Journal of Forestry and Natural Resources
Vol. 3(2), 2024

Research Article

Effects of land use practices on the spatial variability of soil physicochemical properties across a landscape in Wondo Genet, Southcentral Ethiopia

Mikias Biazen Molla[1]*, and Weldesemayat Gorems[2]

Article Info

[1] Department of Geographic Information Science (GIS), Wondo Genet College of Forestry and Natural Resources, Hawassa University, Hawassa, Ethiopia.
[2] Debre Tabor Town Administration, South Gonder, Amhara Regional State

***Corresponding author**: mikiasmolla@gmail.com

Citation: Biazen M. & Gorems W. (2024).Effects of land use practices on the spatial variability of soil physicochemical properties across a landscape in Wondo Genet, Southcentral Ethiopia . *Journal of Forestry and Natural Resources*, 3(2),55-67

Received: 03 October 2024
Accepted: 03 November 2024
Web link: https://journals.hu.edu.et/hu-journals/index.php/jfnr/

OPEN ACCESS

Abstract

This study investigated the changes in physical, chemical and microbiological soil properties resulting from different land use practices. Soil samples were collected from two different depths, 0–30 cm and 30–60 cm, in three adjacent land use types: agricultural land, plantation forest and natural forest. A total of 15 samples were collected for analysis from each land use type. Key soil parameters, including total nitrogen, soil organic carbon and microbial biomass, were quantified using the micro-Kjeldahl and fumigation-extraction methods, respectively. In addition, geostatistical analysis using kriging interpolation techniques was performed within a GIS framework to visualize the spatial variability of soil parameters. The results showed that agricultural land/khate farm had the highest bulk density (0.96 $\pm$ 0.018%), followed by plantation forest/Cupressus (0.93 $\pm$ 0.012%) and natural forest (NF) (0.81 $\pm$ 0.03%). Natural forest had the highest soil organic carbon content (4.25 $\pm$ 0.28%), followed by plantation forest/Podocarpus (2.77 $\pm$ 0.49%) and Coffee based agroforestry (2.92 $\pm$ 0.16%). Furthermore, the total nitrogen content was highest in the top layer of natural forest (0.37 $\pm$ 0.024 μg/g), showing significant differences compared to plantation forest and agricultural land. Microbial biomass carbon was also highest in natural forest (939.84 $\pm$ 46.0 μg/g), followed by plantation forest/Grevillea (712.8 $\pm$ 48.4 μg/g) and agricultural land/Enset (570.2 $\pm$ 38.8 μg/g). Similarly, microbial biomass nitrogen was highest in natural forest (81.0 $\pm$ 3.9 μg/g) and showed significant variations with plantation forest/Grevillea (60.08 $\pm$ 4.2 μg/g) and agricultural land/Enset (40.96 $\pm$ 3.3 μg/g). Overall, our results indicate a strong correlation between microbial biomass and soil physico-chemical properties, which are significantly influenced by vegetation type and soil depth.

Keywords: Spatial distribution, land use types, soil properties, soil mapping, geostatistical analysis

1 Introduction

Most Ethiopians rely on agriculture as their primary source of income and livelihood (Zeleke et al. 2023). This heavy dependence on agriculture has increased the susceptibility to land degradation, leading to socioeconomic and environmental challenges due to inappropriate farming practices, unfavorable terrain, erratic rainfall, low vegetation cover, water erosion, and poor land management (Holmatov 2017; Belachew et al. 2020). To meet the growing global food demand, particularly in developing nations, it is crucial to gradually enhance agricultural productivity while also systematically managing the expansion of agricultural land and integrating it with existing natural resource conservation systems (Hansen et al. 2010; Dokoohaki et al. 2021; Ayoubi et al. 2021). Globally, unsustainable land-use change, and resource exploitation have led to a 0.6% annual loss of forest cover (Hansen et al. 2010; Khormali et al. 2009; Mokhtari et al. 2011; Bargali et al. 2018). The key mechanisms involved in nutrient transformation and cycling, soil organic maintenance, and macro-aggregation for optimum water and aeration are all controlled by soil microbial biomass (Jenkinson and Rayner 2006; Pereira et al. 2013). The soil has a significant nutrient-labeled pool, accounting for 1%–5% of organic carbon and more than 5% of total nitrogen (Bargali et al. 1993; Manral et al. 2020).

The quantity of microorganisms in soil affects its nutritional status and transformation (Norouzi et al. 2010). These microorganisms are important for the breakdown of plant and animal residues and the release of nutrients (Bargali et al. 1993), and their activities are highly susceptible to management measures, including irrigation, fertilizer application, and conventional tillage (Arunachalam and Arunachalam 2002; Kara and Bolat 2008; Bargali et al. 2015). Therefore, the number of soil microorganisms is a key determinant of soil health (Bargali et al. 2019; Tajik et al. 2020). Forest cover with native and nonnative species influences the soil's physical and chemical qualities and ecology and economics (Bargali et al. 1993; Tilman et al. 2001). The transformation of forestland to agricultural land to meet the global economy impacts not only climate change but also the dynamics of soil organic matter, biodiversity, and changes in ecosystem services in general (Tripathi et al. 2007). Moreover, it has a significant influence on soil functions (Kelishadi et al. 2014; Havaee et al. 2014; Ayoubi et al. 2018), including microbial activity, nitrogen, soil organic carbon, and other soil physical qualities (ITTO 2002). Massive collection of wood and non-timber forest resources, overgrazing (Ayoubi et al. 2014), and land-use pattern changes are important factors in land degradation, which modifies soil quality and vegetative cover and disrupts or even inhibits natural forest regeneration (Tripathi et al. 2007; Ayoubi et al. 2011).

During the last two decades, the conversion of land use, for example, from natural forest to cultivated ecosystems has been a common process throughout the world (Vagen et al 2006; Kara and Bolat 2008; Khormali and Nabiallahy 2009), particularly in the tropics. Several scholars have focused on the effects of increasing anthropogenic disturbances, decreasing C budgets (Tilman et al. 2001; Yang et al. 2009; Don et al. 2011), and land-use changes on forest ecosystems in these regions. Moreover, dry and rainy seasons are extreme conditions in tropical ecosystems that have a major influence on productivity, nutrient cycling, microbial biomass, and physicochemical properties of soil (Ayoubi et al. 2018). Hardwood forest areas have been converted to farmland at an alarming rate in recent decades due to increased demand for firewood, timber, pasture, food, and residential dwellings (Ye et al. 2009). In recent decades, ecologists have focused on soil SOC, microbial features, and microbial activity because of the effect of the land-use shift from natural forests to agricultural land and plantation (Ayoubi et al. 2011; Li et al. 213). Total soil quality, including physicochemical and microbiological performance, is recognized as a driver of soil organic matter (Kumar and Ghoshal 2017; Ayoubi et al. 2018). To put it another way, the physicochemical qualities of soil are inextricably linked to soil organic matter (Jackson 1973). Soil microbial properties respond more readily to soil disturbance in any ecosystem than soil chemical or physical properties (Allen et al. 1974; Ashagrie et al. 2007). Studies have demonstrated that changes in land use, especially in temperate climates, substantially affect soil microbial populations (Tripathi and Singh 2009). Land-use change affects important ecosystem functions, including carbon sequestration, climate regulation, and water purification, and all of these are intimately connected to microbial activities. The major land-use change in the study area, the conversion of natural forests to other land-use types, leads to not only climate change, loss of biodiversity, change in ecosystem services, etc but also affects soil biological and physicochemical properties (Tilman et al. 2001; Ashagrie et al. 2007; Allen et al. 1974 and Tripathi et al. 2007). Several studies have documented that the conversion of natural forests to other land-use types significantly influences soil health and quality, particularly in temperate regions (Kumar and Ghoshal 2017). However, the restoration of forests poses a major challenge globally, particularly in the tropics, as the forests in these regions are more vulnerable to land-use change (Kumar and Ghoshal 2017; Jones 2018). Therefore, how land-use changes affect community composition in terms of disturbance and ecosystem restoration in the dry tropics has not yet been studied (Kumar and Ghoshal 2017).

The application of appropriate management approaches for sustained agricultural production necessitates timely and reliable soil information; however, spatial knowledge of soil microbiological and physicochemical parameters at the smallholder farming level is severely restricted (Fikadu et al. 2012). By offering an accelerated, repeated, spatiotemporal view, geospatial technologies have opened new options for improving soil knowledge and show great potential for the gathering and analysis of soil data. GIS and remote sensing are useful methods for assessing large amounts of geographical problems and can enable spatial analysis; hence, there is a tremendous opportunity to enhance the accuracy of soil surveys via the use of GIS and remote sensing technologies. Therefore, the main objective of the present study was to assess the effect of land-use change and to analyze and map the spatial variations in soil microbial and physicochemical properties under different land- use practices in the Wondo Genet, Ethiopia.

2 Methods and Materials

2.1 Description of the study area

The study was conducted in Ethiopia's Wondo Genet, specifically in the Wondo Genet watershed. The watershed is located 13 km from the surrounding town of Shashemene, West Arsi, Oromia Regional State, 38 km from the Sidama regional capital Hawassa, and 263 km from Addis Ababa. It is located between $7^{0}02'$-$7^{0}07'$N latitudes and $38^{0}37'$ and 38^{0} 42' E longitudes (Figure 1). The region lies between 1600 meters and 2500 meters above sea level. The area comprises a series of hills that form the southwestern spur of the Bale Mountains. The agro-climatic zone of the district is traditionally categorized as Woyina-Dega (mid-highland). The mean minimum and maximum monthly temperatures of the study area are 13.8 °C and 27.8 °C, respectively (NMA 2017). The area receives a bimodal rainfall pattern (short rains between February and April, and long rains between June and September) with a mean annual total rainfall of 935 mm (SZPED 2004). According to Erikson and Stern (1987), the main parent materials are volcanic deposits of ignimbrite, ash, lava, and tuff. The geological bedrock of the area consists mainly of acidic rocks, sometimes interbedded with basaltic lava of tertiary origin (Brady and Weil 2002).

The soil of the study area was identified as Mollic Andosol. Andosol is characterized by a soil bulk density of less than 0.9 kg dm3, more clay and Alox, high phosphate retention of 70 % or more, volcanic glass content in the fine earth fraction of less than 10 percent; and thickness of at least 30 cm (; FAO 1998; Brady and Weil 2002; Fantaw 2017). The soil pH of the study area varied between 5.6 and 6.5 (Ashagrie et al. 2007). Natural forest land: This is an area of land made up of bigger trees that are generally taller than 3 m and have a canopy cover of more than 30% (Brady and Weil, 1996). Of the total watershed area, this land-use group comprises 405 hectares, or 14.3% (Figure 1). Plantation forest**:** An area of land consisting of mostly Euqlyputus, Podocarpus, Cupressus, and Grevillea trees. This land-use category accounts for 405 hectares (14.3 percent) of the overall catchment area (Figure 1). Agricultural Land: The plot of land was used to grow various crops and irrigate cash crops, including sugarcane, enset, coffee, and khat, using traditional irrigation schemes. Maize, carrots, potatoes, onions, and other crops are also grown with irrigation. Agricultural land accounted for 174 ha (6.2 percent) of the study area

2.2 Soil sampling techniques

A total of 96 composite soil samples (3 land use types*4 replication* 4 sample plots* 2 soil depths: 0-30 and 30-60cm) were collected from the land-use types: Natural Forest, Plantation Forest, and Agricultural land. The forest area was further divided into six subsites of 100 m × 100 m each. Four soil samples were collected from each subsite and combined to form a single composite sample representing each subsite. The plantation forests were also further divided into Grevillea, Cupprusses, Eucalyptus, and Podocarpus, whereas Khat (*Catha edulis*), Enset (*Ensete ventricosum*), coffee (*Coffea arabica*), and sugarcane (*Saccharum officinarum*) plantations were considered under agricultural land. The soil samples were air-dried at room temperature and passed through a 2-mm sieve before analysis.

2.3 Soil analysis

Standard laboratory procedures for measuring soil physical and chemical parameters (pH (H_2O), organic C, moisture content (%), Porosity, and Bulk density) were followed as proposed by Lam (1983) and Li and Heap (2011). The microbial biomass C was estimated using the chloroform fumigation–extraction method with purified $CHCl_3$ treatment (Hengl 2009; Goovaerts 2012). Using a Gerhardt digester and distillation unit, the N content of the microbial biomass was measured using the micro Kjeldahl method (Bernardi et al. 2017). Microbial biomass C (μg dry soil) and nitrogen were calculated using the following formulas:

$$\text{Microbial Biomass C} = (NF - F) \times 3168$$

$$\text{Microbial Biomass N} = (Fu - NFu) \times 207.407$$

Soil Aggregates: The dry method developed by Khormali and Nabiallahy (2009) was used to estimate soil aggregates. A dried soil sample (100 g) was piled on a set of seven sieves and sieved on a horizontal shaker (92 rpm) for 3 min, separating three dry aggregate size classes: 1000 μm (macro-aggregate), 212–500 μm (meso-aggregate), and 53–150 μm (micro-aggregate) (Singh et al. 2009). To estimate and map soil quality over space, geo-statistics were employed. Kriging is a precise geostatistical approach (Horneck et al. 2007) that is frequently used in various fields (Paudel and Sah 2003). Ordinary kriging is a good spatial model for predicting geostatistical-statistical studies of environmental variables (Nsabimana et al. 2004), such as soil parameters (Hadgu et al. 2009; Manral et al. 2020), in the QGIS 3.8 environment. Finally, using distinct soil parameter ratings, the resulting raster layers of each soil parameter were categorized using the spatial analyst tools of the QGIS 3.8 program (Vibhuti et al. 2020).

3 Results and Discussion

3.1 Physical and chemical properties of soil

3.1.1 Bulk density, porosity, and aggregates

Many soil parameters change as land-use patterns and treatment systems change (Jackson 1973; Ayoubi et al. 2014; Tajik et al. 2020). The study revealed a higher bulk density in soil under agricultural land (0.9 ± 0.064 g/cm^3), followed by plantation forest (0.86 ± 0.32) and natural forest (0.81 ± 0.3). Among land use categories and soil depth, soil porosity exhibited the opposite tendency as bulk density. The natural forest has the highest porosity (0.69%), followed by the plantation forest (0.66%) and agricultural land (0.66%). The values of bulk density and porosity did not differ between land-use categories and along soil depths. Agricultural land, on the other hand, has a higher bulk density than forest soil and plantations. This was most likely related to the reduction of carbon content and improvement of soil because of repeated cultivation and biomass harvesting (Tripathi et al. 2007). The bulk density was likewise lower in soils with significant organic matter concentrations (Kumar and Ghoshal 2017). The high porosity of forest soil allows for optimal oxygen diffusion and water penetration. This demonstrates high structural quality, which is beneficial to the effective development of biological communities (Bot and Benites 2005).

Soil aggregates are naturally formed collections of soil particles that determine the formation of organo-metal complexes in soil (Bot and Benites 2005; Pereira et al. 2013). Across all land-use categories, macro-aggregates comprised 53.9%–67.6% of the soil, followed by meso-aggregates (29.3%–41.9%) and micro-aggregates (4.4%–12.2%) (Table 1). In the top layer of the soil, macro aggregates

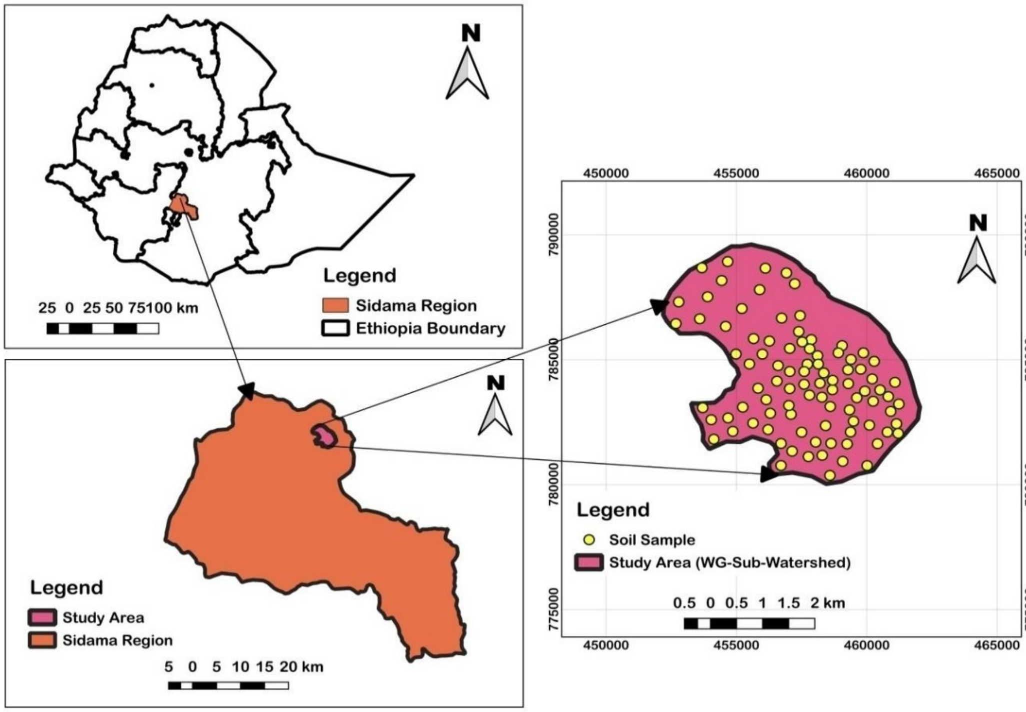

Figure 1: Map of the Wondo Genet sub-watershed with sampling locations

were found at 67.6% on the Khate plantation, whereas the eucalyptus plantation had the lowest percentage at 48.1%. In eucalyptus plantations and natural forests, meso and micro aggregates were greater (41.9%) and (12.1%). The Khate plantation had the highest number of macro-aggregates (67.6%), but the lowest number of meso (25.7%) and micro-aggregates (25.7%) among the plantation land use categories (6.6%). The meso-aggregates (41.9%), micro-aggregates (9.9%), and macro-aggregates (48.1%) were highest in the eucalyptus plantations. Soil aggregates in the natural forest accounted for 53%, 33%, and 12% of the macro, meso, and micro-soil aggregates in the upper soil layers, respectively. This was lower than that of the Cupressus, Podocarpus, and coffee, Khate, Sugarcane, and Enset farms but higher than that of the Eucalyptus and Grevillea. This might be because in a planted forest, there is less interference, and there is a high organic matter content (litters and root biomass) that binds soil aggregates together, leading to better soil structure development. Natural forests, on the other hand, had lower aggregates due to soil disturbance and a higher percentage of micro-aggregates, which were attributed to continuous SOM distribution and quick oxidation, respectively (Gorems and Ghoshal 2020).

Soil structural stabilization is directly related to organic matter inputs (Caravaca et al. 2002). Singh et al. (2009) reported a significant increase in the stability of aggregates with the application of wheat straw. This might be due to the application of organic inputs to soil increasing the cohesion of aggregate binding forces between mineral particles and organic polymers, which decreases the wettability of aggregates and thus the extent of slaking (Spaccini et al. 2004). Tillage accelerates aggregate turnover and increases the decomposition of organic residues when exposed to soil microbes (Singh et al. 2009).

pH, Soil Organic Carbon, and Total Nitrogen

The mean soil pH ranged from 5.6 to 6.8 in the surface layer (0–30 cm) and 5.9 to 6.9 in the subsurface layer (30–60 cm) (Figure 2). The highest soil pH was recorded in sugarcane, whereas the lowest pH was recorded in Cupressus. Cupressus land-use soils were somewhat acidic compared to other land-use types. The soil organic carbon (SOC %) and total nitrogen (tot N %) are presented in Table 2. Soil organic carbon and total nitrogen varied according to land use type and soil depth ($p < 0.05$). Soil organic carbon varies across all land-use types and soil depths, ranging from 1.1% to 4.25%. Natural forests had the highest organic carbon content, followed by plantation forests and agricultural land. The mean topsoil SOC in the natural forest was 4.25%, followed by coffee (2.92%), podocarpus (2.77%), grevillea (2.73%), enset (2.56%), Cupressus (2.50%), eucalyptus (2.25%), and sugarcane (1.56%). Similar studies indicated that forest areas had more OC than Jatropha plantations/reforested areas and the lowest OC levels in the agroecosystem, according to Go (2009) and Gorems and Ghoshal (2020), whereas others

[1]

[1]textValues are mean ± SE. Values with distinct superscripts in each column and rows are substantially different from each other at 5% level of significance (“Letter” indicates among the land use types; “Number” indicates along the soil depths for each aggregate size). Note: C, coffee; K, hat; Su, sugarcane; E, enset; N, natural forest; Eu, eucalyptus; Cup, cuprussus; G, grevillea; Pod, podocarpus; MBC, microbial biomass carbon; S, soil organic carbon; B, bulk density; Mc, moisture content; Po, porosity Note: The superscript letter indicates significance among the land use types in each row, whereas the superscript number indicates significance along the depth in each aggregate size. The superscripts are (number and letter) independent

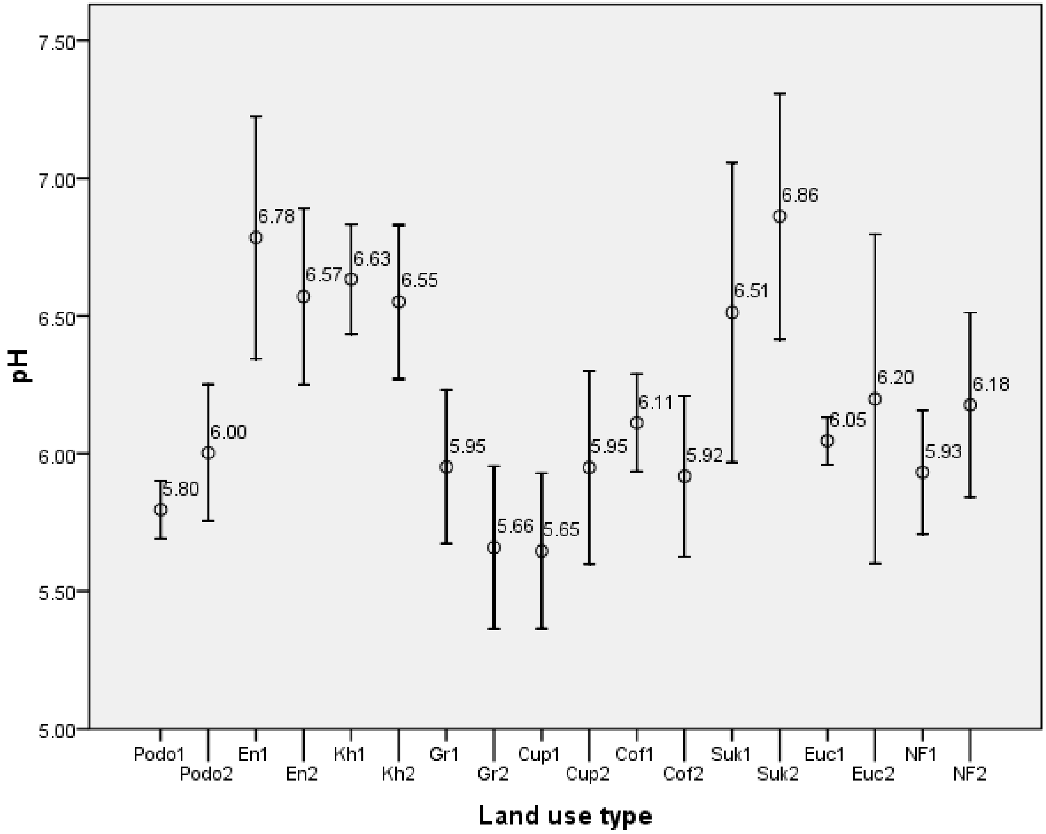

Figure 2: Impacts of land-use change on soil pH.
NB: Podo1- Podocarpus 0-30cm; Podo2- Podocarpus 30-60cm; En1-Enset 0-30cm; En2-Enset 30-60cm; Kh1-Khate 0-30cm; Kh2-Khate 30-60cm; Gr1-Gravillea 0-30cm; Gr2- Gravillea 30-60cm; Cup1- Cupressus 0-30cm; Cup2-Cupressus 30-60cm; Co1-Coffee 0-30cm; Co2-Coffee 30-60; Suk1-Sugarcane 0-30cm; Suk2-Sugarcane 30-60cm; Euc1-Eucalyptus 0-30cm; Euc2- Eucalyptus 30-60cm; Nf1-Natural forest 0-30cm; Nf2-Natural forest 30-60cm.

observed better SOC concentrations in natural forests than in tilled farmlands (Iqbal et al. 2015). Similarly, Srivastava et al. (1991) found that agroforestry yielded the highest SOC, followed by cropland, grassland, and fallow land. Because of the regular buildup of plant biomass and limited intervention in the natural forest, the conversion of natural forest to plantation forest, as well as cash agriculture, resulted in a considerable decrease in SOC (Saha et al. 2010). Furthermore, greater root biomass contributes to the preservation and stability of SOC in aggregates by increasing the return of residues (Paudel and Sah 2003; Ayoubi et al. 2014). Moreover, the presence of diverse leaf litter on the forest floor contributes to the replenishment of SOM and provides better habitats and food for soil organisms, thereby enhancing SOC accumulation.

In the case of OC, soil total N significantly varied according to land use practices and soil depth. The top layer of the natural forest soil had the highest soil total N concentration (Table 2). The order of the concentration of total N along the land use types in the upper layer was NF (0.37%), Gr (0.24%), Podo (0.24%), Coffee (0.25%), Enset (0.22%), Cupr (0.22%), Euc (0.19%), Khate (0.16%), and sugarcane (0.13%) at $p < 0.05$. Several studies have confirmed that agricultural practices reduce soil total N content (Ayoubi et al. 2011; Iqbal et al. 2015). In addition, Goni et al. (2015) demonstrated that under comparable site conditions, natural lands often preserved more soil organic carbon than croplands because of larger residual inputs and lower turnover. Furthermore, soil OC and total nitrogen losses from agricultural land can be due to its removal by crops (Tripathi et al. 2007); and continuous tillage practice (accelerates organic matter oxidation by destroying soil aggregates and exposing newer sites to microbial attack) (Brady and Weil 1996). Although not statistically significant, the total N content derived from coffee and the Enset farm is equivalent to that from the planted forest. This is most likely because there is less intensive agricultural activity than in sugarcane and Khat fields, as well as inputs from broadleaf litter (Li and Heap 2011).

Soil organic carbon and total nitrogen contents were higher in soils from plantations than in agricultural land and cash croplands, but lower than the contents in soils from natural forests (Table 2). The conversion of natural forests to agricultural land for coffee, khat, sugarcane, and enset agriculture resulted in considerable reductions in SOC content, with values of 31.29%, 57.6%, 63.2%, and 39.7%, respectively. In comparison to agricultural land, the increase in SOC and total nitrogen in plantation forests was likely attributable to the addition of nutrient-rich leaf litter to the soil, as well as the recycling of these nutrients (Ye et al. 2009; Vesterdal and Leifeld 2010). The natural forest conversion to eucalyptus, cupressus, graveled, and podocarpus resulted in considerable reductions in SOC content, with lower values of 47%, 41%, 37.5%, and 34.8%, respectively. The Podocarpus plantation (2.77 ± 0.49%, 0.24 ± 0.042%) in the top

Table 1: Percentage distribution of dry aggregate soil types according to land-use types

Soil depth (cm) F-Value	Natural forest		Plantation forest			Agricultural Land				
			EuC	Cupr	Gr	Podo	Coffee	Khat	Sugarcane	Enset
Macro-aggregates (%)										
0-30	53.9 ± 4.6^{1a}	48.1 ± 6.1^{1b}	59.3 ± 8.6^{1c}	48 ± 4.3^{1c}	62.6 ± 8.3^{1a}	62.7 ± 7.6^{1a}	67.6 ± 4.4^{1a}	66.9 ± 6.1^{1c}	62.2 ± 8.7^{1a}	1.736
30-60	48.2 ± 8.9^{1a}	61.7 ± 11.4^{1bc}	70.1 ± 8.1^{1c}	51.9 ± 7.1^{1c}	70 ± 8.7^{1bc}	55.1 ± 8.8^{1c}	79.2 ± 2.9^{1b}	81.5 ± 2.3^{1b}	63 ± 8.9^{1bc}	
Meso-aggregates (%)										
0-30	33.9 ± 1.8^{1ac}	41.9 ± 2.3^{1a}	30.8 ± 5.8^{1ac}	39.7 ± 1.5^{1c}	29.3 ± 5.5^{1c}	25.3 ± 2.1^{1c}	25.7 ± 5.7^{1c}	28.6 ± 5.1^{1c}	29.9 ± 4.2^{1ac}	1.825
30-60	37.5 ± 7.2^{1a}	29.6 ± 7.3^{1b}	19 ± 4.8^{1b}	35.6 ± 7.2^{1c}	24.4 ± 9.9^{1bc}	32.5 ± 7.8^{1ac}	16.1 ± 1.8^{1b}	12 ± 4.7^{1b}	28.1 ± 6.2^{1c}	
Micro-aggregates (%)										
0-30	12.1 ± 4.1^{1a}	9.9 ± 4.5^{1a}	9.8 ± 2.9^{1a}	12.2 ± 5.2^{1a}	7.99 ± 2.9^{1a}	11.9 ± 6.1^{1a}	6.6 ± 2.8^{1a}	4.4 ± 1.4^{1a}	7.8 ± 4.9^{1a}	0.637
30-60	14.2 ± 4.1^{1a}	8.6 ± 4.4^{1a}	10.8 ± 5.8^{1a}	12.4 ± 3.8^{1a}	5.58 ± 1.2^{1a}	12.3 ± 5.1^{1a}	4.6 ± 1.24^{1a}	6.4 ± 2.5^{1a}	8.8 ± 3.15^{1a}	

layer soil had the highest organic carbon and total N, whereas the Eucalyptus plantation ($2.25 \pm 0.1\%$, 0.19 ± 0.01) in the upper layer soil had the lowest organic carbon and total N. The higher contents of soil organic carbon and nitrogen might be due to a higher input of leaf litter from the podocarpus, as well as fewer disturbances (Singh and Ghoshal 2006; Ashagrie et al. 2007). Studies on nutrient cycling have shown that low-quality Cupressus and Eucalyptus litter, which decompose slowly and restricts organic matter intake, eventually results in a decrease in SOC compared with natural forests and other plantations (Erikson and Stern 1987; Ayoubi et al. 2011).

Soil Microbial Biomass Carbon and Nitrogen

Microbial biomass

The level of soil microbial biomass carbon (MBC) showed significant variation with land-use type, ranging from 94.7 μg/g to 939.84 μg/g (Table 3). The mean soil MBC ranged from 131.1 to 939.8 μg/g in the surface layer and from

11.3 to 81 μg/g in the subsurface layer. Soil MBC was the highest (939.84 μg/g) in the upper layer of soil in natural forests, followed by Grevillea, Podocarpus, Cupressus, Enset, Sugarcane, Eucalyptus, and Khat farms. In the lower layer, the highest MBC was observed in the natural forest, whereas the lowest was recorded in the Cupressus plantation. Likewise, the mean microbial biomass nitrogen (MBN) values under natural forest, plantation forest, and agricultural land at both depths were (16.37, 8.11 μg/g; 13.64, 6.97 μg/g; 11.10, 5.3 μg/g), respectively. It was observed that soil MBN tended to decrease with soil depth for all land-use types (Table 3). The order of the level of MBN among the land use types was natural forest, grevillea, enset, podocarpus, eucalyptus, coffee, Khate, Sugarcane, and cupressus. The results for MBC and MBN are similar to those of previous reports (Zeraatpisheh et al. 2021; Ayoubi et al. 2012), with both MBC and MBN differing considerably across forest, pasture, and agricultural areas. The conversion of natural forests into plantation forests and farmland reduces soil organic carbon (SOC) and total nitrogen (tot. N), thereby lowering microbial biomass concentrations (Singh and Ghoshal 2006). Increased availability of resources such as soil organic matter, more diversified organic matter input, and related processes are believed to be the cause of the higher MBC and MBN in natural forests (Hadgu et al. 2009; Bargali et al. 2018).

The findings of the present study revealed a close relationship between MBC and SOC or tot N. In general, there is a direct correlation between the amount of soil microbial biomass and the quantity and quality of C inputs (Fikadu et al. 2012; Fang et al. 2014). Large microbial biomass increases the quantity of nutrients in the organic pool and, depending on soil management, might constitute either a sink or a source of plant-available nutrients. Higher SOC and total N levels in soil microbial biomass may be attributable to the increased ability of microorganisms to immobilize nutrients from decaying cover species residues. Microorganisms use organic waste left in the soil as a source of energy and nutrients. Various land covers contain different chemical elements that can affect microbial characteristics in various ways and to varying degrees. The higher microbial biomass in natural forests that maintain native vegetation provides ideal conditions (macro porosity, litter dry mass, and K and P levels), which help the soil microbiota thrive and establish (Paudel and Sah 2003; Chaudhary et al. 2008). The presence and activity of microbial biomass may result in enhanced plant litter decomposition, soil aggregate formation and stability, enhanced nutrient cycling and transformation, slow release of organic nutrient storage, and disease prevention, among other benefits (Kara and Bolat 2008; Goovaerts 2012).

Among the plantation forests, the highest microbial biomass of C and N was obtained from grevillea, whereas the lowest was obtained from Cupressus. Among the agricultural land, the highest microbial biomass of carbon and nitrogen was obtained from the Enset farm. This is most likely due to an increase in the supply of resources such as soil organic matter, more diversified soil organic input, and related processes that sustain microbial activity (Kara and Bolat 2008; Bhuyan et al. 2013). Moreover, opening of the canopy cover on agricultural land, especially on sugarcane and khat, increases the interference of physical components like moisture content, wind speed, and light intensity. Incident light intensity and wind velocity increase when the canopy opens, lowering moisture content and stimulating organic matter mineralization (Solomon et al. 2024).

Table 2: Soil microbial biomass under three major land-use types: natural, plantation, and farm forests

Soil depth (cm)	NF	Plantation forest				Agricultural Land			
		EuC	Cupr	Gr	Podo	Co	Kh	Suk	En
MBC ($\mu g/g$)									
0-30	939.8 ± 46.0^{a}	422.4 ± 27.9^{e}	131.1 ± 21.1^{f}	712.8 ± 48.4^{b}	538.6 ± 48.3^{c}	387.8 ± 22.5^{e}	372.2 ± 37.4^{e}	240.3 ± 25.2^{c}	570.2 ± 38.8
30-60	475.2 ± 9.2^{c}	242.9 ± 41.2^{e}	94.7 ± 7.8^{f}	211.2 ± 10.5^{d}	211.8 ± 31.6^{d}	278.6 ± 37.1^{e}	293 ± 26.3^{e}	145.7 ± 36.4^{f}	332.6 ± 12.9
MBN ($\mu g/g$)									
0-30	81.0 ± 3.9^{c}	36.4 ± 2.4^{e}	11.3 ± 1.08^{f}	60.0 ± 8.3^{d}	46.4 ± 2.4^{e}	33.4 ± 3.1^{f}	32.0 ± 9.3^{c}	20.7 ± 2.2^{c}	40.9 ± 6.3^{d}
30-60	40.9 ± 0.9^{c}	25.3 ± 5.2^{e}	8.16 ± 0.62^{f}	18.2 ± 10.9^{d}	19.1 ± 2.7^{d}	24.0 ± 13.2^{f}	25.2 ± 6.2^{c}	12.5 ± 6.3^{f}	37.8 ± 11.1

Values are mean ± SE. Values with distinct superscripts in each row differ substantially from each other at 0.05 level of significance.
Abbreviations: Co = coffee, Kh = khat, Suk = sugarcane, E = enset, NF = natural forest, Eu = eucalyptus, Cup = cupressus, G = gravelica, Pod = podocarpus, MBC = microbial biomass carbon, S = soil organic carbon, B = lump density, Mc = moisture content, Po = porosity.

Table 3: Soil chemical properties under different land use types and depths

	pH (H_2O)	N (%)	P (emol+/kg)	K (Cmol/kg)	CEC (emol(+)/kg)	OC g/kg	SAR	ESP %
Land use								
NF	5.5	0.37	3.68	0.23	4.31	6.37	0.043	0.63
PF	5.6	0.35	2.74	0.16	3.87	5.42	0.035	1.67
AL	6.5	0.29	2.96	0.14	5.02	5.03	0.035	1.47
LSD	0.341	0.054*	1.125	0.017	2.202	0.280	0.005*	0.289
Depth								
0–30 cm	5.57	0.30	2.85	0.06	4.46	8.61	0.086	1.182
30–60 cm	6.42	0.18	3.28	0.10	4.52	4.50	0.052	1.601
LSD	0.16	0.015***	0.780	0.013*	1.560	0.758***	0.006	0.203

Soil Chemical Properties

The study of soil properties revealed varying pH values across different land-use types, with natural forest (NF), plantation forest (PF), and agricultural land (AL) exhibiting pH values of 5.523, 5.645, and 6.510, respectively (Table 4). The soil depth analysis indicated that the pH value was 5.566 in the upper layer (0–30 cm) and increased to 6.420 in the subsurface layer (30–60 cm) (Table 4). Overall, these values suggest that the soils in the study area are slightly acidic across all three land-use practices, as supported by prior research (Tripathi et al. 2007; Wang et al. 2007). To illustrate the local distribution of pH at the specified depths of 0–30 cm and 30–60 cm, the pH values of soil samples were sorted and processed using a kriging interpolation technique. The results presented in Table 4 indicate that the majority of soils in the upper layer (0–30 cm) were notably acidic. However, despite the mild acidity, the subsurface layer (30–60 cm) exhibited a wider range of pH values, from 5.23 to 6.510, indicating relatively higher acidity in deeper soil profiles. This highlights the importance of depth for understanding soil acidity and its implications for soil management practices within the study area.

This study revealed significant variations in nitrogen content among the three land-use types ($p < 0.05$) and across different soil depths. The highest total nitrogen (TN) content recorded was 0.370%, with natural forests contributing 0.346% and agricultural land accounting for 0.287% (Table 4). These findings indicate that all three land-use practices result in very low nitrogen levels in the soils, which is supported by previous research (Tripathi et al. 2007; Kara and Bolat 2008). Figures 3a and 3b present the interpolation results for total nitrogen and pH values across the study area, highlighting the relationships between these two important soil parameters. The results demonstrate notable spatial heterogeneities in both pH and total nitrogen levels at various land-use sites, underscoring the complexity of nutrient distribution in the region and potential implications for soil management practices.

The analysis of phosphorus and potassium concentrations revealed that phosphorus levels did not exhibit significant variation across the different land-use types (Smith et al. 2020). This finding confirms that the use or management of land for various purposes, such as agriculture, residential use, and natural use, does not markedly influence phosphorus availability in soil. However, potassium concentrations did show statistically significant differences with soil depth ($p < 0.05$) (Jones et al. 2018), indicating that potassium content may be influenced by soil profile dynamics. While variations in potassium were noted with depth, the absence of significant differences between land-use types implies that broader land management practices may not affect potassium availability as markedly.

To further understand the spatial distribution of phosphorus in the study area, interpolation techniques were applied to visualize its variability across the three land-use types (Figure 4) (Brown et al. 2015). This spatial analysis is crucial because it helps identify areas within the sample region that may have different phosphorus concentrations, which could have implications for nutrient management and soil health.

The carbon concentrations varied from 6.31 to 8.34 g/kg, whereas the natural forest had a maximum value of 8.34 g/kg (Figure 5). The results of the soil laboratory analysis indicated that there were no statistically significant differences in soil characteristics among the

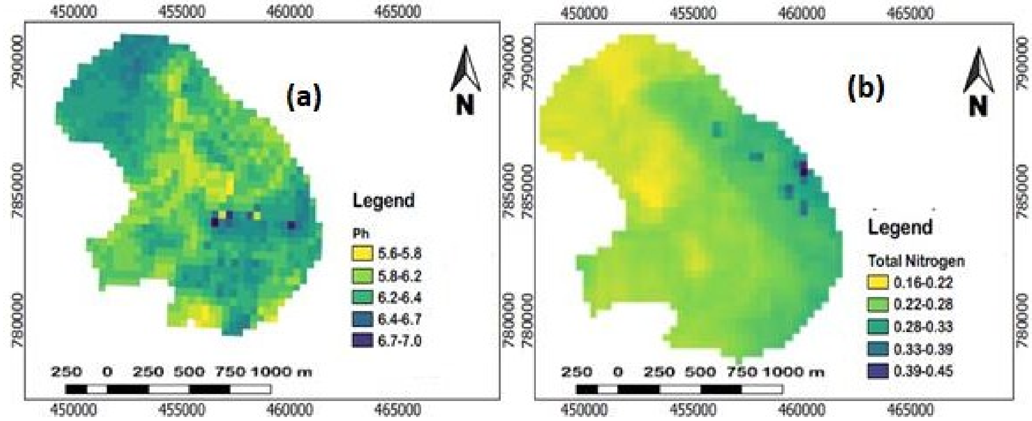

Figure 3: Spatial distribution of pH value (a) and total nitrogen (b) in the study area.

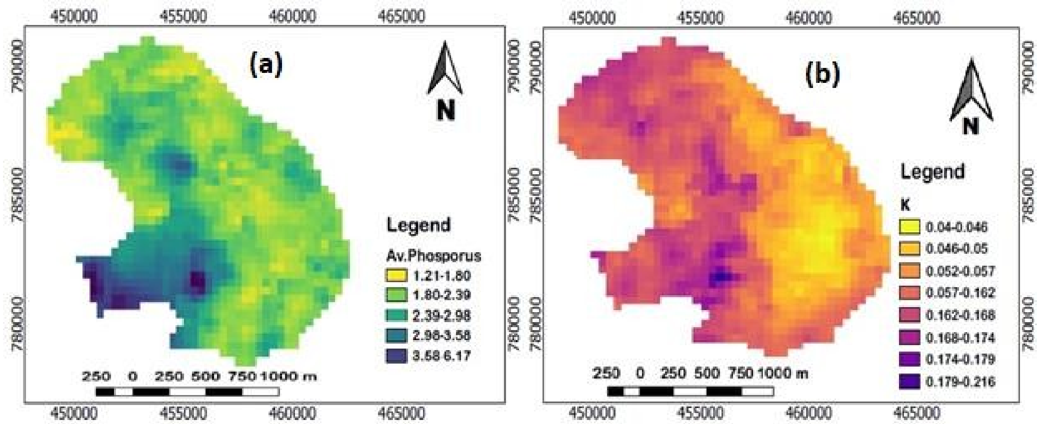

Figure 4: Spatial distribution of phosphorus (a) and potassium (b) in the study area.

three land-use types at a higher level of analysis. This means that when comparing the overall soil properties across various land-use categories, such as agricultural, residential, and natural, the variations were not sufficiently pronounced to be considered statistically significant (Ayoubi et al. 2020). In contrast, the analysis revealed significant variations in soil depth with respect to soil depth ($p = 0.05$). This reveals that soil characteristics change meaningfully at different depths, highlighting the importance of soil profile analysis in understanding soil health and properties. The land use category has exhibited similar soil properties when viewed broadly; soil depth being a crucial factor influencing variations in soil characteristics (Ayoubi et al. 2011). The analysis of regional variability and distribution of cation exchange capacity (CEC) values and soil organic carbon across the research area revealed a limited range (Table 4. As indicated in Figure 5, CEC values for all land-use types ranged from 2.4 to 4.8 cmol/kg, indicating a low capacity for soil to retain and exchange cations due to its foundational characteristics. According to Singh and Ghoshal (2014), a satisfactory CEC value should exceed 10 cmol/kg

of soil, confirming that the CEC values observed in this study may hinder nutrient retention and availability, thereby affecting overall soil health and productivity. This finding highlights the necessity for management practices that enhance CEC and improve soil quality in the region (Fang et al. 214). The analysis of soil samples indicated no statistically significant differences between the three land-use types with respect to soil depth, as both values fell below the acceptable limits. However, significant variations were observed in the sodium adsorption ratio (SAR) among the different land-use types and soil depths (p¡0.01). The findings revealed that most soils across all land-use types and depths exhibited low SAR values (Table 4. Additionally, the exchangeable sodium percentage (ESP %) remained low across all land-use types, with values consistently below 2% (Fikadu et al. 2012). To visualize the distribution of SAR and ESP values, these metrics were plotted and spatially analyzed, as shown in Figures 6(a) and 6(b). This analysis underscores the overall low levels of acidity in the soil samples, which is beneficial for soil health and fertility management.

3.2 Geostatistical analysis

Tables 5 and 6 show how the spatial structure of soil properties was determined by semi- variograms. For every parameter in this model, the best fit is shown for both depths (0-30 cm and

30-60 cm). The Gaussian model performed better for most parameters in the upper soil layer (0–30 cm), although the exponential model performed better for SAR and SOC, and the circular model

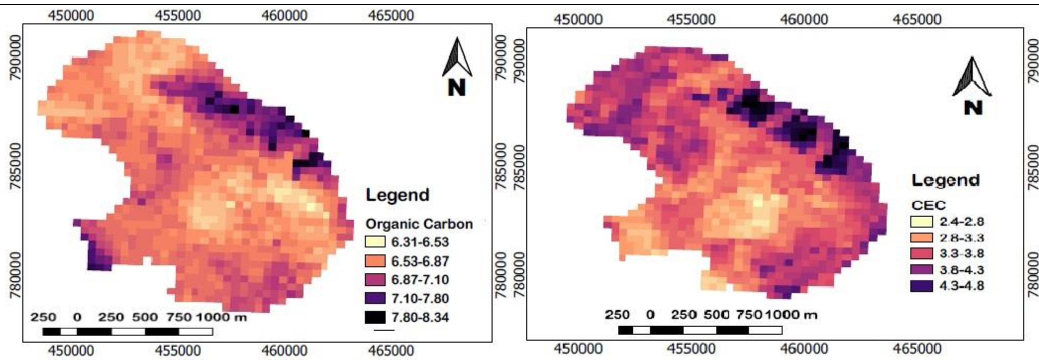

Figure 5: Spatial distribution of soil organic carbon (a) and CEC (b) in the study area.

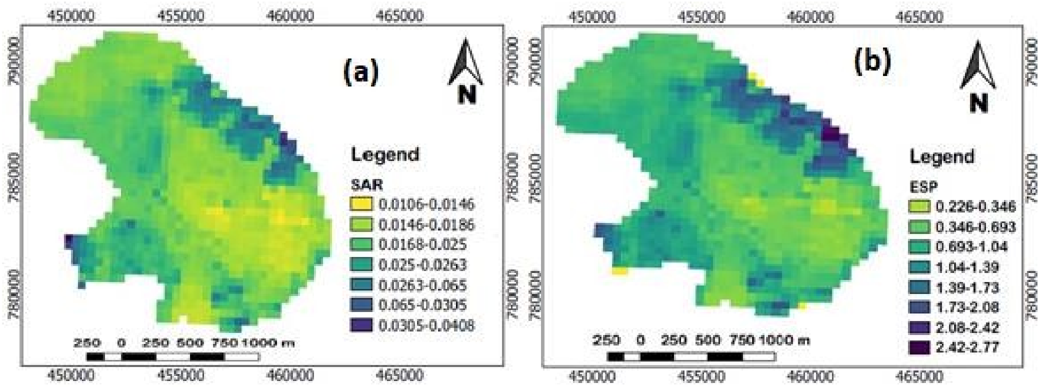

Figure 6: Spatial distribution of sodium adsorption ratio (a) and ESP (b) in the study area.

performed better for the CEC. Although the Gaussian model included most of the parameters in the subsurface layer (30-60cm), descriptive and circular models were better suited to OC, CEC, pH, and SAR, respectively (Table 6). As shown in Tables 5 and 6, the effects of the nugget, herring, and control spectra on each parameter varied between them. The degree of automatic correlation between the sample points was found to be equal to the local dependence rate expressed as percentages. Studies conducted by Horneck et al. (2007), Fikadu et al. (2012), and Gebrejewergs et al. (2019) classified location- dependent variants as highly dependent on location if the ratio is less than 25, moderately dependent if the ratio is between 25% and 75%, and highly dependent on location if the ratio is greater than 75 %. As a result, at the first depth (0-30cm), T. N (percentage), K (cmol / kg), and OC (percentage) were highly dependent on location, whereas pH, P, CEC, SAR, and ESP were moderately dependent. In the second depth, the model shows that T.N, P, and OC are the major location-dependent variables, while pH, ESP, K, SAR, and CEC are also local variables in the middle of this model.

4 Conclusion

Mapping the variety of landforms and examining the impacts of land-use changes are crucial prerequisites for land management. This study showed that the physicochemical properties of soil in the study area were significantly affected by land-use change and various land-use types over time. Total nitrogen, microbial biomass, bulk density, soil organic carbon, and porosity are higher in natural forests, but plantation forests and agricultural land show a decreasing trend. In addition, the Gravillea plantation site and the Enset farm have the highest biomass carbon and nitrogen emissions from plantation forests and farmlands. In contrast, farmland had a higher bulk density than other land uses, whereas natural forests had a lower bulk density but a positive correlation with soil organic carbon, nitrogen, and porosity. The geospatial map of selected areas showed that the farmland of the present study site had low rhizobia and soil OC/tN, but not much potassium and phosphorus. Therefore, soil characteristics are more susceptible to variations in land management and land utilization processes. In addition, there is a loss of essential nutrients that can lead to decreased productivity of agricultural land in the study area. We conclude that the optimum soil management techniques for agricultural land need to be prioritized to increase soil organic carbon, decrease soil pH, enhance nitrogen, and increase rhizobia.

Acknowledgments

The authors are grateful to MRV Center Research for financial support and logistics. The authors sincerely thank the Wondo Genet District Administration and its members for their assistance in this study and for permitting us to conduct this study in the area.

Table 4: Model parameters for soil variables at 30-60 cm depth under four land-use types

Variables	Nugget (Co)	Sill (C1)	Range (A)	Spatial ratio % (Nugget/Sill)	Spatial class	Model
pH (H^+)	0.362	0.859	0.0025	42.14	Moderate	Gaussian
TN (%)	0.0005	0.0041	0.0013	12.20	Strong	Gaussian
P ($cmol^+$/kg)	1.986	4.023	0.0058	49.37	Moderate	Gaussian
K ($cmol^+$/kg)	0.507	2.256	0.0015	22.47	Strong	Gaussian
CEC ($cmol^+$/kg)	2.4679	5.252	0.0724	46.99	Moderate	Spherical
OC (%)	0.2462	5.9286	0.0003	41.5	Strong	Exponential
SAR	5.4356	14.015	0.0042	38.78	Moderate	Exponential
ESP (%)	0.1872	0.4048	0.0029	46.25	Moderate	Gaussian

Note: pH: pH value, TN: total nitrogen value in percent, K: potassium, P: phosphorus, CEC: cation exchange capacity, OC: organic carbon, SAR: sodium adsorption ratio, ESP: exchangeable sodium percentage.

Table 5: Model parameters for soil variables at 30-60 cm depth under four land-use types

Variables	Nugget	Sill	Range	Spatial ratio (%)	Spatial class	Model
pH ($-\log(H^+)$)	1.2045	3.8632	0.0028	31.18	Moderate	Spherical
TN (%)	0.0021	0.0098	0.0012	21.43	Strong	Gaussian
P ($cmol^+$/kg)	0.5711	2.856	0.0046	20.00	Strong	Gaussian
K ($cmol^+$/kg)	2.0016	4.0105	0.0021	49.91	Moderate	Gaussian
CEC ($cmol^+$/kg)	1.0106	3.1157	0.0628	32.44	Moderate	Exponential
OC (%)	0.4004	3.1253	0.0010	12.81	Strong	Exponential
SAR	10.9	16.9001	0.0025	64.50	Moderate	Spherical
ESP (%)	1.0093	2.2545	0.0037	44.77	Moderate	Gaussian

Note: pH: pH value, TN: total nitrogen value in percent, K: potassium, P: phosphorus, CEC: cation exchange capacity, OC: organic carbon, SAR: sodium adsorption ratio, ESP: exchangeable sodium percentage.

Author contributions

Conceptualization: M. B. and W. G.; formal analysis: M. B. and W. G.; methodology: M. B., and W.G; Software, M. B.; writing and original draft: M. B. and W. G.; and writing and review and editing: M. B. and W. G. All authors have read and approved the final manuscript.

Funding

This study was supported by MRV Center Research. The Center has covered the costs of the chemicals, data collection, transport and personal allowance. The role of the center was to follow the overall research activity, such as financial management, managing reports from the researcher, and managing field visits of the researcher.

Competing interests

The authors declare that they have no conflicts of interest.

References

[1] Allen, S. E., Grimshaw, H. M., Parkinson, J. A., Quarmby, C. (1974). *Chemical analysis of ecological materials* (pp. xii-565).

[2] Arunachalam, A., Arunachalam, K. (2002). Evaluation of bamboo in eco-restoration of 'jhum' fallows in Arunachal Pradesh: Ground vegetation, soil and microbial biomass. *Forest Ecology and Management*, 159(3), 231-239.

[3] Ashagrie, Y., Zech, W., Guggenberger, G., Mamo, T. (2007). Soil aggregation, and total and particulate organic matter following conversion of native forests to continuous cultivation in Ethiopia. *Soil Tillage Research*, 94, 101-108.

[4] Ayoubi, S., Emami, N., Ghaffari, N., Honarjoo, N., Sahrawat, K. L. (2014). Pasture degradation effects on soil quality indicators at different hillslope positions in a semiarid region of western Iran. *Environmental Earth Sciences*, 71(1), 375-381.

[5] Ayoubi, S., Karchegani, P. M., Mosaddeghi, M. R., Honarjoo, N. (2012). Soil aggregation and organic carbon as affected by topography and land use change in western Iran. *Soil Tillage Research*, 121, 18-26.

[6] Ayoubi, S., Khormali, F., Sahrawat, K. L., Claudia Rodrigues de Lima, A. (2011). Assessment of soil quality indicators related to land use change in loessial soil using factor analysis in Golestan province, northern Iran. *Journal of Agricultural Science and Technology*, 13, 727-742.

[7] Ayoubi, S., Mirbagheri, Z., Mosaddeghi, M. R. (2020). Soil organic carbon physical fractions and aggregate stability are influenced by land use in the humid region of northern Iran. *International Agrophysics*, 34(3).

[8] Ayoubi, S., Mokhtari, J., Mosaddeghi, M. R., Zeraatpisheh, M. (2018). Erodibility of calcareous soils as influenced by land use and intrinsic soil properties in a semiarid region of central Iran. *Environmental Monitoring and Assessment*, 190(4), 192.

[9] Ayoubi, S., Sadeghi, N., Abbaszadeh Afshar, F., Abdi, M. R., Zeraatpisheh, M., Rodrigo-Comino, J. (2021). Impacts of oak deforestation and rainfed cultivation on soil redistribution processes across hillsides using ^{137}Cs techniques. *Forest Ecosystems*, 8, 1-14.

[10] Bargali, K., Manral, V., Padalia, K., Bargali, S. S., Upadhyay, V. P. (2018). Effect of vegetation type and season on microbial biomass carbon in Central Himalayan forest soils, India. *Catena*, 171, 125-135.

[11] Bargali, S. S., Shukla, K., Singh, L., Ghosh, L., Lakhera, M. L. (2015). Leaf litter decomposition and nutrient dynamics in four dry deciduous forest tree species. *Tropical Ecology*, 56(2), 191-200.

[12] Bargali, S. S., Singh, R. P., Joshi, M. (1993). Changes in soil characteristics in eucalypt plantations replacing natural broadleaved forests. *Journal of Vegetation Science*, 4(1), 25-28.

[13] Bargali, S. S., Padalia, K., Bargali, K. (2019). Effects of tree fostering on soil health and microbial biomass under different land-use systems in the Central Himalayas. *Land Degradation Development*, 30(16), 1984-1998.

[14] Belachew, A., Mekuria, W., Nachimuthu, K. (2020). Factors influencing the adoption of soil and water conservation practices in the northwest Ethiopian highlands. *International Soil and Water Conservation Research*, 8(1), 80-89.

[15] Bernardi, A., Bettiol, G. M., Mazzuco, G. G., Esteves, S. N., Oliveira, P., Pezzopane, J. M. (2017). Spatial variability of soil fertility in an integrated crop-livestock forest system. *Advances in Animal Biosciences*, 8(2), 590–593.

[16] Bhuyan, S. I., Tripathi, O. P., Khan, M. L. (2013). Seasonal changes in soil microbial biomass in different agroecosystems of Arunachal Pradesh, northeast India. *The Journal of Agricultural Sciences*, 8, 66142-152.

[17] Bot, A., Benites, J. (2005). *The importance of soil organic matter: Key to drought-resistant soil and sustained food production*. Viale delle Terme di Caracalla, 00100 Rome, Italy.

[18] Brady, N. C., Weil, R. R. (2002). *The Nature and Properties of Soils* (13th ed.). Prentice Hall, NJ. 960p.

[19] Brady, N. C., Weil, R. R. (1996). *The Nature and Properties of Soils*. Prentice-Hall: Upper Saddle River, NJ, USA.

[20] Brown, J., Smith, A., Johnson, K. (2015). Spatial analysis of soil nutrient distributions. *Journal of Soil Science*, 10(2), 123-145.

[21] Caravaca, F., Masciandaro, G., Ceccanti, B. (2002). Land use in relation to soil chemical and biochemical properties in a semiarid Mediterranean environment. *Soil Tillage Research*, 68, 23–30.

[22] Chadary, D. R., Ghose, A., Chikara, J., Patolia, J. S. (2008). Soil characteristics and mineral nutrients in wild Jatropha population of India. *Communications in Soil Science and Plant Analysis*, 39, 1476-1485.

[23] Dokoohaki, H., Gheysari, M., Mehnatkesh, A., Ayoubi, S. (2015). Applying the CSM-CERES-Wheat model for rainfed wheat with specified soil characteristics in undulating areas in Iran. *Archives of Agronomy and Soil Science*, 61(9), 1231-1245.

[24] Don, A., Schumacher, J., Freibauer, A. (2011). Impact of tropical land-use change on soil organic carbon stock—a meta-analysis. *Global Change Biology*, 17, 1658-1670.

[25] Erikson, H., Stern, M. (1987). Soil study at Wondo Genet Forestry Resource Institute, Ethiopia. *Swedish University of Agricultural Science, International Rural Development Center*, Uppsala, ISSN 0280-4301.

[26] Fang, X., Wang, Q., Zhou, W., Zhao, W., Wei, Y., Niu, L., Dai, L. (2014). Land use effects on soil organic carbon, microbial biomass, and microbial activity in Changbai Mountains of Northeast China. *Chinese Geographical Science*, 24, 297–306.

[27] Fantaw, Y. (2017). Effect of landscape position on soil properties in an agricultural land transect study of the Main Rift Valley area of Ethiopia. *Journal of Science Development*, 5(1), 21-31.

[28] Fikadu, G., Abdu, A., Mulugeta, L., Aramde, F. (2012). Effects of different land uses on the physical and chemical properties of soil in the Wondo Genet area, Ethiopia. *New York Science Journal*, 5(11), 110-118.

[29] Food and Agriculture Organization of the United Nations (FAO). (1998). *World reference base for soil resources*. World Soil Resources Reports 84. FAO, Rome, Italy.

[30] Gebrejewergs, A., Gebremedhn, B., Aklil, G. (2019). Land use impacts on physicochemical and microbial soil properties across the agricultural landscapes of Debrekidan, Eastern Tigray, Ethiopia. *Powerful Food Agriculture*, 5(1), 1708683.

[31] Goni, R., Sharma, N., Iqbal, S., Tiwari, S. C. (2015). Soil organic carbon pool under different land uses in Achanakmar Amarkantak Biosphere Reserve of Chhattisgarh, India. *Current Science*, 110, 771-773.

[32] Goovaerts, P. (2012). *Geostatistics for natural resource evaluation*. New York: Oxford University Press.

[33] Gorems, W., Ghoshal, N. (2020). Effects of land use on soil physicochemical properties at Barkachha, Mirzapur District, Varanasi, India. *African Journal of Agricultural Research*, 16(5), 678-685.

[34] Hadgu, K. M., Kooistra, L., Rossing, W. H., Van Bruggen, A. H. C. (2009). Assessing the effect of *Faidherbia albida*-based land use systems on barley yield at the field and regional scale in the highlands of Tigray, Northern Ethiopia. *Food Security*, 1, 337–350.

[35] Hansen, J., Ruedy, R., Sato, M., Lo, K. (2010). Global surface temperature change. *Reviews of Geophysics*, 48, RG4004–RG4005.

[36] Havaee, S., Ayoubi, S., Mosaddeghi, M. R., Keller, T. (2014). Impacts of land use on soil organic matter and degree of compactness in calcareous soils of central Iran. *Soil Use and Management*, 30(1), 2-9.

[37] Hengl, T. (2009). *A practical guide to geostatistical mapping* (Vol. 52, p. 15). Amsterdam, Netherlands: Hengl.

[38] Holmatov, B., Lautze, J., Manthrithilake, H., Makin, I. (2017). Water security for productive economies: An assessment framework in southern Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, 100, 258-269.

[39] Horneck, D. A., Ellsworth, J. W., Hopkins, B. G., Sullivan, D. M., Stevens, R. G. (2007). Managing salt-affected soils for crop production. USA: Oregon State University Extension Service.

[40] International Tropical Timber Organization (ITTO). (2002). *ITTO guidelines for the restoration, management, and rehabilitation of degraded and secondary tropical forests* (No. 13). ITTO.

[41] Iqbal, A. M., Hossen, S. M., Islam, N. M. (2015). Soil organic carbon dynamics for different land uses and soil management practices in Mymensingh. *Proceedings of the 5th International Conference on Environmental Aspects of Bangladesh*.

[42] Jackson, M. L. (1973). *Soil chemical analysis*. Prentice Hall of India Limited, New Delhi.

[43] Jackson, R. B., Fierer, N., Schimel, J. P. (2007). New directions in microbial ecology. *Ecology*, 88, 1343–1344.

[44] Jones, R., Williams, M., Thompson, L. (2018). The influence of soil depth on potassium availability. *Soil Science Society of America Journal*, 25(4), 321-334.

[45] Kara, O., Bolat, L. (2008). The effects of different land uses on soil microbial biomass carbon and nitrogen in Bartin Province. *Turkish Journal of Agriculture and Forestry*, 32, 281-288.

[46] Kelishadi, H., Mosaddeghi, M. R., Hajabbasi, M. A., Ayoubi, S. (2014). Near-saturated soil hydraulic properties as influenced by land use management systems in Koohrang region of central Zagros, Iran. *Geoderma*, 213, 426-434.

[47] Khormali, F. and Nabiallahy, K. (2009). Degradation of Mollisols as affected by land use change. *J Agric Sci Technol*, 11, 363–374.

[48] Kumar, C.M. and Ghoshal, N. (2017). Impact of land-use change on soil microbial community composition and organic carbon content in the dry tropics. *Pedosphere*, 27(5), 974.

[49] Lam, N. S. N. (1983). Spatial interpolation methods: a review. *American Cartographer*, 10(2), 129-150.

[50] Li, J., Heap, A. D. (2011). A review of comparative studies of spatial interpolation methods in environmental sciences: Performance and impact factors. *Ecological Informatics*, 6(3–4), 228–24.

[51] Li, W., Yang, G., Chen, H., Tian, J., Zhang, Y., Zhu, Q., Peng, C., Yang, J. (2013). Soil available nitrogen, dissolved organic carbon and microbial biomass content along an altitudinal gradient of the eastern slope of Gongga Mountain. *Ecological Society of China*, 33, 266-271.

[52] Manral, V., Bargali, K., Bargali, S. S., Shahi, C. (2020). Changes in soil biochemical properties following replacement of Banj oak forest with Chir pine in Central Himalaya, India. *Ecological Processes*, 9(30).

[53] Mokhtari, K. P., Ayoubi, S., Lu, S. G., Honarju, N. (2011). Use of magnetic measures to assess soil redistribution following deforestation in hilly regions. *Journal of Applied Geophysics*, 75(2), 227-236.

[54] National Metrological Agency (NMA) (2017). Addis Ababa, Ethiopia.

[55] Norouzi, M., Ayoubi, S., Jalalian, A., Khademi, H., Dehghani, A. A. (2010). Predicting rainfed wheat quality and quantity by artificial neural network using terrain and soil characteristics. *Acta Agriculturae Scandinavica Section B–Soil and Plant Science*, 60(4), 341-352.

[56] Nsabimana, D., Haynes, R. J., Wallis, F. M. (2004). Size, activity and catabolic diversity of the soil microbial biomass as affected by land use. *Applied Soil Ecology*, 26(2), 81–92.

[57] Paudel, S., Sah, J. P. (2003). Physicochemical characteristics of tropical soil (Shorea robusta Gaertn.) forests in eastern Nepal. *Himal. J. Sci.*, 1(2), 107–110.

[58] Pereira, J. D. M., Baretta, D., Bini, D., Vasconcellos, R. F., Cardoso, E. J. B. N. (2013). Relationships between microbial activity and soil physical and chemical properties in native and reforested *Araucaria Angustifolia* forests in the state of São Paulo, Brazil. *R. Bras. Ci. Solo*, 37, 572-586.

[59] Saha, S. K., Nair, P. K. R., Nair, V. D., Kumar, B. N. (2010). Carbon storage in soil size fractions under tropical tree-based land-use systems. *Plant Soil*, 328, 433-446.

[60] Singh, S., Mishra, R., Singh, A., Ghoshal, N., Singh, K. P. (2009). Soil physicochemical properties of grassland and agroecosystems receiving varying organic inputs. *Soil Sci Soc Am J*, 73(5), 1530–1538.

[61] Singh, M. K., Ghoshal, N. (2014). Variation in soil microbial biomass in the dry tropics: impact of land-use change. *Soil Research*, 52, 299-306.

[62] Singh, S., Ghoshal, N. (2006). Effect of cultivation on major physical and chemical properties of soil. *Plant Archives*, 6, 611-613.

[63] Smith, P., Davis, S., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., ... Yohe, G. (2020). Biophysical and economic limits to negative CO2 emissions. *Nature Climate Change*, 8(7), 586-593.

[64] Solomon, N., Birhane, E., Teklay, M., et al. (2024). Exploring the role of canopy cover and environmental factors in shaping carbon storage in Desa'a forest, Ethiopia. *Carbon Balance Management*, 19–30. https://doi.org/10.1186/s13021-024-00277-x.

[65] Spaccini, R., Mbagwu, J. S. C., Igwe, C. A., Conte, P., Piccolo, A. (2004). Carbohydrates and aggregation in lowland soils of Nigeria are influenced by organic inputs. *Soil Tiller Res.*, 75, 161–172.

[66] Srivastava, S. C., Singh, J. S. (1991). Microbial C, N and P in dry tropical forest soils: effects of alternate land uses and nutrient flux. Soil Biology and Biochemistry, 23, 117–124.

[67] SZPED. (2004). Sidama administrative zone: a socioeconomic profile. SZPED, Hawassa.

[68] Tajik, S., Ayoubi, S., Lorenz, N. (2020). Soil microbial communities are affected by vegetation, topography, and soil properties in forest ecosystems. Applied Soil Ecology, 149, 103514.

[69] Tilman, D., Fargione, J., Wolff, B., D'antonio, C., Dobson, A., Howarth, R., Swackhamer, D. (2001). Forecasting agriculturally driven global environmental change. Science, 292(5515), 281-284.

[70] Tripathi, N., Singh, R. S. (2009). Influence of different land uses on soil nitrogen transformations after conversion from an Indian dry tropical forest. Catena, 77, 216-223.

[71] Tripathi, S. K., Pandey, R. R., Sharma, G., Singh, A. K. (2007). Litterfall, litter decomposition and nutrient dynamics in a subtropical natural oak forest and managed plantation in northeastern India. Forest Ecology and Management, 240, 96-104.

[72] Vagen, T. G., Andrianorofanomezana, M. A. A., Andrianorofanomezana, S. (2006). Deforestation and cultivation effects on characteristics of Oxisols in Madagascar's highlands. Geoderma, 131, 190-200.

[73] Vesterdal, L., Leifeld, J. (2010). Land-use change and management effects on soil carbon sequestration: Forestry and agriculture. COST 639, 2006-2010, 25-32.

[74] Vibhuti, K., Bargali, S. S. (2020). Effects of size and altitude on soil organic carbon stock in home garden agroforestry systems in Central Himalaya, India. Acta Ecologica Sinica.

[75] Wang, Q., Wang, S., Fan, B. (2007). Litter production, leaf litter decomposition and nutrient return in Cunninghamia lanceolata plantations in South China: Effect of planting conifers with broadleaved species. Plant and Soil, 297(1), 201–211.

[76] Yang, Y., Guo, J., Chen, G. (2009). Effects of forest conversion on soil labile organic carbon fractions and aggregate stability in subtropical China. Plant and Soil, 323(1), 153–162.

[77] Ye, R., Wright, A. L., Inglett, K. (2009). Land-use effects on soil nutrient cycling and microbial community dynamics in the Everglades agricultural area. Science and Plant Analysis, 40, 2725–2742.

[78] Zeleke, G., Teshome, M., Ayele, L. (2023). Farmers' livelihood vulnerability to climate-related risks in the North Wello Zone, northern Ethiopia. Environmental and Sustainability Indicators, 17, 100220.

[79] Zeraatpisheh, M., Ayoubi, S., Mirbagheri, Z., Mosaddeghi, M. R., Xu, M. (2021). Spatial prediction of soil aggregate stability and soil organic carbon in aggregate fractions using machine learning algorithms and environmental variables. Geoderma Regional, 27, e00440.