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RESEARCH ARTICLE

Assessment of Soil Carbon Stock in Different Land Use Types of Eastern Türkiye

Emre Çomaklı ✉ • Müdahir Özgül • Hüseyin Aydın

Atatürk University, Faculty of Agriculture, Department of Soil Science and Plant Nutrition, Erzurum/Türkiye

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ABSTRACT

Soil organic carbon (SOC) is one of the sensitive indicators in monitoring changes in terrestrial ecosystems and land use practices. Studies to determine SOC stocks and increase their capacity are of critical importance in combating climate change and preventing land degradation. This study evaluated SOC stocks in a semi-arid micro-watershed with different land uses in the Eastern Anatolia Region. The land use types examined were identified as moderate rangeland (MR), weak rangeland (WR), agricultural land (AL), and degraded area (DA). Representative areas (1 ha each) were selected based on dominant vegetation and management history. A total of 60 soil samples were collected using a random sampling method, with 15 samples per hectare evenly distributed to minimize spatial variability. Sampling was conducted at two depths: 0-10 cm and 10-20 cm. Bulk density (BD), electrical conductivity (EC), pH, soil texture, calcium carbonate ($CaCO_3$), and SOC analyses were conducted on the soil samples. The research findings revealed statistically significant differences in SOC stocks between land uses ($P<0.001$). The SOC amounts were calculated as follows: MR (50.79 Mg C ha^{-1}) > AL (42.36 Mg C ha^{-1}) > WR (30.86 Mg C ha^{-1}) > DA (11.69 Mg C ha^{-1}). These findings indicate that land use and management practices significantly influence SOC stocks. The highest SOC stocks (50.79 Mg C ha^{-1}) were recorded in MR and conservation of these areas can contribute significantly to carbon sequestration. The lowest SOC stocks (11.69 Mg C ha^{-1}) were recorded in DA and erosion control and vegetation restoration were recommended. For intermediate SOC stocks (42.36 Mg C ha^{-1}) in AL, the use of organic fertilizers and reduced tillage practices can reduce SOC losses. Lower SOC stocks (30.86 Mg C ha^{-1}) were recorded in WR, and improved grazing management was recommended. Additionally, it can be stated that sustainable soil management practices could prevent land degradation and thus contribute significantly to combating climate change.

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1. Introduction

Terrestrial ecosystems are vital habitats for humans. Especially in mitigating the effects of global climate change, storing carbon in terrestrial ecosystems is the most straightforward way to balance atmospheric CO_2 concentrations. The most important carbon sink of terrestrial ecosystems is soil (Ozlu et al., 2022; Pandey et al., 2023). This has particularly increased interest in storing CO_2 and other carbon gases (such as CH_4 and HFCs) in the soil. It is noted that soils store approximately three times the carbon of plant cover ecosystems and about twice as much as the atmosphere (Babur & Dindaroglu, 2020).

Land use and land cover changes interact with local, regional, and global climate processes, altering ecosystem

✉ Correspondence
E-mail address: emrecomakli@atauni.edu.tr

responses, Earth's albedo, the carbon cycle, and the climate system (Houghton, 2018). Land use changes, such as issues related to excessive urbanization and unsustainable land uses, lead to soil degradation (Battaglia et al., 2022). Soil degradation poses a serious threat to the capacity of soil to provide vital ecosystem services, including mitigating the adverse effects of climate change, regulating food production, and maintaining water quality (Dindaroglu et al., 2021). Land use changes that result in soil degradation affect the amount of carbon stored or released in soils, as well as key ecosystem processes like the hydrological cycle (Eze et al., 2023; Sheil, 2018).

Rangelands constitute the second-largest terrestrial ecosystem in Türkiye (Babur et al., 2021). Rangeland contain the highest SOC stocks in soils after forests, accounting for approximately more than one-third of terrestrial carbon reserves (B. Wang et al., 2018). Rangelands cover approximately 25% of the Earth's surface and contain about 12% of terrestrial carbon reserves (Janowiak et al., 2017). Enhancing the long-term productivity of moderate and poor grasslands is critical for combating global climate change by increasing the amount of stored carbon (ÇEM, 2018). Although healthy grassland soils generally have high SOC stocks, the SOC levels in many of these soils have decreased due to intensive management practices (Silver et al., 2018). Unsustainable land management practices, such as excessive and irregular grazing, have led to the significant removal of grassland vegetation, making the grasslands more vulnerable to erosion; this is especially exacerbated by the thinning of grassland cover that prevents soil erosion on sloping terrains (B. Çomaklı et al., 2012; Palta & Lermi, 2019).

Rangelands, particularly in the subsoil, possess high SOC stocks. The variability of grassland vegetation negatively impacts the carbon cycle, so improving it allows for more CO_2 to be sequestered from the atmosphere and stored in above-ground and below-ground biomass, and ultimately in the soil (Yusuf et al., 2015). From this perspective, the amount of SOC, an important indicator of soil fertility, is especially significant in grasslands. Since the variability of grassland vegetation affects the carbon cycle, enhancing it facilitates the removal of more CO_2 from the atmosphere and its storage in above-ground and below-ground biomass, and eventually in the soil. This can be attributed to the abundance of grasses, which increases the amount of stored SOC (Berihu et al., 2017; Qiang et al., 2016). SOC and plants interact with each other in terms of chemical and physical properties and play a crucial role in the nutrient dynamics of the ecosystem. Furthermore, the quantity of subsoil biomass allows for the formation of soils rich in organic matter (Coskun et al., 2016).

Rangelands in Türkiye cover approximately 14.6 million hectares, accounting for 18.8% of the country's total surface area (TÜİK, 2019). However, only 12.4% of these rangelands are in good condition, while 87.6% are in moderate or poor condition. About 40% of Türkiye's rangeland assets are located in the Eastern Anatolia Region (Okcu, 2020), where semi-arid conditions play a critical role in influencing soil organic carbon (SOC) dynamics. In these regions, factors such as grazing intensity, soil type, and climatic conditions significantly accelerate SOC losses. Overgrazing and irregular management have caused serious degradation, leading to substantial reductions in SOC stocks (ÇEM, 2018). Despite these challenges, the amount of carbon stored in Türkiye's rangelands is estimated at approximately 50 tons/ha, highlighting their potential for carbon sequestration (TUBITAK BILGEM YTE, 2018).

Studies on the management of rangelands in Türkiye have revealed the importance of rangelands in livestock production and the problems encountered in rangeland management. Türkiye’s Rangeland Law (Mera Kanunu, 1998) is considered as an important step towards the protection and development of these areas; however, problems such as soil degradation still persist in practice (Gökkuş et al., 2000). A study conducted in pistachio tree areas in south-eastern Türkiye showed that soil organic carbon stocks varied between 0.19-4.44 kg C m^{-2}. This research emphasises the influence of vegetation cover on SOC levels and the carbon sequestration capacity of soil properties such as clay content (Çelik & Acar, 2017).

International studies in similar ecosystems confirm this situation. A study in southern Patagonia revealed the effects of climate, vegetation and desertification on SOC, showing that overgrazing causes erosion of carbon stocks (Peri et al., 2018). In another study conducted in southern Spain with a Mediterranean climate, it was reported that local environmental factors such as soil clay content and depth significantly affect SOC levels (Willaarts et al., 2016).

Factors such as rangeland utilization types, grazing intensity and plant species diversity are decisive in the management of SOC stocks. Sustainable rangeland management practices to be carried out in the Eastern Anatolia Region have critical importance in terms of protecting and increasing carbon stocks in the light of national and international examples.

In agricultural lands, intensive farming practices lead to significant changes in soil organic carbon (SOC) stocks. Intensive tillage practices can reduce SOC stocks, which in turn may lead to a decline in soil fertility. Additionally, intensive soil cultivation accelerates the mineralization of organic matter, resulting in carbon losses (Six et al., 2000). To ensure sustainable land management and increase SOC storage capacity, it is essential to quantify the amount of SOC stored in the soil. Particularly, the effective implementation of sustainable carbon management strategies relies on a comprehensive evaluation of different land uses. In this context, the scarcity of research on grasslands limits the comparability of assessment criteria. Comparing SOC stocks between grasslands, agricultural lands, and rangelands areas is crucial for understanding the impact of different land use types on the carbon cycle. Rangelands, particularly in the subsoil, have high SOC stocks; however, agricultural lands and forested areas are also important SOC storage areas. Enhancing the impact of each land use type on SOC can aid in the development of sustainable carbon management strategies. Furthermore, many studies have shown that the decline in soil quality due to the loss of organic matter and nutrients is often a result of land use or management conditions (Abdalla et al., 2018; Yu et al., 2018). Therefore, even small changes in the SOC reservoir due to variations in land use can significantly impact on the global carbon cycle. This study aims to quantitatively assess and compare SOC stocks across different land uses in a semi-degraded semi-arid micro-watershed. Additionally, this study provides recommendations for effective and efficient sustainable carbon management.

The transition from MR to WR, to AL, and then to DA is critical for studying different land management practices and their long-term effects. These transition processes have been studied, considering specific land use history. Particularly, transitions from MR to WR and from AL to DA have been selected to understand the long-term impacts of intensive grazing and agricultural activities. These transition processes are crucial in assessing the effects of land use changes on Soil Organic Carbon (SOC) stocks. This study focuses on determining and comparing the impacts of these processes on SOC stocks.

The main sources of income in the region are agriculture and livestock farming. Animals in the villages within the micro-watershed are grazed uncontrollably in forest clearings and highlands outside of active agricultural fields. As a result of excessive and intensive grazing, the rangelands have begun to degrade. Over time, the botanical composition in these areas has deteriorated. *Predominantly,* species such as *Koeleria cristata, Astragalus* sp., *Festuca ovina, Stipa sp.,* and *Dactylis glomerata* are found in the rangeland areas. Areas considered as agricultural land are typically soil-tillage farmlands. Soil tillage is conducted using plows that invert the soil, significantly contributing to erosion and progressively decreasing the productivity of the agricultural lands. Agricultural production is carried out not for commercial purposes but to meet the needs of the local population. The main crops are barley, wheat, oats, and alfalfa. On the other hand, degraded areas are those where the bedrock has been exposed due to erosion, making agricultural activities impossible. In these degraded areas, the most common species is *Juniperus communis* L.

2. Materials and Methods

2.1. Study Area

This study was conducted in different land uses in the Narman district (40° 23' N - 41° 54' E) of Erzurum province in the Eastern Anatolia Region (Türkiye) (Figure 1). The elevation of the land varies between 1540 m and 1650 m. The average slope and elevation of MR, WR, AL, and DA are respectively 1610 m, 30%; 1570 m, 30%; 1550 m, 4%; and 1580 m, 30%. These different land use types represent the prevalent land use structures in the region and the transition processes between these structures.

The study area, according to the Newhall simulation model, exhibits a typical typic xeric moisture regime and a mesic soil temperature regime (Newhall, 1972). Climate data indicate that the area's climate conditions range from semi-arid to humid (De Martonne Index) (Dursun & Babalık, 2021; MGM, 2022), with an annual average precipitation of approximately 390.5 mm. In the study area, 52% of the precipitation occurs during the long rainy season (April-July), 20% during the short rainy season (September-November), and the remaining 28% in other seasons. The highest temperature is observed in August (22.5 °C), while the lowest temperature is recorded in January (-3.6 °C), with an annual average temperature of 9.9 °C (Meteorological Station in Oltu district). While mollisol soils have developed in rangeland areas, entisol soils have formed in degraded areas where vegetation has been severely damaged. The region's challenging topographic features and inappropriate land use have resulted in severe erosion (E. Çomaklı, 2019). The research area is located in the Northeast Anatolian Orogenic belt. In this context, characteristics specific to the orogenic belt are predominant (Atalay, 1982).

Significant differences in slope exist among the land use types (ranging from 4% to 30%). The slope classification in the study area was determined by digitizing 1/25.000 scale topographic maps using ArcGIS 10.5 software (E. Çomaklı, 2019).

2.2. Sampling and Laboratory Analysis

In this study, four sampling areas (MR, WR, AL and DA) of 1 ha each were identified to represent different land use types. A total of 60 soil samples were collected from each sampling area using random sampling method. From each sampling area, 15 soil samples were taken from 0-10 cm and 10-20 cm depths.

The selection of 1 ha sampling area for each land type was carried out considering the heterogeneous land structure of the study area and limited accessible areas. In addition, the rugged topography of the micro-basin limited sampling at greater distances and necessitated a more compact area. In addition, the random sampling method was used to avoid possible repetitions and to reflect the heterogeneity in the fields in the best way.

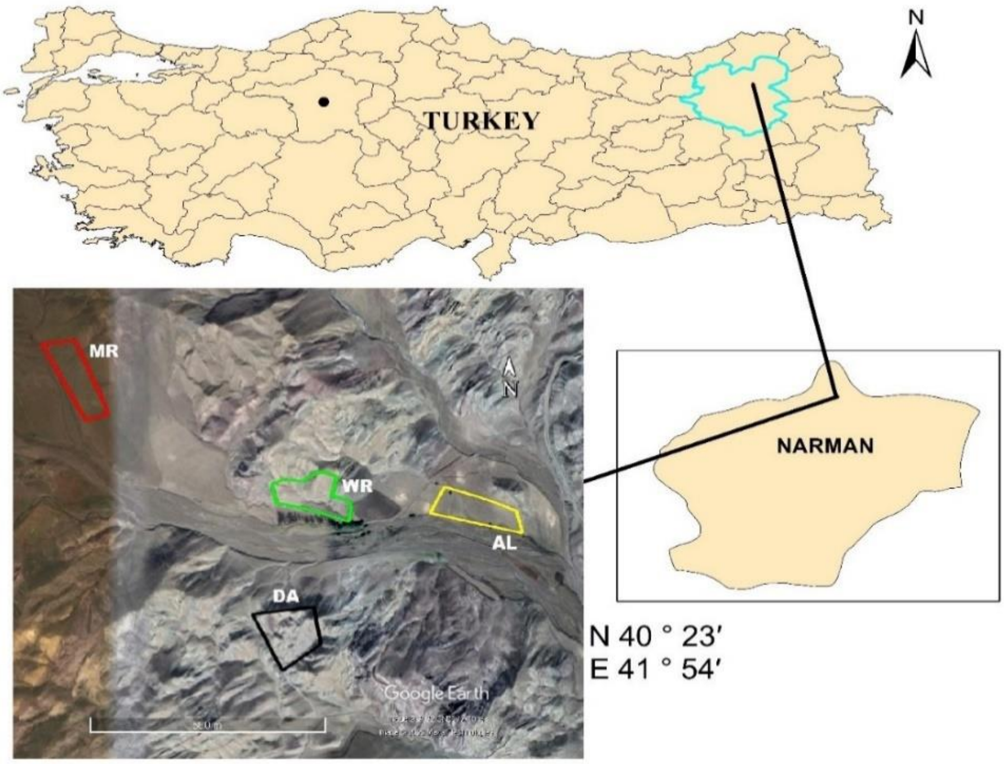

Figure 1. Map of the study area (MR: moderate rangeland, WR: weak rangeland, AL: agricultural land and DA: degraded area).

2.2.1. Soil sampling procedures

Soil samples were collected in October-November 2021 to determine SOC, bulk density (BD), CaCO3, pH, electrical conductivity (EC), and soil texture. A random sampling method was used to collect soil samples from 25 points in each sampling area, using 100 cm^3 steel cylinders (5 cm diameter, 5.1 cm height). Two types of soil samples were taken: disturbed samples for the analysis of SOC concentration, pH, EC, soil texture, and lime ($CaCO_3$) content, and undisturbed samples for bulk density determination. Sampling was conducted at two depth levels, 0-10 cm and 10-20 cm, and average values were calculated for each depth.

All collected samples were transported to the laboratory in plastic bags. Disturbed samples were air-dried, passed through a 2 mm sieve, and prepared for further analysis. For total carbon analysis, these samples were oven-dried at 60°C (Neill et al., 1997), and SOC concentration was measured using a Leco CNS-2000 dry combustion analyzer. Bulk density was calculated from the mass of oven-dried undisturbed samples and the cylinder volume. Electrical conductivity (EC) and pH were measured using a 1:2 soil-to-water ratio, based on methods by Rhoades (1993). Soil texture was analyzed using the Bouyoucos hydrometer method (Gee & Bauder, 1986), and lime ($CaCO_3$) content was determined using the Scheibler Calorimeter method (Loeppert & Suarez, 1996).

2.2.2. Biomass sampling procedures and assessment of rangeland conditions

The transect method was used to collect vegetation data to determine rangeland conditions. Five lines were selected from each rangeland and 10 transect lines were measured along each line (Figure 2). Soil cover rates in rangelands were calculated by dividing the points found in the vegetation study by the total number of measured points (Gökkuş et al., 2000). Rangeland conditions were determined according to the recommended criteria, taking into account 20% multipliers and all reductions (Koç et al., 2003).

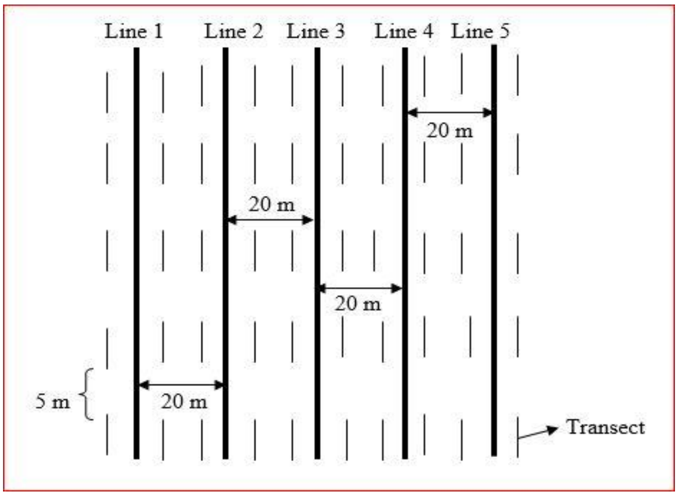

Figure 2. Schematic view of five line transect sampling.

The condition of the rangeland was classified as very good, good, moderate, or poor based on the presence of decreasing, increasing, and invasive plant species. The method developed by Gökkuş et al. (2000) was used to evaluate rangeland conditions according to ecological criteria. Additionally, SOC stocks were calculated separately for each soil depth, and the total SOC content up to a depth of 20 cm was determined by summing the SOC amounts for each depth layer.

2.2.3. Calculation of soil organic carbon (SOC) stocks

The amount of carbon (C) in the studied soil depth (Mg C ha^{-1}) was calculated using the following equation (Tilaki et al., 2021) (Eq. 1):

$$SOC_s(Mg\ C\ ha^{-1}) = \frac{\%SOC}{100} \times Bd\left(\frac{mg}{m^3}\right) \times SD \times 10^4\left(\frac{m^2}{ha}\right) \quad (1)$$

SOC_s is the organic carbon stocks at 0–20 cm soil depth (Mg C ha^{-1}), SOC is the organic carbon content, Bd is the soil bulk density in g/cm^3, SD is the soil depth in m.

2.3. Data Analysis

Data were analyzed using the IBM SPSS Statistics 20.0 program. Data were compared using one-way analysis of variance (ANOVA) and significant differences between means were calculated using Tukey's HSD (honestly significant difference) test. Additionally, principal component analysis (PCA) was performed to reduce data dimensionality, identify key relationships among variables, and improve overall data interpretation.

3. Results and Discussion

3.1. Soil Textural Fractions

In this study, the effects of different land uses on SOC and some soil physicochemical properties were examined. Soil physicochemical properties vary over time and space due to various biotic and abiotic factors such as topography, climate, weathering processes, vegetation, and microbial activities (Bargali et al., 1993; Manral et al., 2020; Paudel & Sah, 2003). This variability also has a significant impact on the particle size distribution of soils. Particle size distribution is a critical factor in determining the physical and chemical properties of soil, which in turn directly influence processes such as erosion and vegetation development (Aderonke & Gbadegesin, 2013). In this context, particle size distribution plays an important role in determining the soil's texture class and its susceptibility to erosion. The findings of this study demonstrate that land use type significantly influences soil texture and its associated properties, which directly impact SOC dynamics. This indicates that improving soil texture through sustainable land management practices could mitigate erosion and enhance SOC storage.

The soil texture class by land use type was identified as SL (Sandy Loam) in both weak rangelands and agricultural lands, SL in moderate rangelands, and SCL (Sandy Clay Loam) in degraded areas. Among the land use types, the highest sand distribution values were observed in rangeland areas (Figure 3). While there was not a significant difference in silt content among the land use types, clay content was found to be highest in degraded areas (34%) and lowest in moderate rangelands (7%). Generally, it is known that clayey soils have higher SOC content compared to sandy soils. However, in degraded areas, due to erosion, the surface sand, silt, and organic residues are carried away, leading to a proportional increase in the clay content. This may be due to the reduction of organic matter in degraded areas as a result of intense erosion and vegetation loss (Y. Wang et al., 2011). Therefore, even with high clay content, SOC levels remain low due to the reduced organic matter content (Zhou et al., 2019). This finding highlights the dual impact of erosion in degraded areas, where clay accumulation increases compaction, but organic matter loss results in low SOC levels. Such areas require targeted interventions such as erosion control and organic matter restoration to restore SOC stocks. The differences in soil texture classes are influenced by factors such as parent material, soil organic matter, and microbial activity. In highly fragmented landscapes, bioclimatic conditions vary over short distances, leading to significant heterogeneity in soil types and their chemical and physical properties. The high clay content and low sand content in degraded areas can result in increased soil compaction and water retention capacity, which may inhibit root growth and lead to SOC loss. The results underline the importance of promoting sustainable grazing and cultivation practices that enhance microbial activity and improve soil texture. Expanding well-managed rangeland areas could serve as a practical solution for increasing SOC stocks while maintaining soil health. Well-managed rangelands and cultivated lands, on the other hand, improve soil structure, promote microbial activity, and enhance organic matter accumulation, thereby increasing SOC stocks. In this context, understanding how soil properties change over time and space and how land management strategies contribute to these changes is crucial for sustainable soil management and combating climate change (Quesada et al., 2011).

The soil texture classes in lands under different use and management practices have been identified as finer-textured in the subsoil and coarser-textured in the topsoil, depending on the erosion conditions of the topsoil. It has been observed that soil organic matter (SOM) undergoes erosion along with complex colloidal surfaces, leading to a reduction in SOC in these areas. Similarly, in sloping and rugged topographic conditions, changes in soil structure over time are expected to result in a decrease in SOC. Indeed, Qi et al. (2018) reported in their study that the slope of the land can lead to the loss of fine soil particles (clay and silt particles), which can result in a texture dominated by larger particles, like sand, due to erosion. The findings suggest that the erosion-prone nature of sloping lands further exacerbates SOC loss by removing finer soil particles and organic matter. This calls for the implementation of land management strategies that stabilize soil on slopes and minimize the erosive impact of water and wind.

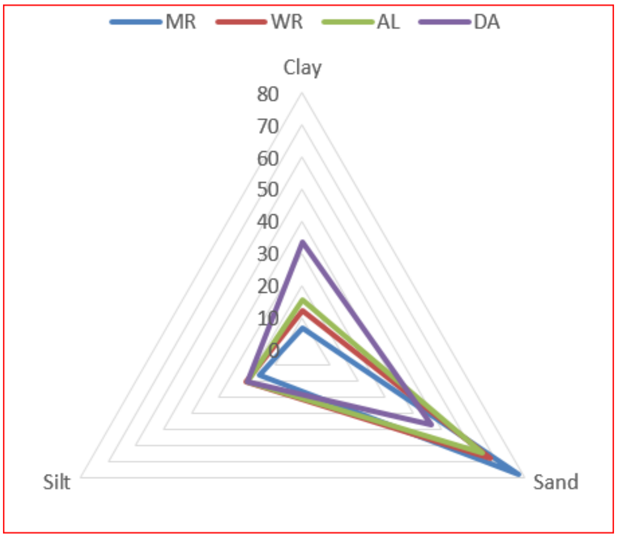

Figure 3. Soil textural fractions according to land use cases. MR: moderate rangeland, WR: weak rangeland, AL: agricultural land and DA: degraded area.

3.2. Soil Bulk Density

The bulk densities calculated for different land uses are as follows: MR (0-20 cm) 1.14 g/cm³; WR (0-20 cm) 1.29 g/cm³; AL (0-20 cm) 1.35 g/cm³; and DA (0-20 cm) 1.42 g/cm³ (Table 1). Bulk density significantly differed across the land use types ($p < 0.05$). At a soil depth of 0-20 cm, the bulk density in DA is approximately 25% higher than in MR. Additionally, bulk density varied significantly with soil depth. In all land uses, an increase in bulk density was observed in the surface soil. This can be explained by the erosion processes in the watershed where the study area is located, which remove the highly porous surface soil with high soil porosity and expose the underlying subsoil (B horizon), resulting in higher measured bulk density values due to compaction conditions (Figure 4).

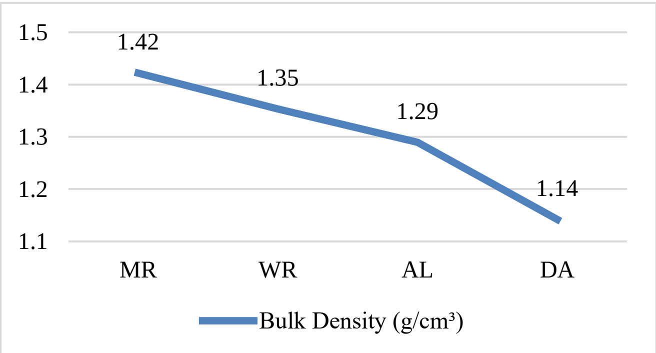

Figure 4. Variation of average bulk density depending on soil depth (0-20 cm) in different land uses. MR: moderate rangeland, WR: weak rangeland, AL: agricultural land and DA: degraded area.

The lower bulk density of MR compared to other soils can be associated with its higher SOC content. Differences in land degradation can lead to variations in soil bulk density (E. Çomaklı, 2019; Takele et al., 2015). The higher bulk density in AL compared to rangelands has been linked to soil compaction caused by the use of heavy machinery during agricultural practices. Similar findings have been reported in other studies (Bargali et al., 2019; Padalia et al., 2018; Vibhuti et al., 2020).

While some studies have shown that low bulk density occurs as SOC content increases, other studies have noted that soils with high SOC content and clay texture can have higher bulk density (Bewket & Stroosnijder, 2003; Chaudhari et al., 2013; Don et al., 2011; Teshome et al., 2016). This may also be related to the degradation of rangelands due to increased soil compaction as a result of overgrazing (Shiferaw et al., 2019). Overgrazing can affect the degree of SOM decomposition by causing physical changes in soil properties, disrupting the soil's structural integrity, and leading to soil compaction (Teshome et al., 2016).

Soil physical properties and bulk density are also closely related to the moisture and temperature regimes under which the soil formed. In the region where the study area is located, soils formed under conditions characterized by a typic xeric moisture regime and a mesic soil temperature regime tend to have lower bulk density. Sandy soils, generally having lower total porosity, tend to exhibit lower bulk density. In contrast, soils with a high clay content typically have higher total porosity and, consequently, higher bulk density (Brady & Weil, 2008; Marschner, 1995).

3.3. Soil pH and EC

Soil pH values were found to be in the following order: AL (8.13 ± 0.41) > DA (7.86 ± 0.48) > WR (7.84 ± 0.48) > MR (7.67 ± 0.55) (Figure 5). Soil pH values differed statistically significantly among the different land use types ($p<0.05$) (Table 1). These differences may be attributed to processes such as dissolution, oxidation, hydration, and others that occur due to the influence of parent material and plant diversity. The chemical composition of the parent rock, particularly its acidic or basic characteristics, can directly affect the soil's pH (Smith et al., 2013). Plant diversity significantly impacts soil pH levels; different plant species can alter the soil microbiota and the availability of mineral elements through root secretions, thereby affecting pH (Jones et al., 2009). Dissolution processes, especially the impact of water on parent rocks, allow the chemical components of minerals to mix into the soil (White & Brantley, 2018).

There is a significant relationship between soil pH and SOC. In MR, near-neutral pH values and high SOC levels were observed. This suggests that the high amount of organic matter may help maintain soil pH at near-neutral levels. Near-neutral pH levels can contribute to slower decomposition of organic matter, leading to higher SOC accumulation. On the other hand, higher pH values and lower SOC levels were observed in DA. Higher pH levels can lead to faster decomposition of organic matter and result in SOC loss. Similar findings were reported in studies by Hai et al. (2010) and Marschner (1995).

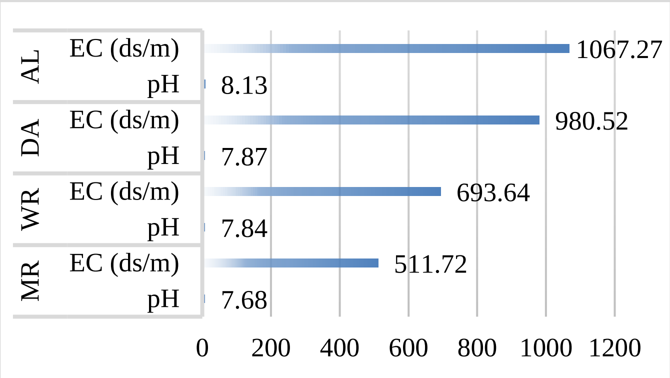

Figure 5. Variation of pH and EC in different land use situations. MR: moderate rangeland, WR: weak rangeland, AL: agricultural land and DA: degraded area.

EC values were found to be in the following order: AL (1067.3 ± 13.3) > DA (980.5 ± 23.0) > WR (693.6 ± 10.7) > MR (511.7 ± 10.4) (Figure 5). A significant difference was recorded between different land use types and soil EC (*p<0.01*) (Table 1). It is likely that EC is influenced by differences in SOC and clay content depending on land use. Similar studies suggest that soluble salts, soil moisture content, soil temperature, and nutrient concentrations also play a role in EC variation. Additionally, as the level of soil degradation increases, EC values in the soil significantly rise (Brevik et al., 2006; Husson et al., 2018; Paillet et al., 2010; Yang & Sun, 2021). In arid and semi-arid regions, land management, agriculture, and climate conditions (especially rainfall and high evaporation) can lead to significant soil salinization. In the other hand the higher EC values in agricultural lands may be due to irrigation and fertilization activities. A study by Zhaoyong et al. (2014) found that irrigation, fertilization, and agricultural activities have a significant impact on increasing soil salinity characteristics.

The relationship between SOC and EC can be explained by the effects of SOC on the solubility of mineral salts and ion mobility. High SOC levels improve soil structure and water retention capacity, allowing soluble salts to be more evenly distributed. This stabilizes EC values and prevents excessive salinization. The low EC values in MR suggest that these areas have higher organic matter content and fewer salinity issues. On the other hand, the high EC values in DA can be associated with the reduction of soil organic carbon and the increase in salt accumulation. This can negatively impact plant growth and soil fertility.

The effects of SOC on EC in different land use types are closely related to the influence of soil organic matter quantity and distribution on soluble salts and nutrient elements. Additionally, sustainable land management and organic matter applications can balance soil EC values, minimize salinity issues, and enhance soil fertility. Indeed, similar results have been obtained in studies by Brevik et al. (2006), Paillet et al. (2010) and Husson et al. (2018).

3.4. Soil $CaCO_3$ content

$CaCO_3$ content (Figure 6) was found to be in the following order across different land use types: AL (18.53 ± 2.88) > DA (11.07 ± 2.57) > WR (10.14 ± 3.43) > MR (9.21 ± 2.55). These data indicate a significant difference between land use types and soil $CaCO_3$ content (*p<0.01*) (Table 1). The high levels of $CaCO_3$ in agricultural lands, in particular, may be attributed to soil cultivation activities and the naturally high calcium carbonate content of the parent material. Additionally, irrigation water sources with high $CaCO_3$ content could contribute to calcium carbonate accumulation in the soil. Similar findings have been reported in studies by Ghorbani et al. (2013), Nazari (2013), Vafaeizadeh et al. (2016), and Hashemi (2017).

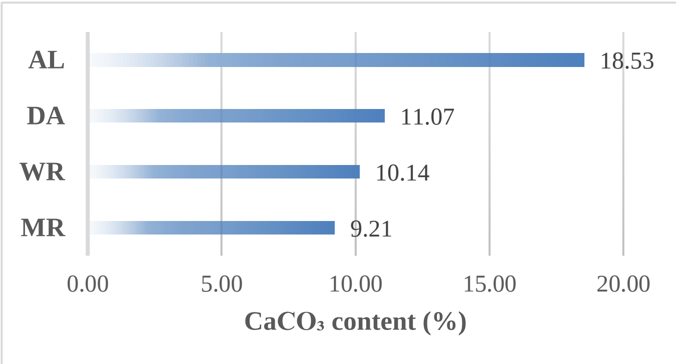

Figure 6. $CaCO_3$ changes in their content according to different land uses. MR: Moderate rangeland, WR: Weak rangeland, AL: Agricultural land and DA: Degraded area.

The relationship between SOC and $CaCO_3$ is quite significant. In soils with high $CaCO_3$ content, the mineralization of organic matter may accelerate, leading to a reduction in SOC stocks. High pH levels can promote the breakdown of organic matter and increase carbon dioxide release during this process. On the other hand, low $CaCO_3$ content can improve soil structure, contributing to the stabilization of organic carbon in the soil (Bronick & Lal, 2005). It has also been noted that in soils with high $CaCO_3$ content, microbial activity may be affected, which can have direct impacts on the SOC cycle (Rasmussen et al., 2007). In the study area, the high $CaCO_3$ content in AL has likely increased the mineralization of SOC, leading to a decrease in SOC stocks. Conversely, the lower $CaCO_3$ content in MR has contributed to the stabilization of organic carbon, thereby preserving higher SOC levels.

3.5. Soil Organic Carbon Stock

Human interventions in ecosystems have adverse effects on SOC stocks. The intensive use of rangelands and improper agricultural practices are the most prominent examples of these negative impacts. Research findings indicate that the highest SOC percentage is found in MR lands, while the lowest is observed in WR and DA lands. SOC contents are ranked as MR > AL > WR > DA. Significant differences were found between land use types and SOC in the study area (*$p<0.01$*) (Table 1). This suggests that land use practices have a significant impact on overall SOC stocks. Overgrazing and intensive agricultural practices lead to the loss of soil organic matter and a reduction in SOC stocks, whereas sustainable agricultural practices and rangeland management help preserve and increase SOC stocks. The high SOC content in MR lands can also be attributed to the increased organic matter resulting from annual vegetation cover. While a reduction in carbon content is expected in agricultural lands due to soil tillage and erosion, higher SOC levels can be expected in areas where erosion is partially controlled and fertilizers are applied (Martinez-Mena et al., 2008; Y. Wang et al., 2011). The low SOC content in WR may be due to factors such as overgrazing, soil compaction, and vegetation loss, while the low SOC content in AL may result from intensive soil tillage, loss of organic matter, and lack of organic fertilizers (Y. Wang et al., 2011). Additionally, intensive irrigation practices in AL can negatively impact soil structure, leading to SOC loss (Martinez-Mena et al., 2008).

Table 1. Change of soil properties according to land uses.

	SOC (Mg C ha^{-1})	CaCO3 (%)	pH	Clay(%)	EC (dS/m)
MR	1.788±0,95^{a}	9.214±2.552^{b}	7.679±0.559^{B}	6.602±0.947^{d}	511.721±10.447^{d}
WR	1.143±0.700^{ab}	10.143±3.43^{b}	7.840±0.485^{AB}	12.269±0.919^{c}	693.640±10.732^{c}
AL	1.642±1.265^{a}	18.532±2.882^{a}	8.130±0.406^{AB}	15.658±1.19^{b}	1067.272±13.325^{b}
DA	0.513±0.265^{b}	11.074±2.574^{b}	7.869±0.485^{A}	33.953±1.530^{a}	980.520±23.032^{a}
p	**	**	*	**	**

Values followed by small and capital in a column shows significant differences at p< 0.01 and p< 0.05 levels, respectively, using Tukey's HSD test. *: Statistical difference at p< 0.05, **: Statistical difference at p< 0.01. MR: moderate rangeland, WR: weak rangeland, AL: agricultural land and DA: degraded area.

Correlation analysis was used to examine the relationship between the five parameters found in soil samples, regardless of land use type. A positive correlation was found between SOC and $CaCO_3$, while a negative correlation was found between SOC and clay content (Table 2). Although various studies have shown a positive correlation between SOC and clay concentration, this relationship is thought to be influenced by land use practices and vegetation diversity (Hishe et al., 2017; Niu et al., 2015). Additionally, a positive correlation was found between $CaCO_3$ content and both pH and EC. The highest correlation coefficient was found between clay content and EC. The correlation between clay and EC, though variable depending on soil conditions, is critically important when evaluating soil properties (Kühn et al., 2009; Reyes et al., 2018; Sudduth et al., 2005).

Table 2. Pearson correlation coefficient between different properties of soils in all sample points.

	SOC (Mg C ha^{-1})	$CaCO_3$ (%)	pH	Clay (%)	EC (dS/m)
SOC	1	0.324**	0.148	-0.429**	-0.185
$CaCO_3$		1	0.430**	0.084	0.641**
pH			1	0.096	0.303**
Clay				1	0.676**
EC					1

**Correlation is significant at the 0.01 level (2-tailed).

The average SOC values at a soil depth of 0-20 cm in the four different land use types were found to be 50.79 Mg C ha^{-1} for MR, 30.86 Mg C ha^{-1} for WR, 42.36 Mg C ha^{-1} for AL, and 11.69 Mg C ha^{-1} for DA (Table 3). The results indicate that SOC decreases significantly with the reduction of vegetation cover. The reduction in vegetation cover due to factors such as overgrazing leads to a decrease in soil organic matter and, consequently, a reduction in SOC levels (Zhou et al., 2019). Agricultural practices have been identified as potentially reducing SOC levels (Maia et al., 2010). However, since carbon emissions were not measured in this study, it can be suggested that the increase in SOC stock in AL and its underlying reasons may be related to different land management practices (Álvaro-Fuentes et al., 2014; Don et al., 2011; Lal et al., 2011). Pearson correlation analysis was conducted to examine the relationships between SOC, $CaCO_3$, pH, clay content, and EC across all sample points. Separate analyses were performed for each land use type (MR, WR, AL, and DA), and no significant differences in the correlation patterns were observed. Therefore, the data were combined to present a general correlation matrix (Table 2). The analysis revealed significant correlations between SOC and other soil properties, particularly clay content and $CaCO_3$ levels, emphasizing the importance of these factors in influencing SOC stocks. Although agricultural practices have been identified as potentially reducing SOC levels (Maia et al., 2010), the results suggest that the increase in SOC stock in AL and its underlying reasons may be related to different land management practices (Álvaro-Fuentes et al., 2014; Don et al., 2011; Lal et al., 2011). Since carbon emissions were not measured in this study, further investigation is needed to understand the role of agricultural management in SOC dynamics.

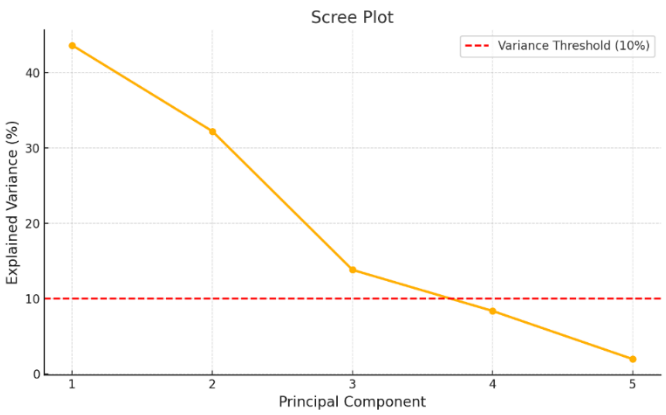

Figure 7. Principal component analysis (PCA) variance distribution.

The elbow point on the graph is clearly seen after the 2nd component. This shows that the components after the 2nd component do not contribute significantly to the total variance and can be neglected (Figure 7). According to the PCA results, an inverse relationship was determined between SOC and EC; SOC has a negative loading (-0.884) on the 2nd component, while EC has a positive loading (0.776). This shows that increasing the amount of organic matter tends to reduce soil salinity and conductivity. While high SOC increases soil fertility, high EC generally negatively affects plant growth. This relationship shows that organic matter applications in soils with salinity problems can improve soil quality by both increasing SOC levels and decreasing EC.

The results indicate that human intervention and land use changes significantly impact SOC stocks. Other studies have also emphasized that sustainable agricultural practices positively influence SOC in soil (Álvaro-Fuentes et al., 2014; Don et al., 2011; Lal et al., 2011; Martín et al., 2016). Additionally, it has been found that the application of organic manure directly increases SOC (Cai et al., 2019; Gravuer et al., 2019; Sykes et al., 2020).

Table 3. Change of SOC stocks by land use.

	SOC(Mg C ha^{-1})
MR	50.792±27.022^{a}
WR	30.855±18.907^{b}
AL	42.356±32.642^{ab}
DA	11.690±6.037^{c}
Overall mean	33.923±27.346
P	*

Values followed by small in a column shows significant differences at $p< 0.05$ levels, using Tukey's HSD test. *: Statistical difference at $p< 0.01$. MR: moderate rangeland, WR: weak rangeland, AL: agricultural land and DA: degraded area.

4. Conclusion

The results showed that there were differences in soil organic carbon stocks in moderate rangeland, weak rangeland, agricultural land, and degraded areas. The total SOC followed the order as MR > AL > WR > DA with the total SOC stocks of each land use as 50.79 Mg C ha^{-1}, 42.36 Mg C ha^{-1}, 30.86 Mg C ha^{-1}and 11.69 Mg C ha$^{-1,}$ respectively. These findings indicate that medium quality rangelands have a high carbon sequestration potential. Accordingly, expanding and rehabilitating medium quality rangeland (MR) areas can be an effective strategy to increase SOC stocks on a larger scale. Interventions such as controlled grazing, erosion control measures, and sustainable afforestation practices are crucial to support this goal. Depending on the condition of the rangelands, rehabilitation measures to increase the amount of carbon stored in the soils may include controlled grazing, erosion control measures, and treatments combining planting and partial afforestation.

The Pearson correlation analysis conducted in this study revealed significant relationships between SOC and key soil properties such as clay content and $CaCO_3$ levels. These findings highlight the critical role of soil texture and carbonate content in influencing SOC stocks. Importantly, the consistency of these relationships across all land use types suggests that general patterns in SOC dynamics are present regardless of specific land management practices. This reinforces the importance of managing soil texture, improving vegetation cover, and controlling carbonate levels to mitigate SOC losses. The Pearson correlation coefficient between SOC (Soil Organic Carbon) and EC (Electrical Conductivity) was calculated as 0.97. This indicates a very strong and positive relationship between SOC and EC.

In weak rangelands and degraded areas, targeted rehabilitation measures are essential to restore soil health and increase carbon storage capacity. Implementing sustainable soil management strategies to promote vegetation and prevent erosion is critical to reverse the negative effects of land degradation. In agricultural lands, conservation tillage practices and the use of organic fertilizers can help maintain and enhance SOC levels.

To ensure long-term ecological balance and address climate change issues, further research should focus on comprehensively monitoring SOC dynamics. Long-term assessments and larger-scale surveys will contribute to a better understanding of SOC dynamics across different land use types and support the development of sustainable land management strategies. Prioritizing environmentally friendly practices that increase SOC retention is vital for mitigating the effects of climate change and protecting soil health.

It is necessary to use soil C management strategies that increase soil C inputs rather than activities that deplete soil C and nutrient reserves. In order to preserve overall ecological stability across a different land use application, comprehensive investigations of soil carbon sequestration and its involvement in climate change mitigation should be carried out, in particular. Because of this, environmentally friendly and sustainable land management strategies that may limit soil organic carbon losses should be chosen in order to enhance the amount of carbon retained in the soil.

Further research could provide a better understanding of the effects of different land use types on SOC stocks. Long-term monitoring and data collection over larger areas in particular could contribute to the development of sustainable land management strategies.

Conflict of Interest

The authors declare that they have no conflict of interest.

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