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Original Research

Effects of Different Land Use Types on Selected Soil Physicochemical Properties at Laga Gur-Micro Watershed, Central High land of Ethiopia

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Abstract

This study aimed to assess the influence of several land use types on selected soil physicochemical properties at the Laga Gur micro-watershed. A total of nine representative composite samples, with three replications per land use type, were collected from a soil depth of 0 to 20 cm. The data were analyzed using a one-way analysis of variance (ANOVA). The results revealed that sandy loam is the predominant particle size distribution, with significant variations in key properties. Soil bulk density was remarkably higher in cultivated lands, while total porosity was maximized in forested areas, indicating better soil structure and aeration there. The chemical analysis revealed that forest lands exhibited significantly higher values of soil total nitrogen and organic carbon than other land use types. In contrast, cultivated lands recorded the lowest concentrations of these nutrients, which can be attributed to continuous tillage and soil erosion. Conversely, available phosphorus was found to be highest in cultivated lands, likely as a result of repeated fertilizer applications. The soil pH values showed slightly acidic conditions, and cation exchange capacity demonstrated consistent nutrient retention across land uses. The findings highlight that unsustainable land use practices degrade soil properties and reduce productivity. To maintain soil health and enhance agricultural sustainability, adopting integrated soil fertility management and sustainable land use strategies is essential. Further research with a larger sample size, diverse land use types, and additional soil parameters is recommended to better understand the underlying mechanisms driving these variations.

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INTRODUCTION

Land use refers to the arrangement and utilization of land cover, which is subject to human intervention and management for various purposes (Ufot *et al*., 2016). The needs of society and the overarching objectives of land allocation render land use inherently flexible and dynamic (Hoogsteen, 2015). Among various forms of land use, cultivated land is particularly susceptible to soil erosion and nutrient leaching. This vulnerability is primarily attributed to land use changes, especially the transformation of natural ecosystems into agricultural lands, which has been identified as a major contributor to global soil degradation (Ekero *et al*., 2022). Since soil constitutes a fundamental resource for diverse land use functions, its mismanagement and overexploitation often lead to severe degradation. This, in turn, results in adverse environmental consequences, including desertification, reduced agricultural productivity, contamination of water resources, and the overall depletion of soil quality and quantity (Abate et al., 2016; Mengistu, 2017; Admas, 2018; Tufa *et al*., 2019). A multitude of factors, including inappropriate land use practices, soil characteristics, topography, and climatic conditions, contribute significantly to the degradation and depletion of soil resources and their quality.

Soil erosion and fertility loss resulting from inappropriate land use practices represent critical challenges in sub-Saharan African countries (Kidanemariam, 2013). Specifically, the unsustainable conversion of natural ecosystems into agricultural land, often accompanied by poor management practices, leads to significant declines in soil fertility, land degradation, and reduced agricultural productivity (Zajícová & Chuman, 2019; Buraka et al., 2023). Moreover, alterations in land cover and the expansion of agricultural practices intensify the loss of soil organic matter and vital nutrients through leaching (Alam et al., 2017). Therefore, a comprehensive understanding of soil health is fundamental for achieving sustainable agricultural development, ensuring food security, and safeguarding environmental quality. Effective land management strategies must be grounded in a thorough understanding of how various land use systems influence soil physicochemical and biological properties (Sabiela *et al*., 2020; Molla *et al*., 2022).

Ethiopia is a developing country whose economy is predominantly reliant on agriculture (IFPRI, 2010; Yihenew, 2015). The agricultural sector employs approximately 85% of the labor force, contributes about 44% to the national gross domestic product (GDP), and accounts for 85% of the country's export earnings (UNDP, 2014). However, the rapid expansion of the population and ongoing environmental changes have accelerated the transformation of forests and grasslands into cultivated land. This transformation has significantly affected soil fertility and altered key soil properties (Seyoum, 2016; Tesfahunegn, 2016). The degradation of the soil's physical, chemical, and biological attributes, primarily driven by unsustainable land use practices, has led to a marked decline in agricultural productivity and heightened levels of food insecurity (Habtamu *et al*., 2014). Comparable patterns of land degradation are prevalent in tropical regions, where economic pressures and efforts to enhance local livelihoods frequently drive the conversion of natural forests into croplands and grazing areas. In the highland regions of Ethiopia, land degradation remains a critical constraint to agricultural productivity and poses a significant threat to the sustainability of rural livelihoods (Dame, 2017).

In particular, unsustainable agricultural practices, deforestation, and inadequate conservation measures have contributed to severe land degradation within the Laga Gur micro-watershed. These unregulated land use activities have led to accelerated soil erosion, water contamination, and a decline in biodiversity, thereby posing significant threats to the livelihoods of surrounding communities. Despite the severity of these environmental challenges, a considerable knowledge gap persists regarding the effects of land use types on the properties of the local soil. Consequently, a comprehensive understanding of the effects of various land use patterns on soil characteristics within the study area is essential for mitigating land degradation and promoting sustainable agricultural practices. Moreover, site-specific investigations provide critical insights necessary for the development of effective land management strategies aimed at preserving soil quality and enhancing ecosystem resilience. Thus, the objective of this study was to evaluate the impact of different land use types on selected physico-chemical properties of soils within the Laga Gur micro-watershed.

MATERIAL AND METHODS

Description of the Study Area

The study was conducted within the Laga Gur micro-watershed, situated in the Girar Jarso District of the North Shewa Zone, Central Highlands of Ethiopia. This area lies along the principal route connecting the capital, Addis Ababa, to Bahir Dar, approximately 112 kilometers to the north of Finfinnee. The micro-watershed is positioned at an altitude ranging from 2,471 to 2,581 meters above sea level (m.a.s.l.). Geographically, it is located between 38°48′00″ and 38°48′45″ East longitude, and 9°43′00″ and 9°44′00″ North latitude (Fig. 1).

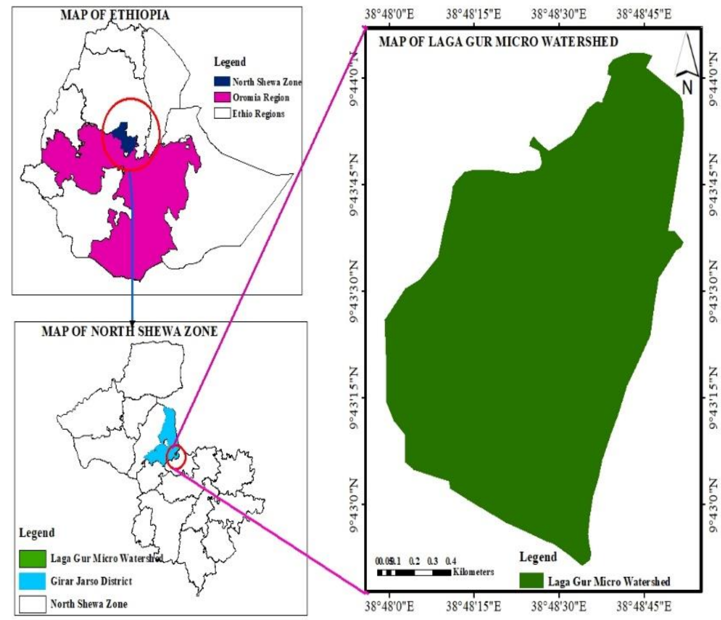

Figure 1. Study area location map

Climate, Soils, Vegetation, and Agro-ecology,

The study area is classified into two distinct agroecological zones: the highland zone (Baddaa) and the mid-altitude zone (Badda Daree), which collectively constitute approximately 70% of the total sampling area. The climatic conditions in this region are characterized by an unimodal rainfall distribution, with the rainy season occurring from March to September. The study area's annual average precipitation is 1,177.6 mm, with the primary wet season, referred to as the summer or Ganna season, spanning from June to September. Conversely, the spring or Arfaasaa season, which extends from March to June, is considered by comparatively lower rainfall. Temperature data indicate that the average minimum monthly temperature is 9.0°C, while the average maximum monthly temperature is 25.0°C (GJDAO, 2022).

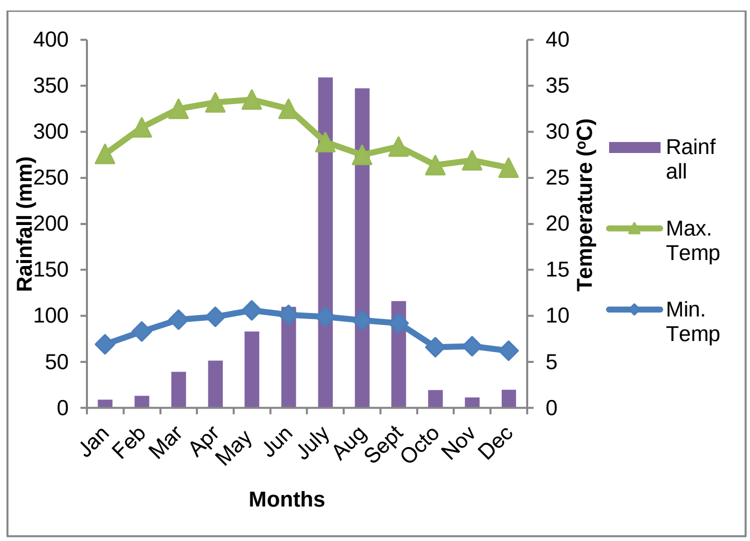

Figure 2. Mean monthly rainfall and mean monthly minimum and maximum temperatures of the Study area for eight years (2014-2022).

Pellic Vertisols represent the predominant soil types in the Girar Jarso district (OPEDB, 2001). Nonetheless, within the study area, soils are locally categorized using indigenous terminology, which includes Biyyee Kotichaa or Biyyee Gurraacha (black soils), Biyyee Diimilee (red soils), and Biyyee Cirrachaa (sandy soils). The natural vegetation in the region is characterized by sparse and discontinuous coverage, with limited tree and grass species. Among the native plant species commonly observed are *Acacia* spp. (Laaftoo), *Olea africana* (Ejersa), and *Cordia africana* (Waddeessa). Additionally, several non-native species have become prevalent in the area, including *Eucalyptus globulus*, *Eucalyptus camaldulensis*, *Grevillea robusta*, and *Juniperus procera* (GJDAO, 2022).

Study site characteristics and sampling

All relevant stakeholders at the Farmer Training Center were primarily engaged in group discussions and key informant interviews to collect primary data. Subsequently, a reconnaissance field survey was conducted to obtain a comprehensive overview of the study area's topography, vegetation cover, landforms, and land use patterns. The predominant land use categories identified included forestland, agricultural land, and pastureland. Traditional subsistence farming, primarily reliant on rainfed agriculture and practiced on privately owned plots, was found to be the dominant mode of crop production. Although cereal crops constitute the major agricultural output in the region, this land use type has undergone considerable changes over the past five decades. Notably, intensive plowing and the removal of biomass have contributed to significant soil erosion and degradation.

Moreover, manual weeding, the application of herbicides, and the improper use of both organic and inorganic fertilizers are commonly employed in land management practices. The second category pertains to grazing land, which is privately owned by farmers and was historically characterized by continuous grazing systems and persistent grass cover. Rill erosion is occasionally observed in certain areas, and cattle manure is routinely collected for domestic energy use. The study area, which was predominantly covered by forest 50 to 60 years ago, now exhibits a significant reduction in the extent of natural forested land. Presently, the region is primarily composed of native forests, trees, and shrubs, as indicated by GJDAO (2022). This specific area was selected due to its relevance to land degradation, exhibiting uniformity in terms of both topographical aspects and geological characteristics across the region.

The region is of particular significance for investigating the impacts of land degradation, resulting from various land use practices, on soil properties. The selection of the study area was guided by multiple factors, including its geographical relevance, environmental diversity, historical importance, stakeholder involvement, continuity of research, comparability to other regions, and potential for scientific contribution. To complement reconnaissance field surveys, Global Positioning System (GPS) technology was employed to capture spatial coordinates and elevation data. Nine composite samples of soils were collected systematically at 0-20 cm depth, via a Randomized Complete Block Design (RCBD) approach to ensure statistical rigor and minimize bias in sample selection. This approach accounted for slope similarity, sampling intensity per unit area, and variations in soil depth.

Subsoil samples were collected using a sampling auger in a systematic "X" pattern from over 15 randomly assigned plots within the watershed, representing various land use treatments due to the inherent heterogeneity of the area. To control bias and launch robust causal links between land use types and soil properties, the sampling procedure was replicated thrice for each distinct land use type. Undisturbed samples were retained for bulk density and porosity evaluations, whereas disturbed samples were collected, labeled, and delivered to the laboratory for comprehensive analysis. After sieving and drying, the soil samples were finely ground into a powder. Organic carbon (OC) and total nitrogen (TN) content were quantified using a 0.5 mm sieve, while additional soil characteristics were evaluated using a 2 mm sieve.

Analysis of soil physicochemical properties

The texture of the soil was examined by using the Bouyoucos hydrometer method (Bouyoucos, 1962). Subsequently, the textural class was ascertained by referencing the USDA soil textural triangle. Following oven drying at 105°C for 24 hours, the dry soil mass was divided by its volume (M (g) / V (cm^3)) to compute the bulk density of the soil samples, as described by Blake (1965). Total porosity was estimated based on bulk density (BD) and particle density (PD) data using the standard formula. An average particle density of 2.65 g/cm^3 was used for the calculations. A suspension for potentiometric pH determination was prepared by mixing soil and water in a 1:2.5 ratio, with the electrical conductivity measured in the resultant suspension, as outlined by Jackson (1973). The organic matter content in the soil was quantified by multiplying the percentage of organic carbon by a conversion factor of 1.724. The determination of organic carbon content was performed using the method described by Walker and Black (1934).

Total nitrogen content was determined through a titrimetric approach utilizing the Kjeldahl method, as outlined by Jackson (1973). Subsequently, the carbon-to-nitrogen (C:N) ratio, also referred to as the soil organic carbon to total nitrogen ratio, was calculated. The cation exchange capacity (CEC) was estimated titrimetrically by distilling ammonium displaced from a sodium chloride (NaCl) solution, following the procedure described by Chapman (1965). To quantify available phosphorus, the Bray-II method was employed, with calorimetric analysis performed using a spectrophotometer, as per the method of Bray and Kurtz (1945). Extraction of exchangeable bases (Ca, Mg, Na, and K) from soil samples was carried out using ammonium acetate (1N NH_4OAc). Sodium and potassium concentrations were analyzed using a flame photometer, while an atomic absorption spectrophotometer (AAS) was utilized for the quantification of exchangeable calcium and magnesium, as described by Chapman (1965).

Statistical Analysis

To assess potential variations in soil physicochemical properties, SAS software version 9.4 (SAS, 2013) was employed to conduct a one-way analysis of variance (ANOVA). At a significance threshold of $p < 0.05$, Duncan's Multiple Range Test (DMRT) was employed to identify significant differences between the mean values of the soil parameters. Furthermore, Pearson's correlation matrix analysis was utilized to explore the relationships between specific soil physicochemical characteristics.

RESULTS AND DISCUSSION

Changes in Soil Physical Characteristics Under Different Land Use Types

Particle size distribution

The distribution of particle sizes across the various land use categories within the study area exhibited no statistically significant differences, as indicated by the analysis of variance (ANOVA) results ($P > 0.05$) (Table 1). Specifically, agricultural land demonstrated a higher mean sand content (52.83%) compared to both forest and grazing land use types, which exhibited lower and comparable mean values for sand (51.17%). The forest land use category was characterized by the highest mean silt fraction (32.5%), whereas grazing land exhibited the lowest mean silt fraction (31.5%). Furthermore, the proportion of clay particles was greatest in grazing land (17.33%) and least in agricultural land (15.33%).

The study area is predominantly characterized by sandy loam soil, a classification that denotes a soil texture predominantly composed of sand particles, thereby indicating a higher sand content relative to other soil constituents.

The predominance of sand particles observed in the current study suggests that the parent materials, climate, soil formation processes, and high rates of erosion in the research area exhibit similarities, consistent with the findings of Sebhatleab (2014). However, in contrast to the present study, Kibret et al. (2023) reported significant variations in soil particle composition across different land use types. The persistent removal of crop yields, coupled with the selective erosion of finer soil particles such as clay and silt, may contribute to the observed increase in sand content within agricultural soils. In a similar vein, Molla and Yalew (2018) identified the primary drivers behind the elevated sand content in agricultural lands as the extraction of crop yields and the preferential erosion of finer soil fractions (clay and silt). Furthermore, an inverse relationship between these variables is evident from the correlation analysis presented in Table 4, which reveals a significant negative correlation between the sand fraction and both the silt fraction and soil organic carbon (SOC) ($r = -0.87^{**}$ and $r = -0.71^{*}$, respectively). Additionally, the similarity in textural classes among the land use categories within the study area may be attributed to the presence of comparable soil parent materials. This observation aligns with the conclusions drawn by Bore and Badadi (2015), further supporting the notion that the underlying geological factors influence soil texture characteristics in the region.

To mitigate the displacement of silt and reduce erosion, the presence of vegetative cover, particularly the root systems of trees, plays a crucial role in the stabilization of soil particles. As highlighted by Assefa et al. (2020), this vegetative cover is likely responsible for the increased concentration of silt particles observed beneath forested areas within the study region, in contrast to adjacent land use types. Conversely, the reduced concentration of clay particles in cultivated soils within the study area can be attributed to the removal of crops and the implementation of tillage practices, which expose the soil to direct rainfall, thereby exacerbating erosion. These findings align with the observations made in Yitbarek's study (2013), which further supports the notion that agricultural practices contribute to the degradation of soil structure and enhanced susceptibility to erosion.

Bulk density

The results of the analysis of variance (ANOVA) indicated that land use categories significantly ($p < 0.05$) influenced soil bulk density (BD) values (Table 1). The cultivation area exhibited the highest BD value (1.27 g cm⁻³), while forest land had the lowest value (0.90 g cm⁻³). These findings align with the substantial variation in bulk density among land use types reported by Pandey et al. (2018). Consistent with the observations of Aytenew and Kibret (2016) and Kibret et al. (2023), the elevated mean BD values in cultivation areas may be attributed to factors such as low soil organic carbon content, the impact of raindrop-induced soil erosion, and continuous tillage practices, all of which contribute to soil compaction and an increase in bulk density (Table 1, Table 2).

Table 1. Effects of different land use types on soil physical properties of the study area

Land use types	Soil physical properties					
	BD(g/cm^3)	TP (%)	Sand (%)	Silt (%)	clay%	Textural class
Forest land	0.90^{b}	69.20^{a}	51.17	32.5	16.33	Sandy loam
Cultivation land	1.27^{a}	52.00^{b}	52.83	31.83	15.33	Sandy loam
Grazing land	1.02^{ba}	61.43^{a}	51.17	31.5	17.33	Sandy loam
CV (%)	13.58	6.41	2.23	1.56	7.9	
P-value	*	**	Ns	Ns	Ns	

Mean values within a column marked with different letters are significantly different at $P \leq 0.05$. 'ns' indicates a non-significant difference at $P > 0.05$; * = significance at $P \leq 0.05$; ** = significance at $P < 0.01$. CV refers to the Coefficient of Variation, BD stands for Bulk Density, and TP represents Total Porosity.

The contents observed in forested areas (Table 1, Table 2) can be attributed to the relatively higher organic matter content, a result that aligns with the findings of Bore and Badadi (2015). The correlation analysis revealed strong negative relationships between soil bulk density and both clay particle content and total porosity, with correlation coefficients of $r = -0.77^{*}$ ($p < 0.05$) and $r = -0.91^{***}$ ($p \leq 0.001$), respectively (Table 4).

Total porosity

The Analysis of Variance (ANOVA) results revealed that total soil porosity (TP) was significantly affected ($P < 0.01$) by the various land use categories. The TP values across agricultural and forested regions ranged from 52.00% to 69.20%, respectively, as depicted in Table 1. Forested soils exhibited higher mean TP values, which can be attributed to the higher organic matter content and lower clay concentrations compared to agricultural soils (Table 1). This finding is consistent with the observations made by Biazen (2022), who reported the highest TP percentages in forested land use types. Furthermore, as presented in Table 4, a strong positive correlation ($r = 0.84^{**}$, $p < 0.01$) was observed between soil TP and soil organic carbon, further supporting the interdependence between these two variables.

In contrast, the correlation coefficient ($r = 0.63$) between total phosphorus (TP) and clay concentration was positive, yet it did not reach statistical significance. According to the FAO (2006) assessment, all land use types exhibited very high total phosphorus (TP) levels (> 40%), suggesting that the soil possessed enhanced aggregation, which is conducive to optimal crop growth conditions and promotes ideal microbial aeration.

The Influence of Land Use Types on the Chemical Properties of Soil

Soil pH and electrical conductivity

The results of the ANOVA analysis indicated that the soil pH (1:2.5 H_2O) was not significantly influenced by the land use categories ($P > 0.05$) (Table 2). In the study area, the mean soil pH values for the forest and agricultural land use categories were relatively similar, both measuring 6.13, representing the highest and lowest values, respectively. These findings contrast with those of Sabiela et al. (2020), who reported a significant variation in soil pH values based on land use types. The observed higher soil pH in forested areas can be attributed to the greater abundance of exchangeable bases, organic matter, and cation exchange capacity, which are typically more prevalent in such environments (Table 2, Table 3).

Table 2. Effect of Land Use Types on Selected Soil Chemical Properties (pH, EC, TN, SOC, C:N Ratio, and Available Phosphorus) in the Study Area.

Land use types	Chemical properties					
	PH- H_2O (1:2.5)	**EC (dS/m)**	**TN (%)**	**SOC (%)**	**C: N**	**Av. P (ppm)**
Forest land	6.23	0.21	0.26^a	2.99^a	11.5	7.09^b
Cultivation land	6.13	0.18	0.07^b	0.79^b	11.28	10.92^a
Grazing land	6.17	0.16	0.15^b	1.71^b	11.4	6.15^b
CV (%)	1.8	10.99	26.32	26.16	2.76	16.69
P=value	Ns	Ns	**	**	Ns	**

Mean values within a column accompanied by the different letter(s) are significantly different from each other at $P \le 0.05$, **=significant at $p \le 0.0$, ns=not significant at p>0.05, CV = Coefficient of variation, PH-power of hydrogen, EC=electrical conductivity, TN=total nitrogen, SOC=organic carbon, and Av. P = Available phosphorus.

The depletion of essential basic cations, resulting from persistent soil disturbances, erosion, and the repeated application of ammonium-based fertilizers such as diammonium phosphate ((NH4)2HPO4), commonly used in cereal-dominant agricultural systems, is hypothesized to be a primary factor contributing to the observed low soil pH in cultivated lands, as suggested by previous studies (Tilahun, 2015; Molla and Yalew, 2018). Importantly, the minimal variation in soil pH across different land-use types may be attributed to the robust buffering capacity inherent in the soils of the study area. Utilizing Tadesse's (1991) soil pH (1:2.5 H2O) rating scale, the average soil pH values across all land use categories indicate that the soils are mildly acidic.

Electrical conductivity (EC) was not significantly affected (p > 0.05) by the land use categories. The EC values observed for grazing and forest land uses fell within a narrow range (0.16 to 0.21 dsm^{-1}) (Table 2), which may be attributed to the comparable levels of soluble salts across all land use types. The higher EC value observed in forested areas could be linked to the relatively greater exchangeable bases, aligning with the findings of Tufa *et al.* (2019). Conversely, the lower EC value observed in grazing land could be due to the combined effects of concentrated grazing, the exclusion of animal dung, and prolonged exposure to direct rainfall, which facilitate the erosion and leaching of soluble salts, as previously reported by Seyoum (2016). According to the salinity classification system outlined by the US Salinity Laboratory Staff (1954), the soils within the research area are categorized as nonsaline (<2 dSm^{-1}), indicating that the concentrations of soluble salts present are unlikely to exert any significant influence on crop growth and productivity.

The soil pH values across the different land use categories suggest that the soils are predominantly acidic, as per the soil pH (1:2.5 H_2O) rating system proposed by Tadesse (1991). The land use classifications did not exhibit a statistically significant impact on electrical conductivity (EC) (p > 0.05). This indicates that the concentrations of soluble salts across the various land uses were comparable. The EC values for grazing and forest land uses were observed to be within a narrow range, specifically between 0.16 and 0.21 dS m^{-1} (Table 2). According to Tufa et al. (2019), the elevated EC value observed in forested areas may be attributable to a higher concentration of exchangeable bases in these soils Conversely, the reduced electrical conductivity (EC) values of the grazing land may be attributed to several factors, including intensive grazing, the removal of animal waste, and the persistent exposure of the field to direct rainfall. These conditions likely facilitate the erosion of the soil and the leaching of soluble salts, contributing to the observed decrease in EC levels.

Soil organic carbon

Soil organic carbon (SOC) concentrations were found to be significantly influenced by land use types (P < 0.01), as determined through analysis of variance (ANOVA). Among the land use categories examined, forest land exhibited the maximum SOC content (2.99%), whereas agricultural land demonstrated the lowest value (0.99%) (Table 2). The data presented in the graph indicate that a notable reduction in SOC concentrations occurred when the forested land in the study area was converted to agricultural and grazing uses. The elevated SOC levels observed in forest land may be attributed to the continuous accumulation of plant residues coupled with minimal soil disturbance, which likely facilitates the preservation of organic carbon. These findings are consistent with the observations of Defera *et al*. (2019) and Biazen (2022), who highlighted the significant role of plant litter accumulation in enhancing SOC content within forest ecosystems.

Variation in soil organic carbon (SOC) concentrations was significantly influenced by land use types, as confirmed by ANOVA (P < 0.01). Forested land exhibited the highest mean SOC content (2.99%) among the evaluated land use categories, while agricultural land exhibited the lowest mean SOC concentration (0.99%) (Table 2). These findings underscore the pronounced decrease in SOC levels following the conversion of forested areas to agricultural and grazing land uses. The elevated SOC concentrations observed in forest ecosystems can be attributed to the continuous deposition of plant litter and minimal soil disturbance, factors that contribute to the accumulation of organic matter. This observation aligns with the findings of Defera et al. (2019) and Biazen (2022), who emphasized the role of plant litter accumulation in enhancing SOC storage within forest ecosystems.

Additionally, SOC showed a weak but positive correlation with both clay and cation exchange capacity (CEC), with correlation coefficients of r = 0.35 and r = 0.12, respectively. This indicates that the soil's nutrient pool and the availability of exchangeable basic cations at the soil exchange sites exert a limited yet discernible effect on SOC levels. According to the SOC content classification by Tadesse (1991), the agricultural lands within the study area are categorized as low in SOC, whereas grazing and wooded lands fall under the medium category.

Total Nitrogen and Carbon to Nitrogen Ratio

Significant differences in total nitrogen (TN) content were observed among land use types ($P \leq 0.01$) (Table 2). The mean TN concentration was lowest under cultivated land (0.07%) and highest under forested land (0.26%). This discrepancy can likely be attributed to the substantial organic matter and soil organic carbon (SOC) content in forested land, which is closely correlated with higher TN levels (Table 2). In contrast, intensive agricultural practices, which reduce the retention of plant residues and accelerate the mineralization of organic matter, particularly in cereal-based cropping systems, appear to contribute to the lower TN concentrations observed in cultivated land. Similarly, Tufa *et al*. (2019) also reported the highest TN content in forest land. The correlation analysis showed a strong and significant positive relationship between SOC and TN ($r = 0.99^{***}$) at $p \leq 0.001$ (Table 4).

In contrast, Aytenew and Kibret (2016) reported that cultivated land exhibited the lowest total nitrogen (TN) content, which aligns with the present study's findings. The reduction in TN levels in agricultural soils may be attributed to leaching caused by excessive rainfall, corroborating the observations of G. Selassie and Ayanna (2013) and Bore and Badadi (2015). Based on the classification system proposed by Tadesse (1991), the TN concentrations in the study area were categorized as high, medium, and low for forest, grazing, and cultivated land use types, respectively. Furthermore, studies by Admas (2018) and Kibret et al. (2023) demonstrated that land use types significantly influence TN content, further supporting the results of the current investigation.

The results of the analysis of variance indicated that land use categories did not significantly affect the carbon-to-nitrogen (C:N) ratio ($P > 0.05$) (Table 2). Forested land exhibited the highest mean C:N ratio (11.5) among the land use categories, while agricultural land displayed the lowest value (11.28). This elevated C:N ratio in forested areas may be attributed to the enhanced biological activity typically associated with such ecosystems, as reported by Gebrelibanos and Assen (2013) and Defera et al. (2019). Conversely, the lower C:N ratio in cultivated land could result from intensive agricultural practices, residue removal, and soil erosion, aligning with the former finding of Chimdi *et al*. (2012). Furthermore, Power and Prasad (1997) proposed that the optimal carbon to nitrogen (C:N) ratio for soils lies within the range of 8:1 to 15:1. This assertion is verified by the present study, whose results align with this established recommendation.

Available phosphorus

Available phosphorus (Av. P) in the study area showed a significant variation across land use types ($P \leq 0.01$) (Table 2). Forested land exhibited the lowest mean Av. P content (7.09 ppm), while cultivated land demonstrated the highest concentration (10.92 ppm). This variation might be due to the extensive use of synthetic fertilizers such as diammonium phosphate (DAP), the regular application of bovine manure, and enhanced soil weathering processes in agricultural areas compared to adjacent land uses. These findings are consistent with previous studies that have documented an increase in the concentration of available phosphorus in agricultural soils due to the continuous application of manure and phosphorus-based fertilizers (Aytenew and Kibret, 2016; Chemeda, 2017; Kibret *et al*., 2023).

The forest land exhibited the lowest mean value of available phosphorus (Av. P), which can be attributed to the relatively slower decomposition rate of organic matter in environments characterized by lower temperatures and reduced aeration. These conditions are typically more prevalent in forest ecosystems compared to agricultural lands. This finding suggests that soil organic matter (OM) does not have a significant effect on the availability of phosphorus in grazing and forest soils. Table 4 illustrates a strong negative correlation ($r = -0.73^{*}$, $P < 0.05$) between available phosphorus (Av. P) and soil organic carbon (SOC). Based on Olsen's (1954) classification system for available phosphorus, the soils in the study area were categorized as having medium levels of accessible phosphorus in cultivated fields, and low levels in both pasture and forest lands. This suggests that the fixation of native phosphorus in the study area may be significantly influenced by both grazing and forest land use types.

Cation exchange capacity

The analysis of variance indicated that cation exchange capacity (CEC) in the study area was not significantly influenced by different land use types ($P > 0.05$) (Table 3). The land use types with the highest mean CEC values were forested land (49.91 cmol (+) kg^{-1}) and agricultural land (48.48 cmol (+) kg^{-1}). The elevated CEC observed in these land use types can be attributed to the higher soil organic carbon (SOC) content typically associated with forested areas (Tables 2 and 3). This finding aligns with previous studies by Adugna and Abegaz (2016) and Takele et al. (2014), which similarly reported the highest CEC values under forest land use. The preliminary conclusion drawn by Molla et al. (2022) is corroborated by the present data, which demonstrates that the cation exchange capacity (CEC) of the soil remains relatively invariant across different land uses. However, underlying factors such as soil type, parent material, and the stability of soil functions may contribute to the negligible fluctuations in the mean CEC values observed across the various land uses within the study area.

Table 3. Effect of land use types on selected soil chemical properties (CEC, Exchangeable: Ca, Mg, Na, K) cmol $_{(+)}$/kg and % of PBS) of the study area.

Land Use Types	**CEC (cmol$_{(+)}$/kg)**	**Exchangeable base (cmol $_{(+)}$/kg**				**% of base saturation**
		Ca	**Mg**	**Na**	**K**	**(PBS)**
Forest land	49.91	33.27	7.73	0.46	0.4	80.87
Cultivation land	48.48	24.97	8.07	0.37	0.38	70.67
Grazing land	49.59	29.10	6.67	0.47	0.31	76.5
CV (%)	17.2	12.12	13.02	12.96	14.62	15.14
P-value	Ns	Ns	Ns	Ns	Ns	Ns

Mean values within a column followed by different letter(s) are significantly different from each other at P >0.05, ns = not significant at P>0.05, CV = Coefficient of variation, and CEC = Cation exchange capacity.

Furthermore, the high CEC values suggest that the soils in the study area possess a strong buffering capacity against external changes, as noted by Seyoum (2016). A strong positive correlation ($r = 0.78^*$, $p < 0.05$) was observed between cation exchange capacity (CEC) and the carbon-to-nitrogen ratio (C:N). Conversely, CEC displayed a negligible positive correlation with both bulk density ($r = 0.11$) and pH ($r = 0.03$), as presented in Table 4. According to the classification by Hazelton and Murphy (2007), the CEC of soils across all land-use types in the study region was categorized as exceptionally high. This suggests that the soils in the area exhibit a pronounced buffering capacity, enabling them to effectively withstand induced environmental changes.

Exchangeable bases (EB)

The ANOVA results showed that land use types did not have a statistically significant effect on exchangeable base cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) ($p > 0.05$) (Table 3). The results of the ANOVA indicated that the influence of land use types on the exchangeable bases (Ca^{2+}, Mg^{2+}, Na^+, and K^+) was not statistically significant (Table 3, $p > 0.05$). Despite this, the data revealed variations in the mean concentrations of exchangeable bases across the different land use categories within the study area. Specifically, the average exchangeable calcium (Ca^{2+}) content in cultivated land was recorded at 33.27 cmol (+) kg^{-1}, whereas in forested land, it was 24.97 cmol (+) kg^{-1}. These findings, as presented in Tables 2 and 3, suggest that elevated levels of soil organic carbon (SOC), pH, and cation exchange capacity (CEC) in forest land may contribute to the higher concentrations of exchangeable bases observed in this land use type. This observation aligns with previous studies conducted by Adugna and Abegaz (2016) and Yitbarek (2013).

Similarly, Shambel et al. (2024) reported that land use classifications had no significant effect on exchangeable bases. However, these findings contradicted those of Molla et al. (2022), who demonstrated that land use categories exerted a considerable influence on exchangeable bases. Other studies suggest that the reduced mean values observed may be due to factors such as intensive cultivation and the removal of agricultural harvests (Seyoum, 2016; Defera et al., 2019; Donis and Assefa, 2017). In the current study area, exchangeable calcium (Ca^{2+}) concentrations were found to be exceptionally high, as classified by FAO (2006).

The mean exchangeable magnesium (Mg^{2+}) content was highest in cultivated land (8.07 cmol (+) kg^{-1}) and lowest in grazing land (6.67 cmol (+) kg^{-1}) (Table 3). The results of this study contrast with those of Paul *et al*. (2019), who stated the lowest exchangeable Mg^{2+} concentrations in agricultural land. However, the higher exchangeable Mg^{2+} in cultivated land may be attributed to the application of animal manure during cereal crop cultivation, as well as the incorporation of crop residues left on the field. Furthermore, the exchangeable Mg^{2+} concentrations in cultivated land, forests, and grazing areas are consistent with the high values reported by FAO (2006).

The contents of exchangeable potassium (K^+) were highest (0.4 cmol (+) kg^{-1}), and lowest (0.31 cmol $_{(+)}$ kg^{-1}) (Table 3) under forest and grazing land use type, respectively. The relatively high K^+ content in forest soils could be attributed to the abundance of organic matter, consistent with the findings of Tufa *et al*. (2019). Conversely, the reduced K^+ concentrations observed in grazing areas may be primarily attributed to nutrient depletion resulting from intensive grazing pressure, erosion, and diminished organic inputs such as animal excreta. These findings are in agreement with those reported by Shambel et al. (2024), who also observed similar trends in K^+ distribution across varying land-use types. Moreover, as presented in Table 4, exchangeable potassium (K^+), soil organic carbon (SOC) ($r = 0.09$), and clay content ($r = 0.05$) exhibited positive, though statistically non-significant, correlations ($p > 0.05$). Based on the classification criteria established by FAO (2006), the mean concentrations of exchangeable K^+ across all land use categories were generally categorized as moderate.

The highest values (0.47 cmol (+) kg^{-1}) of exchangeable sodium (Na^+) were recorded in the grazing land, while the lowest value (0.37 cmol (+) kg^{-1}) was observed in the cultivated land. This variation may be attributed to the accumulation of urine, animal excreta, and decomposing plant residues, which likely contribute to the elevated Na^+ levels in grazing areas. Furthermore, exchangeable Na^+ demonstrated positive correlations with soil pH ($r = 0.11$), organic carbon (OC) ($r = 0.54$), and total phosphorus (TP) ($r = 0.57$), as presented in Table 4; however, these correlations were not statistically significant ($p > 0.05$). These associations may partially account for the numerical differences in exchangeable Na^+ concentrations observed across the distinct land use systems in the study area. According to the FAO classification (2006), the levels of exchangeable Na^+ across all land use types in the study region fall within the medium range.

Overall, the results of both the analysis of variance (Table 3) and correlation analysis (Table 4) indicated no statistically significant differences ($P > 0.05$) in the concentrations of exchangeable Mg^{2+}, Na^+, and K^+ among the various land use types. Based on the arithmetic mean values across these land use categories, the relative abundance of exchangeable base cations in the soils exhibited the following order: $Ca^{2+} > Mg^{2+} > Na^+ > K^+$. This trend deviates from the typical sequence reported by Defera *et al*. (2019), who observed the order $Ca^{2+} > Mg^{2+} > K^+ > Na^+$ in soils with a pH of 5.5 or higher. The observed inconsistency in the distribution of exchangeable base cations within the study area's soils may be attributed to imbalances in the concentrations of these cations.

Percent base saturation (PBS)

The land use categories within the study area did not exhibit a statistically significant influence on percent base saturation (PBS) (Table 3). The mean PBS in cultivated land was 70.67%, whereas forest land exhibited a comparatively higher value of 80.87%. This elevated PBS in forest land may be attributed to greater organic matter accumulation and higher concentrations of exchangeable base cations. Comparable findings were reported by Molla and Yalew (2018), who observed maximum PBS levels in forest ecosystems and the lowest in cultivated fields. The reduced PBS observed in agricultural land may be associated with lower soil pH and a diminished sum of base cations (Table 2), corroborating the findings of Seyoum (2016).

Percent base saturation (PBS) was not significantly influenced by the different land use categories within the study area (Table 3). The PBS recorded in forest land was 80.87%, whereas it was notably lower in cultivated land, at 70.67%. The relatively higher PBS values observed in forested areas may be attributed to the greater accumulation of soil organic matter and the increased availability of exchangeable base cations, compared to other land use systems. These findings are consistent with those reported by Molla and Yalew (2018), who observed the highest PBS values in forested ecosystems and the lowest in cultivated soils. The reduced PBS in agricultural land may be associated with its lower soil pH and diminished sum of exchangeable bases, as indicated in Table 2, which corroborates the findings of Seyoum (2016). Furthermore, PBS exhibited a positive, though statistically non-significant ($p > 0.05$), correlation with organic carbon (OC) ($r = 0.42$), clay content ($r = 0.53$), soil pH ($r = 0.43$), and exchangeable cations, including calcium, magnesium, sodium, and potassium ($r = 0.27$, 0.26, 0.24, and 0.42, respectively) (Table 4). These observations are consistent with the findings reported by Kedir (2015). In general, the cation exchange sites of most soil samples were predominantly saturated with basic cations, particularly Ca^{2+} and Mg^{2+}. The concentration of PBS in the study area was classified as extremely high in forested ecosystems, with comparatively elevated levels also detected in pasture and cultivated lands, in agreement with the classification criteria proposed by Hazelton and Murphy (2007).

Table 4. Pearson's correlation matrix for selected soil physicochemical parameters of Laga gur micro-watershed of Girar Jarso District

	BD	TP	pH	EC	Sand	Silt	clay	TN	OC	CN	Av. P	CEC	Ca	Mg	Na	K	PBS
BD																	
TP	-0.91***	1.00															
pH	-0.25	0.2	1.00														
EC	-0.47	0.48	0.93***	1.00													
sand	0.4	-0.38	-0.79**	-0.89**	1.00												
silt	0.03	0.01	0.72*	0.75*	-0.87**	1.00											
clay	-0.77*	0.63	-0.08	0.05	0.01	-0.49	1.00										
TN	-0.84**	0.85**	0.62	0.81**	-0.70*	0.42	0.37	1.00									
OC	-0.83**	0.84**	0.63	0.82**	-0.71*	0.45	0.35	0.99***	1.00								
CN	0.56	-0.47	0.11	0.03	-0.24	0.58	-0.73*	-0.23	-0.2	1.00							
Av. P	0.63	-0.6	-0.3	-0.53	0.68*	-0.52	-0.15	-0.73*	-0.73*	-0.07*	1.00						
CEC	0.11	-0.07	0.03	0.02	-0.17	0.35	-0.42	0.10	0.12	0.78*	-0.25	1.00					
Ca	-0.77*	0.79**	0.58	0.76*	-0.68	0.39	0.4	0.91***	0.91***	-0.16	-0.54	0.2	1.00				
Mg	0.15	-0.26	-0.04	-0.13	0.11	-0.03	-0.12	-0.20	-0.20	0.00	-0.19	-0.24	-0.55	1.00			
Na	-0.37	0.57	0.11	0.33	-0.26	0.27	-0.09	0.54	0.54	-0.08	-0.65	0.01	0.25	0.31	1.00		
K	-0.02	0.21	0.13	0.08	0.33	-0.32	0.05	0.09	0.09	-0.43	0.4	-0.38	0.01	0.01	0.27	1.00	
PBS	-0.52	0.45	0.43	0.47	-0.25	-0.03	0.53	0.44	0.42	-0.76*	-0.16	-0.81**	0.27	0.26	0.24	0.42	1.00

*=significant at $p \le 0.05$, **=significant at $p \le 0.01$ and ***=highly significant at $p \le 0.001$, BD = Bulk Density, TP=Total porosity, Av. P = Available Phosphorous, CEC = Cation Exchange Capacity, TN = Total Nitrogen, SOC = Soil Organic carbon, C: N=Carbon to nitrogen ratio, PBS = Percent Base Saturation and Exchangeable Base (Ca^{2+}, $Mg^{2+,}$ Na^{1+} and K^{1+})

CONCLUSIONS AND RECOMMENDATION

The findings of this study revealed that land use types had a significant influence on several soil physicochemical properties. Soils in the study area were predominantly classified as sandy loam in texture. Specifically, various land use practices exhibited distinct effects on the levels of available phosphorus (Av. P), bulk density (BD), total porosity (TP), soil organic carbon (SOC), total nitrogen (TN), and other key soil properties. Cultivated lands experienced increased bulk density and nutrient depletion, primarily due to continuous tillage, erosion, and the removal of crop residues. In contrast, forested areas displayed superior soil structure, characterized by higher porosity, SOC, and TN. Additionally, the elevated levels of available phosphorus in agricultural lands could be attributed to the application of fertilizers.

The conversion of forest land to cultivated land leads to soil degradation, primarily through nutrient depletion and compaction. Notably, the lowest levels of soil organic carbon (SOC) and total nitrogen (TN), along with the highest bulk density, were observed in cultivated land, indicating a higher degree of soil degradation compared to other land use types in the study area. To mitigate these adverse effects and promote sustainable agricultural practices, effective land management strategies are crucial. Further research involving larger sample sizes, diverse land use types, and additional soil properties is necessary to validate these findings and enhance the understanding of the interactions between land use and soil quality.

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