respectively.

3.1.4. Total Porosity. Coffee landuse (62%) and top soil (60%) show a higher mean value of TP than cropland (55%) and subsoil (59%) (Table 2). Like BD, TPs were significantly

Table 2: Effects of land use and soil depth on physical properties of soils in the Chentale watershed.

Treatments	Sand (%)	Silt (%)	Clay (%)	MC (%)	BD (g/cm^3)	TP (%)
Type land use						
CL	17^a	20.3^a	62.7^a	22.3^a	1.2^a	55^a
Coffee	34^b	31^b	35^b	21.73^a	1.01^b	62^b
Soil depth						
0–15 cm	26.2^a	26.5^a	47.3^a	20.1^a	1.06^a	60a
15–30 cm	25^a	24.6^a	50.4^a	23.8^b	1.09^a	59a
CV (%)	16.2	9.8	9.2	5.5	6.8	6.3

CL: cropland; MC (%): moisture content; BD (g/cm^3): bulk density; TP (%): total porosity; figures followed by the same letter figures followed by the same letter within a column for a given treatment and variable are not significantly different from each other at $P \leq 0.05$; CV: coefficient of variation.

Table 3: Mean square (MS) and results of a two-way ANOVA of soil physical properties under two land use and two soil depths in Chentale watershed.

Soil properties	Land use			Depth			Interaction		
	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
Sand (%)	1717.04	100.29	<0.0001**	9.37	0.55	0.47	863	50.42	<0.0001
Silt (%)	704.17	130.3	<0.0001**	20.16	3.73	0.067	362.2	67	<0.0001
Clay (%)	4620.37	223.98	<0.0001**	57.04	2.77	0.111	2338.71	113.37	<0.0001
BD (gcm^{-3})	0.122	22.03	0.0001**	0.0057	1.03	0.3213	0.0637	11.53	0.0004
TP (%)	232.71	16.47	0.0006**	0.596	0.04	0.839	116.65	8.27	0.0023
MC (%)	1.65	1.1	0.306	81.03	53.95	<0.0001	41.34	27.53	<0.0001

*Significant at $P \leq 0.05$; **significant at $P \leq 0.01$; *P*: probability.

Table 4: Effects of land use and soil depth on some soil chemical properties in Chentale watershed.

Treatments	pH	EC (dS/m)	OM (%)	N (%)	C : N	Av.P (ppm)
Land use						
CL	5.65^a	0.015^a	2.27^a	0.11^a	12.37^a	8.12^a
Coffee	7^b	0.05^b	3.9^b	0.19^b	11.7^a	23.2^b
Depth						
0–15 cm	6.32^a	0.03^a	3.3^a	0.16^a	11.025^a	16.4^a
15–30 cm	6.3^a	0.03^a	2.8^b	0.13^b	13.1^a	14.9^b
CV (%)	4.2	14.6	7.4	18.9	17.5	4.4

CL: cropland; pH: power of hydrogen; EC: electrical conductivity; OM: organic matter; TN = total nitrogen; C : N: carbon to nitrogen ratio; Av.P: available phosphorous; figures followed by the same letter in a column for a given treatment and variable are not significantly different from each other at $P \leq 0.05$; CV: coefficient of variation.

($P \leq 0.01$) affected by land use, whereas the effect of soil depth was not significant (Tables 2 and 3). The higher TP in coffee landuse could be due to its higher OM content, lower BD, and intensive cultivation and compaction on cropland [7, 10, 17]. According to the rating of total porosity [43], the percent TP of both land uses in each depth was very high (>40%). The high total porosity observed in the study area implies better aggregation and indicates better soil conditions for crop production.

3.2. Soil Chemical Properties among Land Use and Soil Depth

3.2.1. Soil Reaction (pH). Table 4 shows that the mean pH values of the cropland (5.65) were significantly lower than those of the coffee landuse. Additionally, it was significantly varied between the two land uses ($p < 0.01$) but not with respect to its interaction with depth (Tables 4 and 5). The variation is justifiable where the lowest pH value in cropland may be due to continuous removal of basic cations by crop harvest, intensive cultivation that enhanced the leaching of basic cations, application of inorganic fertilizers, and increased microbial oxidation of the substrate that produces organic acids, which provide H ions to the soil solution and thereby lower soil pH [44, 45]. These are also depicted in the Enset-based agroforestry system in the central and southern highlands of Ethiopia [9, 10].

In general, as the rating suggested for pH [46], it falls in the neutral range for coffee landuse and the moderately acid range for cropland. The availability of various nutrients for crops (teff, wheat, etc.) may be reduced due to the low soil pH observed in croplands.

3.2.2. Electrical Conductivity (EC). The EC content varied from 0.011 to 0.025 dS/m with a mean value of 0.014 dS/m in cropland and from 0.016 to 0.094 dS/m with a mean value of 0.049 dS/m for coffee landuse (Table 4). The EC of the soil was significantly ($P < 0.05$) affected by the land use and the interaction with the depth of the soil, but not by the depth of the

Table 5: Mean square (MS) and results of a two-way ANOVA of soil chemical properties under two land use and two soil depths in Chentale watershed.

Soil properties	Land use			Depth			Interaction		
	MS	*F*	*P*	MS	*F*	*P*	MS	*F*	*P*
PH	5.1	62.9	0.0001**	0.000033	0	0.98	0.0021	0.003	0.8
OC (%)	3.45	18.89	0.0025**	1.056	5.77	0.043*	0.112	0.61	0.456
OM (%)	10.22	18.73	0.0025**	3.15	5.77	0.043*	0.34	0.61	0.456
TN (%)	0.031	12.83	0.0072**	0.002	8.97	0.0172*	0.000075	0.03	0.86
C/N Ratio	4.5	0.98	0.35	15.2	3.26	0.1	0.78	0.17	0.69
EC (dS/m)	0.0069	331.77	<0.0001	0.000022	1.06	0.315	0.00346	166.42	<0.0001
Av.P (ppm)	675.8	28.36	0.0007**	50.8	2.13	0.18	54.8	1446.7	<0.0001
Ca (Cmol (+)/kg)	43.28	7.03	0.0149	1.321	0.21	0.6479	22.30	3.62	0.0445
Mg (Cmol (+)/kg)	0.534	309.65	<0.0001	0.5340	0.09	0.771	0.267	154.87	<0.0001
Ca/Mg ratio	1.7	0.88	0.37	0.0008	0	0.98	1.44	0.74	0.41
Na (Cmol (+)/kg)	0.6868	88.83	<0.0001	0.0066	0.86	0.3637	0.346	44.85	<0.0001
K (Cmol (+)/kg)	43.98	1552.82	<0.0001	0.246	8.69	0.0077	22.11	780.75	<0.0001
PBS	616.9	7.66	0.0244**	30.8	0.38	0.55	236.2	2.93	0.13
CEC (Cmol (+)/kg)	88.935	5.40	0.0303	0.015	0.00	0.9762	44.47	2.70	0.0905

*, **Significant at $p < 0.05$ and $p < 0.01$, respectively; *P*: probability.

soil (Table 5). Consistent with this finding, the higher EC under undisturbed soil (land use) is due to the accumulation of OM and more ion [7]. According to the tropical soil manual [47], the EC of both land uses falls under the no-saline condition (low EC <2 dS/m) condition. Generally, the EC values recorded for soils of different land uses in different soil layers are not in the range that could cause harm to the growth of sensitive plants.

3.2.3. Organic Matter (OM). The OM matter content was significantly ($P < 0.01$) affected by land use and soil depth (P 0.05), where the mean values of coffee landuse (3.93%) and topsoil (3.3%) are higher than cropland (2.27%) and subsoil (2.8%) (Tables 4 and 5). However, the interaction of land use with soil depth did not show significant variation (Table 5). The most probable source of variations between land uses for soil OM content could be variations in the intensity of cultivation, cropping systems, and soil management practices. The highest OM content of the soil in coffee landuse may be due to the dense canopy cover, less disturbance of the soil, and lower OM decomposition rates due to the lower soil temperature due to mulching and shading. On cropland, this can be justified due to higher rates of decomposition and the complete removal of crop biomass from the field. Similarly, studies in the central and southern highlands reported that organic carbon percentages in Enset-based agroforestry were more than double that of croplands [9, 10].

On the other hand, the mean value of OM decreased by 33.6% with soil depths from the surface to the subsoil layers. The relatively higher OM content in the topsoil could be attributed to the presence of remnant biomass, while its decrease with the depth of the profile could be due to decreasing root biomass due to the farming system, which is dominated by shallow-rooted cereals (the plow layer is limited to 15–20 cm). These results of OM are consistent with those found in several studies (e.g., [7, 9, 10, 45, 48]).

According to the rating given for OM by [49], the overall mean of OM in cropland (2.26%) falls in the low range, and the mean of OM in coffee landuse (3.93%) qualifies for the medium range. Furthermore, the results indicate that the fertility status of the soils in the cropland shows depletion and calls for rehabilitation interventions.

3.2.4. Total Nitrogen (TN). The soil TN content was significantly ($P < 0.01$) affected by land use and soil depth ($P < 0.05$), while its interaction was not significant (Tables 4 and 5). Furthermore, the mean value of soil TN in the topsoil (1.7%) was higher than in the subsoil (1.3%) (Table 4). This may be attributed to the rapid mineralization of the soil OM after continuous cultivation and increased aeration. The reduction of the input of plant residues into the soils of these cropland has also contributed to the depletion of soil OM [10]. Similarly, a report shows that less biomass return results in less soil total nitrogen content cultivated land [50]. Another study noted that crop residues on croplands were continuously removed from the field to use as a source of fuel, livestock feed, and income generation [51]. Furthermore, more tillage and no addition of fertilizer that replaces the removed TN by continuous tillage are the main reasons for decreasing N content in cropland [52].

Additionally, as with OM, mean TN values decreased significantly with soil depth for both land uses (Tables 4 and 5). The higher total soil nitrogen content in the topsoil layer could probably be due to the relatively better return of biomass and crop residues and the higher OM content of the topsoil. Studies also reported that TN was higher in the top soil than in the subsoil, probably due to OM losses caused by mineralization in the subsoil [53, 54]. Higher TN and exchangeable bases in the upper soils could partially illustrate the contribution of shading and soil cover to reducing leaching and improving the nutrient retention capacity of coffee soils [55]. Based on the nitrogen rating [42], it was low and medium in cropland and coffee landuse, respectively.

3.2.5. Carbon to Nitrogen Ratio (C : N). The C : N was not significantly ($P < 0.05$) affected by land use, soil depth, or its interaction (Tables 4 and 5). However, it was numerically

higher in cropland (12.7 : 1) than in coffee landuse (11.7 : 1). The variation in C : N values between land uses could be due to variations in the intensity of cultivation, the quality of organic material present in the soil, and associated management practices. Likewise, the intensity of cultivation results in a reduction in OM and TN and an increase in the soil C : N ratio [56]. Changes in land use type and intensity of cultivation have been reported to have a more pronounced effect on soil N than organic C, resulting in a higher C : N ratio [57].

Generally, a report shows that soils with C : N ratios in the range of 10–12 provide more nitrogen more than microbial needs [38]. Therefore, the results obtained for both land uses showed the optimal range for active microbial activities in the mineralization of organic residues. The overall mean values in the topsoil and subsoil soils fall into the medium range (Tables 4 and 5). According to the rating suggested for C : N [47], the overall status of the C : N ratio in cropland and coffee land landuse is medium.

3.2.6. Available Phosphorous (AP). The mean value of available phosphorus in coffee landuse exceeds 2.9 times the mean value of croplands (Table 4). Consequently, AP showed a significant variation ($p < 0.01$) between land use and soil depth, except for their interaction (Tables 4 and 5).

The disparity in AP may be due to the higher content of OM and the lower content of clay particles in the coffee landuse, while the removal of crop residues, thus the lower content of the OM content, and traditional intensive tillage practices could have contributed to the lower level of available P in cropland. It is obvious that intensive tillage increases the oxidation of organic carbon, leading to the depletion of OM and AP. Existing reports also in line with this finding [7, 10, 58, 59]. On the other hand, the decrease in AP in most soils in Ethiopia is due to the impacts of fixation and abundant crop harvests [60]. Similarly, in this study, it was observed that AP was positively correlated with OM ($r = 0.86^{**}$) (Table 6).

Taking into account the depth of the soil, the mean value of AP in the topsoil exceeds 16% in the subsoil. This may be due to the reduced level of adsorption or the lower rate of fixation of AP as a result of the lower content of clay particles. Indeed, this finding was consistent with some of the earlier studies [61–64]. According to the suggested rating [47], AP was medium on cropland and higher in coffee landuse. The overall mean AP in the soil of the cropland was below the requirements for moderately demanding crops and high-demanding crops [65].

3.2.7. Exchangeable Bases (K, Na, Ca, and Mg). Table 5 shows that all exchangeable basic cations varied significantly ($P < 0.01$) for K, Mg, and Na and P (<0.05) for Ca among land use, but were not significantly ($P > 0.05$) affected by depth, except Na and the interaction of land use with soil depth. Furthermore, the mean value can be sorted as Ca > Mg > Na > K for cropland and Ca > K > Mg > Na for coffee land use (Table 7). Specifically, the mean value of Ca exceeds 9.2 and 6.8 times those of Mg and K in cropland and coffee landuse, respectively. Consequently, the cropland had significantly lower mean exchangeable Ca, exchangeable Mg, exchangeable K, and exchangeable Na than the coffee landuse (Tables 5 and 7). The decrease in the exchangeable basic cations content of soil in cropland could be due to the lower/removal of OM, the highest intensity of cultivation, leaching, soil erosion, and poorer soil management practices than coffee landuse. This is consistent with [7, 48, 66, 67].

The mean values of Ca, Mg, Na, and K in the topsoil differ by approximately 0.19, −0.15, and −0.01 (Cmol (+)/kg) from the subsoil, respectively. Except for Na, exchangeable basic cations did not vary significantly along soil depth ($P > 0.05$) (Table 7). Significantly higher exchangeable Na was recorded in subsoil than in topsoil, which shows an increase from topsoil (0.6 Cmol (+)/kg) to subsoil (0.67 Cmol (+)/kg) (Table 7). This may be due to leaching of the cation (Na) into the lower soil layers. Consistently, a report shows that an increase in the concentration of basic cations with depth may suggest the existence of a downward movement of these exchangeable constituents, including exchangeable Na within the profile [7, 68].

Based on the rating of exchangeable basic cations set by FAO [43], the Ca, Mg, Na, and K values in croplands were rated as high, medium, medium and medium, respectively, and very high, medium, high, and very high, respectively, in coffee landuse. From the soil fertility point of view, exchangeable Ca, Mg, Na, and K in both land uses were in the range of medium to very high. This indicates that the soils of the study area are not deficient in exchangeable basic cations.

Furthermore, the amount of each exchangeable basic cation, their proportion, and their interaction have an effect on crop cation uptake. The Ca to Mg ratio of the studied soils was 8.89 : 1 and 9.1 : 1 in cropland and coffee landuse, respectively (Table 7). It has been noted that antagonistic effects exist when there are unbalanced amounts of exchangeable basic cations present in the soil. For example, K 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 [69]. According to the same author, the recommended ratio of K : Mg is <5 : 1 for field crops, while it should not exceed 10 : 1–15 : 1 to prevent Mg deficiency [69]. Indeed, the Ca: The Mg ratio of the soils studied falls in this range.

3.2.8. Cation Exchange Capacity (CEC) and Percent Base Saturation (PBS). The highest mean value of CEC was recorded from coffee landuse (37.2 Cmol (+)/kg) and subsoil (35.45 Cmol (+)/kg) (Table 7). The CEC varied significantly ($P < 0.01$) with land use but was not affected by depth or the interaction of the main factors ($P > 0.05$) (Tables 5 and 7). Variation in CEC values may be due to variations in OM and soil management practices, as intensive cultivation and low OM content have been found to reduce CEC on croplands compared to undisturbed land in general [7–9]. Based on the CEC rating [42], the soils of the two land uses are qualified for a higher range.

The PBS of the soils in the study area showed significant differences ($p < 0.01$) between the types of land use but did not show a significant difference in response to depth or

Table 6: Pearson's correlation matrix for various soil physicochemical parameters.

	BD	TP	Clay	MC	PH	EC	Av.P	OM	Ca	Mg	K	Na	CEC	TN
BD	1													
TP	−0.9**	1												
Clay	0.85**	−0.85**	1											
MC	0.07 ns	−0.07 ns	0.16 ns	1										
PH	−0.77**	0.77**	−0.89**	−0.32 ns	1									
EC	−0.64**	0.64**	−0.62*	−0.1 ns	0.72**	1								
Av.P	−0.72**	0.72**	−0.72**	−0.42 ns	0.87**	−0.44 ns	1							
OM	−0.77**	0.77**	−0.75**	−0.47 ns	0.84**	0.57 ns	0.86**	1						
Ca	−0.22 ns	0.22 ns	−0.45 ns	−0.31 ns	0.53 ns	0.48 ns	0.58*	0.45 ns	1					
Mg	−0.66*	0.66*	−0.8**	−0.18 ns	0.92**	0.7*	−0.8**	0.72**	0.68*	1				
K	−0.75**	0.75**	−0.84**	−0.24 ns	0.97**	0.69*	0.85**	0.81*	0.58*	0.97**	1			
Na	0.66 ns	−0.52 ns	0.68*	−0.13 ns	0.86**	0.73**	−0.6*	0.57 ns	0.52 ns	0.88**	0.9**	1		
CEC	−0.65*	0.65*	0.61*	0.13 ns	0.69*	0.91**	0.53 ns	0.46*	0.45*	0.69*	0.7*	0.78**	1	
TN	−0.66*	0.66*	−0.71**	0.55 ns	0.74**	0.27 ns	0.78**	0.91**	0.4 ns	0.63*	0.72**	0.41 ns	0.15 ns	1

*Significant at $P < 0.05$, **highly significant at $P < 0.01$, ns: nonsignificant at $p > 0.05$.

Table 7: Effects of land use and soil depth on exchangeable basic cations; and CEC, Ca : Mg ratio and PBS of soils in the study area.

Treatment	Ca	Mg	K	Na	Ca : Mg	CEC	PBS (%)
Land use							
CL	19.3[a]	2.1[a]	0.37[a]	0.48[a]	8.89[a]	33.3[a]	66.6[a]
Coffee	22[b]	2.39[b]	3.07[b]	0.82[b]	9.1[a]	37.2[b]	77.2[b]
Soil depth							
0–15 cm	20.9[a]	2.25[a]	1.8[a]	0.6[a]	9.08[a]	33.38[a]	74.53.7[a]
15–30 cm	20.4[a]	2.25[a]	1.62[b]	0.67[a]	9.013[a]	35.2[a]	69.41[a]
CV (%)	11.9	1.84	9.7	13.4	15.7	14.6	12.8

Ca: calcium; Mg: magnesium; K: potassium; Na: sodium; Ca : Mg: calcium to magnesium ratio; CEC: cation exchange capacity; PBS: percentage of base saturation; Main effect means within a column followed by the same letter are not significantly different from each other at $P \leq 0.05$; CV: coefficient of variation.

interaction effects (Tables 5 and 7). Taking into account the main effect of land use, PBS on coffee landuse is 1.16 times higher than cropland (Tables 5 and 7). Variations in PBS are similar to those observed in exchangeable basic cations, especially Ca and Mg, because processes that affect the extent of basic cations also affect PBS. Thus, the variability in PBS could also be due to variations in pH, OM content, intensity of cultivation, and soil management practices. A study attested that less disturbed land uses that have moderate OM and optimum pH have a relatively higher PBS than cropland [70].

According to the base saturation rating suggested for the overall PBS [42], it was rated high in both land uses, indicating the presence of very weak leaching conditions in coffee landuse and croplands.

4. Conclusions

This study confirmed that most of the soil chemical parameters, namely, soil pH, exchangeable Na, calcium, soil C, nitrogen, available P, exchangeable basic cations, and total porosity, were significantly lower on croplands compared with those on coffee landuse. The soil moisture content, electrical conductivity (EC), and Ca: Mg did not show significant differences for land uses. In terms of depth, the mean values of the soil parameters, including OM and total nitrogen (TN), significantly ($P < 0.05$) decreased with increasing soil depth, while Na concentration increased significantly with increasing soil depth. But most of the physical and chemical parameters did not vary significantly with depth. Certainly, it can be concluded that most soil properties vary significantly due to differences in tillage and cropping practice in the study area. It was clearly observed that there is an indication of a decline in soil fertility, particularly in croplands compared to coffee landuse.

In general, the main soil fertility constraints in the study area include low pH, low organic matter and organic carbon content, and low total nitrogen content in cropland in all soil layers. Therefore, the soils of the cropland require more attention with the continuous use of compost, crop rotation, fallowing, and intercropping leguminous crops with cereals to sustain soil fertility and productivity in the area.

For further information and intervention, the following points are forwarded:

(1) Considering the low status of OM and N, it could be recommended to include management practices that increase those low status parameters in the system when the land is continuously cultivated, and further studies are recommended on the selection of appropriate leguminous species that bring N to the system, nutrient flows, and soil plant analysis.

(2) The result of the comparison between coffee landuse and cropland indicates that coffee landuse maintained soil parameters, as reflected by improved soil

nutrients and carbon storage. Therefore, intensifying widely adopted agroforestry systems, such as coffee-based around the homestead, could be an option to improve soil nutrient and carbon storage. However, further research on the extensive measurement of coffee yield would be interesting to put into practice.

(3) The soil analysis itself cannot go beyond the identification of soil nutrient status due to the intricate nature of the soil. Therefore, the nutrient supply power of the soils and the demanding levels of the plants need further correlation and calibration work to develop a site-soil-crop-specific fertilizer recommendation. Nutrient ratings should also be done considering the local situation in the area.

Data Availability

Research data will be available upon request to the corresponding author.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Supplementary Materials

The standard reporting checklist (AgroEcoList 1.0.) of the study, including the details of (a) experimental/ sampling setup, (b) study site, (c) soil, (d) livestock management, (e) crop and grassland management, (f) outputs, and (g) finances. (*Supplementary Materials*)

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