DOI: https://doi.org/10.20372/star.V14.i1.04
ISSN: 2226-7522 (Print) and 2305-3372 (Online)
Science, Technology and Arts Research Journal
Sci. Technol. Arts Res. J., Jan. – March 2025, 14(1), 32-48
Journal Homepage: https://journals.wgu.edu.et
Original Research

Evaluating Selected Soil Properties Under Different Land Use Types and Soil Depth at Arjo-Dhidhessa Sugar Estate, Western Ethiopia.

Workina Geleta*[1], Fekadu Fufa[2], Abdissa Bekele[3]

[1]Research Scholar, Department of Soil Resource and Watershed Management, Wollega University, Shambu, Ethiopia

[2] School of Civil and Environment Engineering, Jimma University, Institute of Technology, Jimma, Ethiopia

[3]College of Natural Resources and Environmental Science, Oda Bultum University, Chiro, Ethiopia

Abstract

In Ethiopia, an inappropriate land use system causes significant forest loss, which intensifies soil erosion as well as soil degradation. The study was conducted at Arjo-Dhidhessa Sugar Estate, western Ethiopia, to evaluate the effects of different land use types and soil depths on selected soil characteristics related to soil fertility. Fifteen soil samples were collected at three soil depths of 0-30cm, 30-60cm, and 60-90 cm from different land use types, including fallow, cropland, irrigated land, forest land, and shrub land. The results indicated that forest land generally exhibited the highest levels of clay content (67%), total porosity (54.28%), pH (5.84), and organic matter (2.45%). In contrast, the upper layers of the cropland showed elevated levels of zinc (1.52 mg/kg) and copper (2.89 mg/kg). Conversely, irrigated land contained significantly higher amounts of iron (122.96 mg/kg) and manganese (284.75 mg/kg). Correlation analysis revealed strong positive relationships between organic matter, copper, and zinc. The findings underscore the importance of land use types and soil depth in agricultural productivity and long-term sustainability, recommending strategies to enhance soil fertility through micronutrient availability, land restoration, and reduced chemical fertilizer use.

Article Information

Article History:
Received: 10-01-2025
Revised: 18-02-2025
Accepted: 30-03-2025

Keywords:
Land uses Soil depth, DTPA-extractable micronutrients, and Soil organic matter.

*Corresponding Author:

Workina Geleta

E-mail: workinaga@wollegauniversity.edu.et

INTRODUCTION

Agricultural productivity is greatly influenced by soil fertility, especially in regions close to the tropics like Africa. This is because soil erosion and drainage can jeopardize the cultivated zone (Liu et al., 2023). In subtropical Africa, maintaining soil fertility is a significant challenge because rapid population growth across millions of square kilometers poses a significant issue (Wendimu, 2021). Agriculture workers take for granted that agricultural plants are always significantly poorer than grasslands and woods (Bore & Bedadi, 2015).

Micronutrients are essential nutrients that plants require in very small amounts; typically present in plant tissues at concentrations lower than 100 mg/kg (Prasad et al., 2023). These nutrients, including zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), and nickel (Ni) are essential for crop growth and yield (Aleminew & Alemayehu, 2020). The accessibility of micronutrients in soils is influenced by several factors, such as land use types, soil depth, pH, electrical conductivity (EC), organic carbon (OC), clay content, and calcium carbonate levels, which affect the accessibility of specific micronutrients in soils (Ding et al., 2023). Micronutrients are more accessible when there is a higher amount of organic carbon present, but they may become less soluble when the pH is raised (Bore & Bedadi, 2015).

Changes in land cover and agricultural practices significantly influence soil micronutrient levels, which are essential for the growth of plants (Buraka et al., 2022). Intensive agriculture, continuous cropping, and excessive chemical fertilizer use can lead to deficiencies in essential micronutrients (Asmamaw et al., 2023). In addition, chemical fertilizers can alter the balance of micronutrients in the soil, leading to deficiencies or toxicity (Desta, 2018). Several studies indicated that soil depth also plays a crucial role in micronutrient availability, with micronutrients stored in organic matter and their availability impacted by land use patterns (Wubie & Assen, 2020; Hussein, 2023). Cropland soils often experience nutrient depletion and micronutrient deficiencies owing to heavy farming methods and the removal of crops from the field (Aleminew & Alemayehu, 2020). Fallow land can exhibit variable micronutrient levels depending on previous land use and management practices, and leguminous cover crops have higher levels of micronutrients such as nitrogen, phosphorus, and iron than fallow land left bare (Gupta et al., 2023).

The status of micronutrient availability is influenced by soil properties like pH, OC, and clay content, as well as land use and soil depth (Dessalegn et al., 2014). Among these factors, soil pH and OC are particularly significant, as they can both positively and negatively affect micronutrient availability (Shete et al., 2016). Studies have revealed that the concentrations of essential micronutrients such as potassium (K), magnesium (Mg), iron (Fe), copper (Cu), and chromium (Cr) vary with land use types (Liu et al., 2023). According to research, as soil depth increases, the concentration of several micronutrients tends to decrease. For instance, in the previously mentioned study, soil samples collected from deeper strata (20–40 cm) showed lower micronutrients than those collected from shallower depths (0–20 cm) (Liu et al., 2023). Zinc, iron, copper, and manganese are essential for plant growth and play a role in several physiological functions. The fact that its concentration usually decreases as soil depth increases suggests that it generally changes with soil depth (Shete et al., 2016).

Effective soil management and the preservation of soil quality depend on an understanding of how soil responds to farming practices throughout time (Liu et al., 2023). Land use types, soil depth, pH, and organic carbon content are some of the variables that influence the availability of micronutrients (Dhaliwal et al., 2023). Establishing the Sugar Factory Estate has significantly accelerated land use changes and soil degradation in different parts of Ethiopia due to agricultural expansion (Shete, et al., 2016; Gebeyehu and Abbink, 2022). The Arjo-Dhidhessa sugar factory established extensive irrigation in the Dhidhessa Basin in 2009 (Teweldebrihan et al., 2020). Understanding these changes is crucial, yet the influence of land use types and soil depth on the soil micronutrients in this study area has not been adequately studied. There is a lack of spatially relevant data in this study area, specifically regarding the effects of land use and soil depth on soil properties. This gap is particularly concerning given the rapid expansion of irrigation and its potential consequences for soil health. Unfortunately, it is important to assess the availability of soil micronutrients at different soil depths and land use types to ensure responsible land resource management and improve sustainable agricultural productivity in the study area. Therefore, the main objective of the study is to evaluate the effects of land use types and soil depth on selected soil characteristics at the Arjo-Dhidhessa Sugar Estate in western Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

Arjo-Dhidhessa Sugar Estate is located in the East Wallaga Zones of the Oromia Region, 395 km west of Addis Ababa, and 18 km from Jimma Arjo District (Figure 1). The estate shares boundaries with specific areas of the Buno Bedele and sections of the Jimma Zones within the Oromia Regional State, which is located in western Ethiopia. Geographically, it lies between latitudes $7^0$36'00’’ and $9^0$36' 00" north and longitudes $35^0$32'00" and 37°34'00" E. Topographically, the subbasin spans an area of 27,800 km², featuring elevations that vary from 620 to 3,203 meters above sea level, excluding peaks over 35,000 meters. A significant portion of the region (67.2%) exhibits steep slopes (> 8%), whereas the remaining 32% consists of moderate to less steep slopes (< 8%). The study area experiences yearly mean rainfall of 1400 mm, with a peak occurring from May to October.

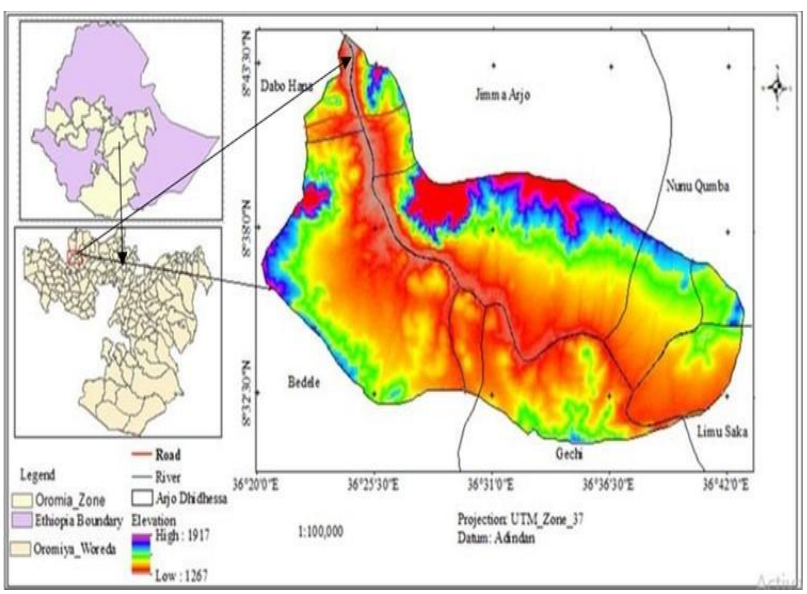

Figure 1. *Map of the study area*

Land use types and soil geology

Arjo-Dhidhessa's characteristics are a variety of land use categories and soil types that are connected to the region's geomorphology. A wide range of vegetation types, ranging from natural forests, shrublands, agricultural land, and grasslands, covers the sub-basin (Tolessa et al., 2020). According to the Arjo-Dhidhessa feasibility study (2005), the dominant soils in the basin are Alisols and Acrisols with the occurrence of other soil types, such as vertisols and nitisols (Tolessa et al., 2020). The soil types are mostly black soil, and occasionally red and brown soil, which makes it suitable for sugarcane development (Tadese et al., 2020). Shallow to extremely deep, well-drained, clay loam-to-clay-textured soils characterize the soils of a plateau that are stream-dissected and have flat to mild undulations (Tadese et al., 2020). Precambrian basement rocks, which are high-grade genetic and pre-tectonic granites that are part of the Algae group, comprise most of the research area (Tolessa, 2020).

Climate

The study area experiences yearly mean rainfall of 2,221 mm based on data collected over 39 years (1983–2022). The highest precipitation occurs in July at 428.3 mm, while January sees the least at 16.98 mm (Figure 2). This unimodal rainfall pattern shows a gradual increase from April to July, followed by a decline through December. Temperature ranges from 11.2°C to 38.5°C, with a yearly mean of 23.7°C (1983-2022). Monthly minimum temperatures typically fluctuate between 11.2°C and 17.1°C, while maximum temperatures fall between 29°C and 38.5°C (Figure 2).

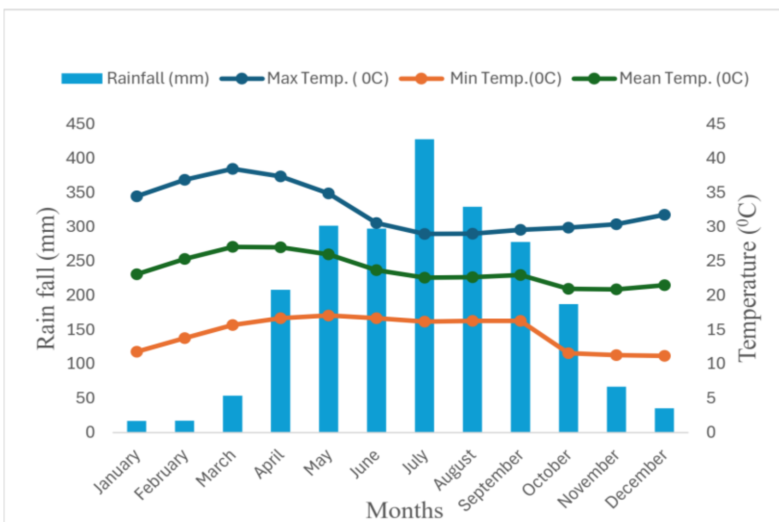

Figure 2. *Rainfall and temperature distributions in the study area*

Sampling site and soil sampling methods

The sampling locations were chosen based on the dominant land use types in the study area. Soil samples were obtained randomly from various land uses, including croplands, forestlands, irrigated areas, fallow land, and shrublands. Forestland acted as a control for comparing the physical and micronutrients of the soil across different land uses. For all types of land use, three soil depths were used to collect samples of both disturbed using an auger and undisturbed using core sampler soil. Thus, a total of 15 undisturbed and 15 composite soil samples were collected on April 12/2023 at three different soil depths (0–30, 30–60, and 60–90 cm). Global Positioning System (GPS) coordinates were recorded for each sampling location (Figure 3). To determine the bulk density and soil moisture content, undisturbed soil samples were collected from the pits at three distinct depths via a core sampler. Except for total nitrogen (TN) and organic carbon (OC), which were run through a 0.5 mm sieve, packed in a labeled polyethylene bag, authorized, and delivered to the soil testing laboratories of Fincha Sugar Estate and the central soil laboratory of Haromaya University, the collected combined soil samples were dried in the air, carefully mixed, smashed and passed through a 2 mm sieve for each parameter examined.

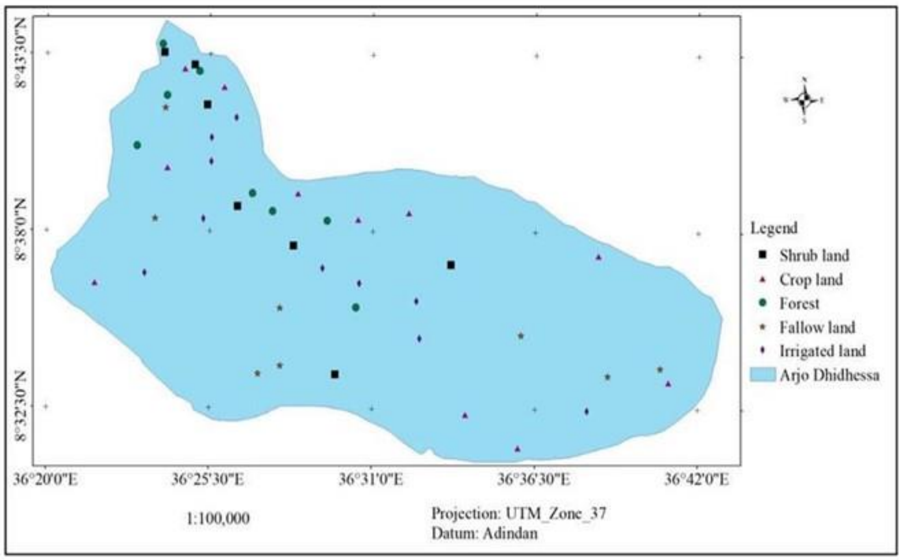

Figure 3. *Spatial distribution of the actual soil sampling points at the study site*

Analyzing the physicochemical parameters of the soil

The composite soil samples were air-dried, combined, squashed, and pureed through a 2 mm mesh for each parameter under analysis. Organic carbon (OC) was then processed through a 0.5 mm mesh. Using a core sampler, undisturbed samples from each type of land use were used to calculate the bulk density (ρb) of the soils. After weighing to determine the field moisture content, these samples were dried for 24 hours at 105°C in an oven. The following formula was then used to determine the bulk densit.

$$Bulk\ density(\rho b) = \frac{Dry\ mass\ of soilsample(DM)}{Volumeofthecoresampler(cm^3)}$$

where ρb is the bulk density (g/cm^3), DM is the dry mass (g) of the soil sample, and V is the core sampler volume (cm^3).

The total porosity was calculated from the measurements of the dry bulk density (ρb) of the soil and the soil particle density (ρs) as follows:

$$Total\ porosityy(\%) = (1 - \frac{\rho b}{\rho s})\ X100 \quad (2)$$

Where ρb is the bulk density (g cm^{-3}) and ρs is the particle density, which is assumed to be 2.65 g cm^{-3}.

A pH meter (model 4070) was used to test the soil response (pH) at a soil-to-water ratio of 1:2.5. The Walker-Black fast titration method, as described by Nelson and Sommers (1983), was used to measure soil organic carbon (SOC). The SOC readings were then multiplied by 1.724 (organic matter = 1.724 × % carbon) to calculate soil organic matter (SOM).

To determine exchangeable acidity (EA), soil samples were saturated with a potassium chloride solution and then titrated with sodium hydroxide. The diethylenetriaminepentaacetic acid (DTPA) technique (Lindsay & Norvell, 1978) was used to determine the available micronutrient levels (Fe, Mn, Zn, and Cu). An atomic absorption spectrophotometer (AAS) was used to measure the concentrations at the appropriate wavelengths. The central soil laboratory of Haromaya University and the soil testing laboratories of Fincha Sugar Estate conducted examinations of the micronutrients and physicochemical characteristics of the soil.

Statistical data analysis

R software (version 1.1.463) and Microsoft Excel were used for all data analysis. To find variations in soil parameters among different land use types, analysis of variance (ANOVA) was used ($P < 0.05$). The least significant difference (LSD) tests were used for mean comparisons at the 0.05 significance level when an ANOVA showed significant differences ($P < 0.05$). The Pearson correlation matrix is used to determine the correlation coefficients between pairs of variables.

RESULTS AND DISCUSSIONS

Status of selected soil physical properties under different land use types and soil depth

Soil textural class

The composition of (clay, silt, and sand) was substantially ($P \leq 0.01$) influenced by land use types and soil depth (Table 1). The combined influences of land use and soil depth resulted in the largest percentages of sand (27.28%) and silt (20.6%) in the uppermost layer of forestland when compared to fallow and irrigated land. On the other hand, the top layer of fallow land had a small amount of clay (54.56%), while the bottom surface layer of the cornfield had the most (72.16%). (Table 1). The disintegration of organic matter, leaf litter, and root growth are some of the variables that might improve soil structure and increase sand and silt accumulation, which may account for the greater sand and silt contents in forestland under the surface layer (Amsalu & Shegaw, 2019). However, cultivation methods, which can mix and redistribute soil particles, maybe the cause of the greater amount of clay in the cropland's subsurface layer. This would result in a higher clay content at deeper depths (Geremew et al., 2023).

The current outcome is in line with Wubie & Assen(2020), who reported that because the soil selectively removes clay fractions from the surface, croplands have lower clay fractions and higher sand fractions. The accumulation of organic matter and vegetation cover under forestland is what causes the highest amount of clay, although significant rainfall in the area might be the reason for the highest sand substance (Geremew et al., 2023). While the sand and silt contents reduce the soil depth in the soil profile from the surface to the subsurface, the clay content increases under all land use types (Habtamu, 2018).

Bulk density (ρb)

Bulk density (ρb) was substantially (P < 0.001) influenced by both land use and soil depth (Table 1). Considering the combined effects of land use types and soil depth, the highest bulk density was associated with crops (1.43 g/cm^3) in the deep soil layer, whereas the lowest bulk density was found in forests (1.1 g/cm^3) in the upper soil layer (Table 1). Heavy agricultural operations, including tillage, machinery use, and crop weight, maybe the cause of increased bulk density in croplands in subsurface soil layers (Weldewahid et al.,2023). Compaction of the soil can result from these processes, which also decrease the pore space and increase the bulk density.

However, the decline in bulk density beneath forestland in the topsoil layer could indicate a less compacted soil structure. Higher amounts of organic matter input are common in forest environments, which can help improve the soil structure and reduce compaction (Chemeda & Kibret., 2017). The presence of tree roots and other plants can also assist in maintaining soil porosity, avoiding compaction, enhancing the consolidation of soil, and encouraging the development of roots with less resistance to root infiltration because forests contain a significant amount of organic matter (Wubie & Assen et al., 2023). Overall land use patterns have a higher bulk density (ρb) as soil depth increases due to several variables, including compaction, reduced organic material content, less accumulation, restricted root penetration, and fewer pores in subsurface soil layers (Minase et al., 2016). This outcome was consistent with research by Minase et al. (2016), who found that the surface soil layer (0–20 cm) of farmed land in the Abobo region of western Ethiopia had the lowest bulk density.

Total porosity (Tp)

The total porosity content (Tp) was substantially (P < 0.001) influenced both by land use types and soil depth (Table 1). Taking into the combined influence of land use types and soil depth, the total porosity on the forestland surface was the highest (58.49%), whereas the total porosity on the subsurface of the cropland was the lowest (43.38%) (Table 1). The increased levels of organic matter and plant roots present in forested environments may contribute to porosity. The highest total porosity in forests and shrublands may be caused by vegetation, which encourages the growth of organic materials and improves the ability to penetrate roots. This promotes better water infiltration and soil movement, as well as enhanced aeration and nutrient cycling (Habtamu et al., 2018). However, croplands are often subjected to relatively high levels of tillage and chemical pesticide inputs, which can cause soil compaction and a reduction in porosity. The downward decrease in overall Porosity may be caused by the weight under the soil above the soil layer and a decrease in SOM with soil depth (Minase et al., 2016). Compared with overlying soil layers, deeper soil layers may be more compacted and have lower porosity due to their weight and pressure, which can impact drainage and root growth, limiting the overall productivity of the soil (Habtamu et al., 2018).

Table 1

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

Soil depth	LUT	Physical properties					
		Clay (%)	Sand (%)	Silt (%)	Texture	ρb(gm⁻3)	Tp (%)
0-30 cm	FaL	54.56[h]	27.36[a]	54.56[h]	Clay	1.2[a]	54.72[b]
	CL	58.48[fg]	20.08[c]	58.48[fg]	Clay	1.35[a]	47.92[d]
	FL	59.48[f]	27.28[a]	59.48[f]	Clay	1.1[a]	58.49[a]
	IL	52.56[g]	22.28[b]	52.56[g]	Clay	1.3[a]	50.9[c]
	ShL	57.47[de]	26.36[a]	57.47[de]	Clay	1.2[a]	54.72[b]
30-60 cm	FaL	63.48[de]	20.32[c]	17.2[cde]	Clay	1.3[a]	50.94[c]
	CL	62.38[c]	23.4b	14.12[hij]	Clay	1.38[a]	46.79[de]
	FL	66.23[c]	19.04[cd]	14.4[hi]	Clay	1.2[a]	54.72[b]
	IL	59.84[de]	20.36[c]	19.8[bc]	Clay	1.38[a]	45.66[ef]
	ShL	62.08[e]	23.44[b]	14.48[ghi]	Clay	1.32[a]	50.94[c]
60-90 cm	FaL	66[c]	17.56[de]	16.44[ghi]	Clay	1.4[a]	47.17[de]
	CL	72.16[a]	15.36[f]	12.48[def]	Clay	1.43[a]	44.15[fg]
	FL	70.16[b]	17.44[de]	12.48[jk]	Clay	1.23[a]	50.18[c]
	IL	62.91[de]	17.32[e]	18.44[bc]	Clay	1.41a	43.38[g]
	ShL	64.16[d]	19.36[c]	16.48[def]	Clay	1.34[a]	50.94[c]
SEM (±)		0.36	0.57	0.42		0.63	0.57
LSD (0.05)		1.05	1.67	0.96		0.96	1.67
CV (%)		1.74	4.73	6.3		16.76	2
P value		***	***	***		***	***

*Mean values in rows and columns that are marked with different letters indicate significant differences, while the same letters suggest no significant difference. Differences were highly significant at (P < 0.001) ** and (P < 0.001) ***, with 'Not significant' (Ns). Standard Mean Error (SEM), Coefficient of Variation (CV), Bulk Density (ρb), Total porosity (Tp), Fallow land (FaL), Cropland (CL), Forestland (FL), Irrigated land (IL), Shrubs land (ShL).*

Status of selected soil macronutrient properties under different land use types and soil depths

Soil pH

Soil pH was not significantly (P > 0.05) influenced by both land use types and soil depth (Table 2). The pH was highest (5.84) under forestland and lowest (5.17) under irrigated land (Table 2). The reason for the higher pH found in forestland is that forest ecosystems typically accumulate more organic matter from the breakdown of vegetation and leaf litter, which might result in a pH that is more neutral to slightly acidic (Liu et al., 2023). Furthermore, a greater diversity of soil microorganisms that may help control soil pH can result from the presence of trees and other flora in wooded areas (Weldewahid et al., 2023).

In contrast, the lower pH measured on irrigated land could be the result of various factors, such as higher input levels of fertilizer, agrochemicals, irrigation techniques, and crop choices (Asmamaw et al.,2023). This outcome is also consistent with the research of Asmamaw et al. (2023), who reported that the soil pH is lower on cultivated land than on uncultivated land; the soil pH is lower in nearby forests and grazing areas. The soil pH values vary among forestland, fallow land, cropland, irrigated land, and shrub land, with acidity levels ranging from acidic to moderately acidic (Weldewahid et al., 2023). Based on the proposed soil pH classification, the samples collected from the subsurface of soils were found to be strongly acidic, whereas the soil samples collected at the surface of the land were found to be moderately acidic, based on the rate of (Alemu et al., 2016).

Soil organic matter (SOM)

Soil organic matter was substantially influenced by both land use types and soil depth (Table 2). Soil organic matter was highest at 2.96% on the upper soil layer of the forestland, whereas cropland and irrigated land were the lowest at 1.27% and 1.29%, respectively, at the deeper soil layer (Table 2). The organic matter in forestland tends to be high because of the decomposing vegetation, organic material from leaves, and plant detritus that accumulate there. Compared with other land use patterns, wood has a greater organic matter content because of its dense vegetation, which continuously adds organic matter to the soil (Geremew et al., 2023).

However, cropland and irrigated land are frequently disturbed by practices like tillage, crop removal, and fertilizer and pesticide use, all of which can have an impact on the soil's organic matter content. Because organic materials either decompose quickly or are removed from the system, intensive farming methods may reduce the amount of organic matter in the soil (Weldewahid et al., 2023). According to Tebekew et al. (2024), the accumulation of plant and animal waste, the return of biomass, and the breakdown in the soil surface layer are the main causes of the increase in organic matter in the upper soil layer across all land use types. The decrease in soil organic matter can be explained by both a higher return of biomass for the surface decomposition of plant litter and a decrease in soil organic matter content with increasing soil depth (Tebekew et al., 2024).

Exchangeable Acid (EA)

Exchangeable acidity (EA) was substantially ($P < 0.001$) influenced both by land use types and soil depth (Table 2). The highest exchangeable acidity of 4.34 mg/kg was found on the topsoil layer under irrigated land, and the lowest exchangeable acidity of 0.41 meq/kg was found in the deeper soil layer under forestland (Table 2). Many factors could contribute to the high exchangeable acidity shown in the surface soil layer under irrigated land. Acidification of the soil can result from intensive farming practices that use agricultural products, insecticides, and irrigation over time (Bore & Bedadi et al., 2015). In particular, when nitrogen-based fertilizers are used excessively, nitrification and nitrate leaching can exacerbate soil acidity (Abure, 2022). A previous study (Abure, 2022) reported that relatively greater EA was recorded in the soils of cultivated land than in those of other types of land use.

In contrast, the underlying soil layer under forestland exhibited low exchangeable acidity, suggesting a more neutral pH and potentially better buffering capacity. According to Belay et al. (2023), forestland generally has a relatively high input of organic matter, which can help regulate the soil pH and minimize the accumulation of exchangeable acidity.

Status of selected soil micronutrient properties under different land use types and soil depth

Extractable iron (DTPA-Fe)

The result indicated that extractable iron (DTPA-Fe) was substantially ($P < 0.001$) impacted by different types of land use and soil depth (Table 2). The result showed that irrigated land had the highest iron content (122.96 mg/kg), followed by cropland (108.83 mg/kg) at the top soil layer, whereas forestland had the lowest iron content (55.43 mg/kg) in the deeper soil layer (Table 2). The highest iron concentration found under irrigated land at the topsoil layer could be related to the frequent fertilization and cultivation of irrigated land, which can affect the amount of iron available in the soil. Furthermore, the surface soil layer is more exposed to environmental elements such as weather and rainfall, which can lead to iron buildup in this area (Asmamaw et al., 2023). This result is consistent with those of studies conducted by Tebekew et al. (2024) in different areas of Ethiopia.

In contrast, the low iron concentration found in the subsurface soil layer in the forest can be attributed to the characteristics of the forest soils. Since forest soils are often richer in organic matter and more acidic, the amount of iron accessible may be lower. The lower iron content at this location may also be due to the reduced sensitivity of the subsurface soil layer to external inputs and processes as opposed to the surface soil layer. According to the adopted critical level, nearly all the sugarcane-growing soil in the study region had an optimal Fe content (Alemu et al., 2016). Almost any soil in the areas under study had a surface Fe content of greater than 80 mg kg^{-1} at a depth of 0-30 cm, which is adequate for crop production, and a subsurface Fe content of less than 80 mg kg^{-1} at depths of 30-60 cm and 60-90 cm, which is adequate for crop production in Ethiopian soils (Alemu et al., 2016).

Extractable copper (DTPA- Cu)

The result indicated that extractable copper (DTPA- Cu) was substantially ($P < 0.001$) impacted by different types of land use and soil depth (Table 2). The result indicated that the highest copper content of (3.31 mg/kg) was obtained on irrigated land at the topsoil layer, and a low copper content of 1.31 mg/kg was obtained on forestland in the deeper soil layer (Table 2). Management practices typically associated with agriculture may be responsible for the higher copper content of the surface soil layer under irrigated land. Fertilizers containing copper can be introduced into the soil by frequent fertilization in irrigated areas. Furthermore, the surface soil layer of irrigated fields is more accessible to outside inputs and processes, which can lead to copper accumulation in this area (Habtamu, 2018). This finding is consistent with a study by Sharma et al. (2021), who reported that the use of fertilizers and insecticides containing copper increased the concentration of copper in agricultural soils.

However, the low copper concentration found in the deeper soil layer in the forest land could be rooted in the inherent characteristics of the forest soils. The availability and movement of copper in the soil could be affected by the acidic and organic-rich nature of forest soils (Habtamu, 2018). The inadequate quantity of Cu in the soils may have been caused by the methods used in the areas under investigation, including low soil OC, low organic fertilizer input, not using Cu-containing fertilizer, and nutrient loss through continuous cropping. This result is also in line with research by Sharma et al. (2021), who found that forest soils normally have intermediate copper levels due to air particle deposition. This is consistent with the findings of Tebekew et al. (2024), who found that copper levels in shrubland soil are frequently comparable to those in forest soil due to similar environmental factors. Most of the soils in the areas under study fall between 1.31 and -3.31 mg kg^{-1} Cu at all soil depths, which is the ideal range for agricultural output in Ethiopian soils (Alemu et al., 2016).

Extractable manganese (DTPA-Mn)

The result clearly showed that extractable manganese (DTPA-Mn) substantially ($P < 0.01$) was impacted both by land use types and soil depth (Table 2). The highest manganese concentration of (284.75 mg/kg) was detected at the topsoil layer of the cropland, whereas the lowest concentration of 102 (mg/kg) was detected in the deeper soil layer of the fallow land (Table 2). Croplands that are regularly subjected to intensive farming practices, such as tilling, fertilization, and irrigation, can accumulate manganese in the topsoil, which is the reason why there is relatively high manganese content in the surface soil layer of croplands (Shar et al.,2018).

In contrast, natural processes, including leaching, erosion, and mineral weathering, may explain the reduced manganese concentration in the subsurface soil layer of fallow land (Elias et al.,2022). The topsoil had the highest concentration of manganese, while the deeper soil layers had lower concentrations. According to several studies (Abure,2022), the manganese content decreases as the depth of the soil increases. Elias et al. (2022) stated that the amount of manganese (Mn) in the soil is highly impacted by land use. Overall, almost all the soils in the studied areas range from 102-374.1 mg kg^{-1} Mn at all the surface depths, which is sufficient for crop production, based on the rating for Ethiopian soils (Alemu et al., 2016).

Extractable zinc (DTPA-Zn)

The result indicated that extractable zinc (DTPA-Zn) was substantially ($P < 0.001$) impacted by different types of land use and soil depth (Table 2). The top-soil layer of the cropland had the highest content (1.52 mg/kg), whereas the deeper soil layer of the shrubland had the lowest (0.12 mg/kg) concentration of zinc (Table 2). Agricultural activities, including the use of zinc-containing fertilizers and herbicides, may be responsible for the increase in the zinc content of cropland in the surface layer. Owing to the often-intensive management of crops, zinc gradually accumulates in the topsoil (Kaba,2020). Zinc is a micronutrient that is necessary for plant growth, and plants can become healthier and more productive when there is enough zinc in the soil (Yalew et al., 2020). These results align with the findings of (Kumar et al.,2022), who reported that the highest zinc concentration was observed in irrigated land.

However, the natural dynamics of the dispersion of zinc in the soil might be responsible for the decreased concentration of zinc in the subsurface soil layer of the shrubland. It is possible that shrublands receive less zinc from external sources than croplands do because they have a more diversified plant community and experience less disturbance (Kumar et al.,2022). The deeper soil layer of shrublands may have lower zinc levels due to mineral corrosion, leaching, and erosion (Yalew et al., 2020). According to the Ethiopian soil rating (Ethio SIS,2014), all the soils in the studied areas had zinc contents that were below the critical range, ranging from 0.21 to 1.52 mg kg^{-1} at all surface and deep soil depths. The only exceptions were fallow land, cropland, and irrigated land, which had low levels at the soil's surface depth for crop production (Alemu et al., 2016).

Table 2

Interaction effects of land use types and soil depth on selected soil chemical properties

Soil depth	LUT	pH	SOM	EA	Fe	Cu	Mn	Zn
(cm)			%	cmol/kg	mg/kg	mg/kg	mg/kg	mg/kg
	FaL	5.8^{a}	2.16^{a}	0.59d	95.14^{a}	2.31^{a}	284.25^{a}	1.17^{a}
	CL	5.6^{a}	1.94^{a}	4.13^{a}	108.83^{ab}	2.89^{ab}	374.1^{ab}	1.52^{b}
0-30 cm	FL	6.2^{a}	2.96^{a}	1.5^{c}	105.68^{b}	2.05^{bc}	271.5^{bc}	0.79^{ab}
	IL	5.3^{a}	2.15^{a}	4.34^{a}	122.96^{b}	3.31^{dc}	284.75^{cd}	1.0^{c}
	ShL	6.1^{a}	2.3^{a}	0.54^{d}	80.99^{c}	2.05^{a}	208.6^{a}	0.51^{cd}
	FaL	5.3^{a}	2.15^{a}	1.36^{c}	79.72^{a}	1.63^{ba}	174.2^{b}	0.28^{b}
	CL	5.4^{a}	1.77^{a}	1.79^{c}	89.88^{b}	1.83^{a}	237.3^{a}	0.13^{c}
30-60 cm	FL	5.73^{a}	2.5^{a}	1.41^{c}	73.83^{c}	1.75^{b}	137.5^{ab}	0.45^{c}
	IL	5.1^{a}	1.89^{a}	0.47^{d}	94.57^{ab}	1.93^{c}	207.7^{cb}	0.65^{cd}
	ShL	5.8^{a}	2.27^{a}	1.37^{c}	77.04^{bc}	1.63^{bc}	176^{dc}	0.32^{d}
	FaL	5.11^{a}	1.49^{a}	1.61^{c}	68.4^{a}	1.63^{a}	102^{a}	0.121^{d}
	CL	5.73^{a}	1.29^{a}	3.29^{a}	68.89^{b}	1.45^{ab}	103.3^{a}	0.121^{d}
60-90 cm	FL	5.6^{a}	1.89^{a}	0.43^{d}	55.43^{c}	1.31^{b}	107.6^{a}	0.25^{bc}
	IL	5.12^{a}	1.27^{a}	3.29^{b}	78.52^{b}	1.42^{b}	159.3^{ab}	0.47^{bc}
	ShL	5.5^{a}	1.58^{a}	2.89^{b}	68.67^{ab}	1.63^{a}	165.9^{a}	0.12^{dc}
SEM (+)		0.57	0.58	0.12	0.057	0.34	0.11	0.22
LSD (0.05)		1.63	1.67	0.35	1.67	1.67	1.67	0.623
Cv (%)		17.9	18.3	18.32	1.2	14.8	0.5	17.5
P value		Ns	**	***	***	***	***	***

*All mean values within rows and columns followed by different letters are significantly different and the same letters are not significantly different, highly significant at (P< 0.001) ***, Not significant (Ns), Standard Mean Error (SEM), Coefficient of Variance (Cv), Land use type (LUT), Iron (Fe), Cu(Copper), Zinc(Zn) and Manganese(Mn), Fallow land (FaL), Cropland (CL), Forestland (FL), Irrigated land (IL), Shrubs land (ShL).*

Correlations of the physicochemical and micronutrient parameters with the soil properties

The Pearson correlation matrix shows the correlation coefficients between pairs of variables in Table 3, showing that the clay content, pH, organic matter (OM), exchangeable acidity (Ex A), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) contents are significantly related.

Strong negative correlations exist between the clay content and Fe (- 0.742**) and Mn (-

0.802**), indicating that a relatively high clay content may limit the availability of these micronutrients (Mesfin et al., 2018). pH is significantly positively correlated with Cu (0,774**) and Zn (0.384*), suggesting that slightly alkaline conditions may increase the availability of these micronutrients (Zhao et al., 2023).

Soil organic matter is positively correlated with the retention and availability of Cu (0.818**) and Zn (0.494**). These correlations emphasize the importance of managing soil properties to optimize nutrient availability. For example, adjusting pH and increasing organic matter can increase micronutrient levels, which play vital roles in crop health and yield (Liu et al., 2023).

Table 3

Pearson's correlation matrix for the physical and chemical properties of soil

	Clay	pH	SOM	EA	Fe	Cu	Mn	Zn
Clay	1							
pH	0.112	1						
SOM	0.001	.927**	1					
EA	-0.025	0.118	0.107	1				
Fe	-.742**	0.062	0.209	-0.142	1			
Cu	-0.234	.774**	0.818**	-0.006	.525**	1		
Mn	-.802**	0.082	0.159	0.008	.883**	.469**	1	
Zn	-.504**	.384**	.494**	0.09	.641**	.666**	.695**	1

*A number not designated by * is not significant, significant at ($P < 0.01$)**, significant at ($P < 0.001$)***, Soil organic matter(SOM), Exchangeable acid(EA), Iron(Fe), Copper(Cu), Manganese(Mn), zinc(Zn).*

CONCLUSIONS

This study elucidates the significant effects of land use types and soil depth on the properties of soil at the Arjo-Dhidhessa Sugar Estate in western Ethiopia. The study demonstrates that varied land use, such as cropland, forestland, fallow land, irrigated land, and shrub land, significantly affects soil properties and micronutrient availability. Forestland exhibited superior soil characteristics, including higher organic matter and clay content, compared to cropland and irrigated land. This suggests that maintaining forest cover is crucial for enhancing soil health and fertility. The study found that topsoil generally contains higher levels of micronutrients, while deeper layers show a decline in micronutrient availability.

This suggests the importance of topsoil in sustaining soil fertility. The study reveals that

irrigation practices for sugar production notably alter the physicochemical characteristics and micronutrient levels in the soil. Indicating that irrigation can have both beneficial and detrimental effects on soil quality, irrigated land displayed higher levels of exchangeable acidity and certain micronutrients. The findings emphasize the importance of considering soil depth when assessing soil properties. As soil depth increases, the status of micronutrients also tends to decrease, suggesting that deeper soil layers may play a critical role in the availability of soil micronutrients. Compared to the other land use types, the largest concentrations of organic matter and clay were found in the forestland's surface soil layer. On the other hand, the highest amounts of available Fe, Cu, Mn, and Zn were found in cropland and irrigated land. These levels were noticeably higher than those associated with other alterations in the pattern of land use and cover. The availability of micronutrients, especially copper and zinc, was found to be significantly associated with organic matter. This suggests that enhancing soil organic matter could be a viable strategy for improving micronutrient availability, which is essential for crop growth.

Recommendations

The results indicate that strategies must focus on enhancing soil organic matter by implementing techniques including mulching, cover crops, and the addition of organic amendments. This can improve the availability of micronutrients and retention of nutrients, which is essential for soil fertility. Studies suggest that it is crucial to implement sustainable land management techniques that reduce reliance on chemical fertilizers. Promoting natural fertilizers and organic farming can help preserve soil quality and minimize nutrient depletion. More research is needed to better understand the intricate relationships between land use, soil depth, and soil qualities. Routinely monitoring soil quality indicators may inform land management decisions and sustainable farming practices.

CRediT authorship contribution statement

Workina Geleta: Conceptualization, writing original draft, data maturation methodology **Fekadu Fufa:** Review and editing, supervision **Abdissa Bekele:** Validation, Resources, Formal Analysis, Supervision

Declaration of competing interest

The authors declare that there is no conflict of interest.

Data availability

Data will be made available on request

Acknowledgments

The authors thank the Department of Soil Resource and Watershed Management, Wollega University, Nekemte, for providing the necessary support.

REFERENCES

Abure, T. (2022). Status of Soil Acidity under Different Land Use Types and Soil Depths: The Case of Hojje Watershed of Gomibora District, Hadiya Zone, Southern Ethiopia. *Applied and Environmental Soil Science*, *2022*, 1–13. https://doi.org/10.1155/2022/706 066

Aleminew, A., & Alemayehu, M. (2020). Soil fertility depletion and its management options under crop production perspectives in Ethiopia:Areview. *AgriculturalReviews*, *41*(2), 91-105. https://doi.org/10.18805/ag.R-136

Alemu, L. B., Tekalign, M. A., Wassie, H. W., & Hailu, S. D. (2016). Soil micronutrients status assessment, mapping and spatial distribution of Damboya, Kedida Gamela and Kecha Bira Districts, Kambata Tambaro zone, Southern Ethiopia. *African Journal of Agricultural Research*, 11(44), 4504–4516. https://doi.org /10.5897/ajar20 16.11494

Amsalu A and Shegaw. (2019). Effect of eucalyptus plantations on soil properties: The case of Entoto Area, Northern Addis Ababa, Ethiopia. *Journal of Environment and Earth Science*, *9*(6), 49-62. https://doi.org/10.7176 /JEES/9-6-05

Asmamaw, D. K., Janssens, P., Dessie, M., Tilahun, S. A., Adgo, E., Nyssen, J., Walraevens, K., Assaye, H., Yenehun, A., Nigate, F., &

Cornelis, W. M. (2022). Effect of deficit irrigation and soil fertility management on wheat production and water productivity in the Upper Blue Nile Basin,Ethiopia.*Agricultural Water Management*, 277, 108077 .https://doi.org/10.1016/j. agwat. 2022. 108077

Belay, A. M., Selassie, Y. G., Tsegaye, E. A., Meshesha, D. T., & Addis, H. K. (2023). Soil pH mapping as a function of land use, elevation, and rainfall in the lake tana basin, northwestern of Ethiopia. *Agrosystems Geosciences & Environment*, *6*(4),1-14. https://doi. org/10.1002/agg2. 20420

Bore, G., & Bedadi, B. (2015). Impacts of land use types on selected soil physico-chemical properties of Loma Woreda, Dawuro Zone, Southern Ethiopia. *Science, Technology and Arts Research Journal*, *4*(4), 40-48. https://doi.org/110.4314/star.v4i4.6

Buraka, T., Elias, E., Suryabhagavan, K. V., & Lelago, A. (2022). Assessment of soil erosion risks in response to land-use and land-cover changes in Coka watershed, Southern Ethiopia. *Geology Ecology and Landscapes*, *8*(2), 140–153. https://doi.org/10.1080/24 749508.2022.2 109825

Chemeda, M., & Kibret, K. (2017). Assessment of soil physical and chemical properties as affected by different land use types in Warandhab Area of Wollega Zone, Oromia Regional State. *J Adv Stud Agric Biol Environ Sci, 4*(1), 41-60. https://doi.org/10.19080/IJESNR.2017.04.555634

Dessalegn, D., Beyene, S., Ram, N., Walley, F., & Gala, T. S. (2014). Effects of topography and land use on soil characteristics along the topo sequence of Ele watershed in southern Ethiopia. *Catena*, *115*, 47-54. https://doi.org/10.1016/j.catena.2013.11.007

Desta, H. A. (2018). Effects of land use systems on soil fertility at antra Watershed, Chilga district, northwestern highlands of Russia. *Universal Journal of Agricultural Research, 6*(6), 194-208. https:// doi.org /10.13189 /ujar.2018.0 606 02

Dhaliwal, S. S., Sharma, V., Shukla, A. K., Kaur, J., Gupta, R. K., Verma, V., & Singh, P. (2023). Interactive effect of land use systems on depth-wise soil properties and micronutrients minerals in North-Western, India. *Heliyon*, *9*(2),13-591. https://doi.org/10.1016/j.heliyon.2023.e13591

Ding, Y., Jia, Y., Zong, Z., Wang, X., & Zhang, J. (2023). Study on the fine particle migration characteristics of silty clay under cyclic loading. *Geotechnical and Geological Engineering, 41*(8), 4549-4558. https://doi.org/10.1007/s10706-023-02532-3

Feyissa, M. (2015) 'Remote Sensing GIS Based Spatio-temporal Land Use/ Cover Study of Western Ethiopian Highlands –A Case of Jima Arjo District', *Science, Technology and Arts Research Journal*, 4(1), 139-148. https://doi.org/10.4314/star.v4i1.24.

Gebeyehu, A. K., & Abbink, J. (2022). Land, sugar and pastoralism in Ethiopia: Comparing the impact of the Omo-Kuraz sugar projects on local livelihoods and food (in) security in the lower Omo Valley. *Pastoralism, 12*(1), 1-32.https://doi.org/10.1186/s13570-022-00242-8

Geremew, B., Tadesse, T., Bedadi, B., Gollany, H. T., Tesfaye, K., & Aschalew, A. (2023). Impact of land use/cover change and slope gradient on soil organic carbon stock in Anjeni watershed, Northwest Ethiopia. *Environmental Monitoring and Assessment*, *195*(8), 971. https://doi.org/10.1007/s10661-023-11537-7

Gupta, N., Yadav, K. K., Kumar, V., Kumar, S., Chadd, R. P., & Kumar, A. (2018). Trace elements in soil-vegetables interface: Translocation, bioaccumulation, toxicity and amelioration - A review. *The Science of the Total Environment, 651*, 2927–2942. https://doi.org/10.1016/j.scitotenv.2018.10 .047

Habtamu, A. (2018). Effects of Land Use Systems on Soil Fertility at Antra Watershed, Chilga District, Northwestern Highlands of Ethiopia. *Universal Journal of Agricultural Research, 6*(6), 194-208. https://doi.org/10.13189/ujar.2018.060602

Hussein, A. (2023). Impacts of land use and land cover change on vegetation diversity of tropical highland in Ethiopia. *Applied and Environmental Soil Science*, *2023*, 1–11. https:// doi.org/10.1155/2023/2531241

Kaba, F. T., Doda, M. B., & Kanido, C. K. (2020). Levels of selected essential and non-essential metals in the soil and ginger (zingiber officinale) cultivated in Wolaita Zone, Ethiopia. *Journal of Agricultural Chemistry and Environment*, *9*(4), 276-298. https:// doi.org/10.4236/jacen.2 020.940 21

Kumar, S. S., Wani, O. A., Mir, S. A., Babu, S., Sharma, V., Chesti, M. U. H., Baba, Z. A., Sofi, P. A., Wani, F. J., Dar, S. R., Singh, R., & Yadav, D. (2022). Soil carbon dynamics in the temperate Himalayas: Impact of land use management. *Frontiers in Environmental Science*,68(2),162-169. https://doi.org/10.33 89 / fenvs. 2022.1009660

Li, Y., Gong, J., Liu, J., Hou, W., Moroenyane, I., Liu, Y., ... & Yi, Y. (2022). Effects of different land use types and soil depth on soil nutrients and soil bacterial communities in a karst area, Southwest China. *Soil Systems*, *6*(1), 20. https://doi.org/10.3390/soilsystems601002 0

Lindsay, W. L., & Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal*, *42*(3), 421–428. https ://doi.org/10.2136/sssaj1978.0361599500420 0030009x

Liu, J., Yang, K., Tariq, A., Lu, L., Soufan, W., & Sabagh, A. E. (2023). Interaction of climate, topography and soil properties with cropland and cropping pattern using remote sensing data and machine learning methods. *The Egyptian Journal of Remote Sensing and Space Science*, 26(3), 415–426. https://doi.org/10.10 16/j.ej rs. 2023.05.0

Mesfin, S., Taye, G., Desta, Y., Sibhatu, B., Muruts, H., & Mohammedbrhan, M. (2018). Short-term effects of bench terraces on selected soil physical and chemical properties: landscape improvement for hillside farming in semi-arid areas of northern Ethiopia. *Environmental Earth Sciences*, *77*(11), 1-14. https://doi.org/10.1007/s12665-018-7528-x

Minase, N. A., Masafu, M. M., Geda, A. E., & Wolde, A. T. (2016). Heavy metals in agricultural soils of Central Ethiopia: the contribution of land use types and organic sources to their variability. *Open Journal of Soil Science, 6*(6), 99-112. https: //doi.org /10.4236 /ojss.2016.66011

Nelson, D., & Sommers, L. (1982). Total carbon, organic carbon, and organic matter. *Agronomy Monograph/ Agronomy*, 539–579. https: //doi.org /10.2134/ agronmonogr 9.2.2ed.c29

Prasad, P., Subbaiah, P. V., Rajasekhar, N., Reddy, I., Rajanarasimha, M., Krishi, K. R., Kendra, V., Garikapadu, J., & Acharya, N. (2023). Assessment of Available Major and Micronutrient Status of Soils under Varied Cropping Systems of N.T.R district, Andhra Pradesh. *Indian Journal of Ecology*. https://doi.org/10.55362/ije/2023/3900

Shar, S. H., Mahar, A. R., Rajpar, I., Saand, M. A., Mirbahar, A. A., Ansari, K. A., & Sirohi, M. H. (2018). Assessment of soil quality of Taluka Thari Mirwah, district Khairpur, Sindh, Pakistan. *Int. J. Econ. Environ. Geol*, *9*(3), 13-18. https://d1wqtxts1x zle7.cloudfront.net/605 93161/4.20190914-34413

Sharma, S., Singh, P., Angmo, P., & Dhaliwal, S. S. (2021). Micro-nutrient pools and their mobility in relation to land-use system in a cold high altitude Himalayan mountainous region. *Agroforestry Systems*, *95*(8), 1395–1412. https://doi.org/10.1007/s10457-021-00623-9

Shete, M., Rutten, M., Schoneveld, G. C., & Zewude, E. (2016). Land-use changes by largescale plantations and their effects on soil organic carbon, micronutrients and bulk density: empirical evidence from Ethiopia. *Agriculture and human values*, *33*, 689-704. https://doi.org/10.1007/s10460-015-9664-1.

Tadese, M., Kumar, L., Koech, R., & Kogo, B. K. (2020). Mapping of land-use/land-cover changes and its dynamics in Awash River Basin using remote sensing and GIS. *Remote Sensing Applications: Society and Environment*, *19*(1), 100-352. https://doi.org/10.1016 / j.rsase. 2020. 100352.

Tebekew, F. A., Tadesse, T. B., Alemu, D. A., & Ayalew, A. A. (2024). Soil Physicochemical Properties Variation under Annual Crop and Coffee Landuse in the Chentale Watershed, Upper Blue Nile Basin, Ethiopia. *Applied and Environmental Soil Science*, 2024, 1–11.https:// doi.org/10.1155/2024/2921614

Teweldebrihan, M. D., Pande, S., & McClain, M. (2020). The dynamics of farmer migration and resettlement in the Dhidhessa River Basin, Ethiopia. *Hydrological Sciences Journal*, *65*(12),1985-1993.https://doi.org/10.1080/02626667.2020.1789145

Tolessa, T., Dechassa, C., Simane, B., Alamerew, B., & Kidane, M. (2020). Land use/land cover dynamics in response to various driving forces in Didessa sub-basin, Ethiopia. *GeoJournal*, *85*(3),747–760.https://doi.org/10.1007/ s10708-019-09990-4

Weldewahid, Y., Habtu, S., Taye, G., Teka, K., & Gessesse, T. A. (2023). Effects of long-term irrigation practice on soil quality, organic carbon and total nitrogen stocks in the drylands of Ethiopia. *Journal of Arid Environments*, *214*, 104982.https://doi.org/10.1016/j.jaridenv2023.104982

Wendimu, G. Y. (2021). The challenges and prospects of Ethiopian agriculture. *Cogent Food & Agriculture*, *7*(1),192-3619. https://doi.org/10.1080/23311932.2021.1923619

Wubie, M. A., & Assen, M. (2020). Effects of land cover changes and slope gradient on soil quality in the Gumara watershed, Lake Tana basin of North–West Ethiopia. *Modeling Earth Systems and Environment*, *6*(1), 85-97. https://doi.org/10.1007/s40808-019-00660-5

Yalew, S., Asmare, B., & Mekuriaw, Y. (2020). Effects of fertilizer type and harvesting age on species composition, yield and chemical composition of natural pasture in the highlands of Ethiopia. *Biodiversitas Journal of Biological Diversity, 21*(11),4999-5007. https://doi.org/10.13057/biodiv/d211103

Zhao, X., He, W., Xue, L., Chen, F., Jia, P., Hu, Y., & Zamanian, K. (2023). Particle size distribution and depth to bedrock of Chinese cultivated soils: Implications for soil Classification and management. *Agronomy*, *13*(5), 12-48. https://doi.org/10.3390/agronomy13051248