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Sema Kaplan[a*]

[a] Dr., Erciyes University, semakarabag@gmail.com

[*] Corresponding Author

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# Effects of Different Land Uses on Soil Quality Indicators in and around Mount Erciyes

## Abstract

**Background/Aim:** Land use changes alter soil physical and chemical properties, with significant consequences for soil quality and ecosystem sustainability. This study aimed to determine the effects of different land use types (pasture, meadow, field, orchard-garden, coniferous forest, oak forest, recreation, and wetland) on soil quality indicators in and around Mount Erciyes.

**Methods:** Soil samples were collected from depths of 0-10 cm and 10-20 cm. Texture, organic matter, pH, electrical conductivity (EC), lime ($CaCO_3$), available phosphorus ($P_2O_5$), aggregate stability, exchangeable cations (Ca, Mg, K, and Na), and cation exchange capacity (CEC) were analyzed.

**Results:** Land use type had statistically significant effects on most of the soil properties examined ($p \leq 0.01$). In surface soils, meadow and pasture areas exhibited higher organic matter (2.95-3.18%), aggregate stability (0.63), and CEC (10.51-27.31 me 100 $g^{-1}$) values, while these were lower in field and recreation areas. Wetlands differed from other land use types with higher $CaCO_3$ (13.13%), EC (1.03 dS $m^{-1}$), exchangeable K (1.92 me 100 $g^{-1}$), and Na (2.91 me 100 $g^{-1}$) contents. Similar trends were observed at 10-20 cm depth: meadow, pasture, and oak forest areas showed higher organic matter and aggregate stability values, whereas these were lower in field areas. Wetlands again stood out with high EC, Na, and CEC values.

**Conclusion:** Soil quality was higher in meadow, pasture, and forest areas with preserved natural vegetation, whereas agricultural and recreational use led to decreases in some soil quality indicators. These findings provide important insights for developing sustainable land management strategies in semi-arid and volcanic ecosystems.

**Keywords:** Land use, Soil quality, Organic matter, Aggregate stability

# Erciyes Dağı ve Çevresinde Farklı Arazi Kullanımlarının Toprak Kalite Göstergeleri Üzerine Etkileri

## Öz

Arazi kullanımındaki değişimler, toprakların fiziksel ve kimyasal özelliklerini etkileyerek toprak kalitesi ve ekosistem sürdürülebilirliği üzerinde önemli sonuçlar doğurmaktadır. Bu çalışma, Erciyes Dağı ve çevresinde farklı arazi kullanım tiplerinin (mera, çayır, tarla, bahçe, iğne yapraklı orman, meşelik, rekreasyon ve sulak alanlar) toprak kalitesi göstergeleri üzerindeki etkilerini belirlemek amacıyla yürütülmüştür. Toprak örnekleri 0-10 cm ve 10-20 cm derinliklerden alınmış; tekstür, organik madde, pH, elektriksel iletkenlik (EC), kireç ($CaCO_3$), yarayışlı fosfor ($P_2O_5$), agregat dayanımı, değişebilir katyonlar (Ca, Mg, K ve Na) ile katyon değişim kapasitesi (KDK) belirlenmiştir.

Sonuçlar, arazi kullanım şeklinin incelenen toprak özelliklerinin büyük çoğunluğu üzerinde istatistiksel olarak önemli etkiler oluşturduğunu

göstermiştir (p≤0.01). Yüzey topraklarında çayır ve mera alanları daha yüksek organik madde (%2.95-3.18), agregat dayanımı (0.63) ve KDK (10.51-27.31 me 100 $g^{-1}$) değerleri ile öne çıkarken, tarla ve rekreasyon alanlarında bu özelliklerin daha düşük olduğu belirlenmiştir. Sulak alanlar ise yüksek $CaCO_3$ (%13.13), EC (1.03 dS $m^{-1}$), değişebilir K (1.92 me 100 $g^{-1}$ toprak) ve Na (2.91 me 100 $g^{-1}$ toprak) içerikleriyle diğer arazi kullanım tiplerinden ayrılmıştır. Benzer eğilimler 10–20 cm derinlikte de gözlenmiş; çayır ve meşelik, mera ve meşelik alanlar daha yüksek organik madde ve agregat dayanımı değerleri gösterirken, tarla alanlarında bu değerler daha düşük bulunmuştur. Sulak alanlar ise yüksek EC, Na ve KDK değerleri ile dikkat çekmiştir.

Araştırma sonuçları, doğal vejetasyonun korunduğu çayır, mera ve orman alanlarında toprak kalitesinin daha yüksek olduğunu, tarımsal ve rekreasyonel kullanımın ise bazı toprak kalite göstergelerinde azalmaya neden olduğunu ortaya koymuştur. Bu bulgular, yarı kurak ve volkanik ekosistemlerde sürdürülebilir arazi yönetimi stratejilerinin geliştirilmesine katkı sağlayabilecek önemli bilgiler sunmaktadır.

**Anahtar kelimeler:** Arazi kullanımı, Toprak kalitesi, Organik madde, Agregat dayanımı

## 1. INTRODUCTION

Changes in land use and land cover are among the most important factors affecting the physical, chemical, and biological properties of soils [1,2]. Land use changes resulting from human activities alter the physicochemical structure of soils, leading to a decline in soil fertility and the degradation of ecosystem functions. In particular, the destruction of forest areas reduces aggregate stability and intensifies processes such as surface runoff, floods, drought, erosion, and desertification [3,4].

Over the last century, the expansion of agricultural activities and population growth have caused significant changes in land use worldwide [5,6]. Scenarios projecting future agricultural land use emphasize that, despite increases in crop productivity, the need to feed a wealthier and larger global population will probably require further agricultural expansion. Estimates indicate that billions of hectares of natural ecosystems could be converted to agriculture by 2050, accompanied by increases in nutrient loading and pesticide use and adverse effects on ecosystem services and biodiversity [7,8]. The conversion of forest areas to agricultural land causes degradation of the natural ecosystem, weakening of soil structure, loss of organic matter, and an increased risk of erosion.

Changes in land management practices also exert significant effects on soil properties. Bringing sloping areas under cultivation, overgrazing, inadequate fallow practices, and the lack of policies supporting sustainable land management lead to significant changes in the physical and chemical properties of soils [9,10]. Similarly, the conversion of forest areas to agricultural land reduces organic matter inputs, decreases soil fertility, accelerates the loss of soil organic matter and nutrient elements, and substantially increases the risk of erosion [11,12]. Agricultural intensification and changes in land cover accelerate land degradation processes by increasing the leaching of organic matter and nutrient elements [13,14].

The effects of land use on soil properties have been demonstrated by studies conducted in different regions of the world. For example, a study carried out in the karst regions of Romania determined that the conversion of forest areas to agricultural land had significant effects on pH, phosphorus, total nitrogen, base saturation, exchangeable cations, and cation exchange capacity. The same study reported that agricultural areas had the lowest soil organic carbon contents [14]. Similarly, a long-term study conducted in Ethiopia found that forest areas decreased by 37.8% between 1957 and 2017, whereas agricultural areas increased by 36.7%, and it was emphasized that this change accelerated land degradation processes [15].

Land use change is a dynamic process that refers to the transformation of the Earth's surface under the influence of human activities, climate change, fires, floods, and other natural processes [16,17]. This process is an important tool for understanding the mutual interaction between humans and the environment and is of great importance for the development of sustainable land management practices.


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Andisols, which cover 0.8% of the Earth's surface, are widely distributed in volcanic regions, primarily the western coasts of the Americas, Kamchatka, Japan, New Zealand, Hawaii, and Iceland [18]. In Türkiye, extensive volcanic areas are also found, particularly in Eastern and Central Anatolia [19,20]. These soils, which have high natural fertility owing to their mineralogical and physical characteristics [21], have also been investigated in Türkiye in terms of their andic properties and classification [22]. In the volcanic agricultural soils east of Mount Erciyes, low organic matter and lime contents, low aggregate stability, and a high erosion tendency have been reported [23].

Although the effects of land use on soil properties have been investigated in different regions, studies on this subject in the volcanic ecosystems of Türkiye with semi-arid climatic conditions are limited. In particular, the number of comprehensive studies jointly evaluating the effects of different land use types on the physical and chemical properties of soils in and around Mount Erciyes is quite small. Because it contains different altitudinal belts, various vegetation types, and different land use forms within the same geographical region, Mount Erciyes constitutes an important natural laboratory for examining land use-soil relationships. This study aimed to compare some physical and chemical properties of soils in the meadow-pasture, forest (oak and coniferous), agricultural areas (field and orchard), wetlands, and recreation areas commonly found in and around Mount Erciyes.

## 2. MATERIALS AND METHODS

[Describe the experimental setup, data collection, and analysis processes.]

### 2.1. Study Area

The research was conducted in and around the volcanic Mount Erciyes located within the boundaries of Kayseri province. Mount Erciyes is one of the most important volcanic formations of the Central Anatolia Region and contains different altitudinal belts, vegetation types, and land use forms together. The study area was selected to cover meadow, pasture, forest, agricultural land, wetland, and recreation areas.

The region exhibits a continental climate, with hot and dry summers and cold, snowy winters. The long-term mean temperature is 10.6 °C, and the mean annual total precipitation is 392 mm.

Geologically, the Kayseri region comprises units belonging to different periods extending from the Paleozoic to the Cenozoic. The center of the region is situated within a graben system formed as a result of tectonic movements that developed during the Quaternary period. Metamorphic, sedimentary, ophiolitic, and volcanic rock assemblages of terrestrial and marine origin are widely observed throughout the province; in particular, volcanic materials such as ignimbrite, andesite, and volcanic ash occur at a marked density in the İncesu, Develi, and Tomarza districts surrounding Mount Erciyes [23]

**Figure 1.** Location of the study area: Mount Erciyes and its surroundings, Kayseri, Türkiye

### 2.2. Method

Soil samples were collected as composite samples obtained by mixing soil from three points within a 1 m radius area at depths of 0-10 cm and 10-20 cm at each sampling point, from a total of 40 points. The sampling points were distributed according to land use types as 5 pasture, 3 meadow, 7 field, 4 orchard, 5 coniferous forest, 5 oak forest, 5 recreation, and 6 wetland sites; two samples were taken from two different depths (0-10 cm and 10-20 cm) at each point, yielding a total of 80 soil samples. After the samples were brought to the laboratory, they were air-dried, sieved, and made ready for analysis. The organic matter content of the soils was determined according to the Smith-Weldon method [24]. Soil texture was analyzed using the Bouyoucos hydrometer method [25]. Soil reaction (pH) was measured with a glass-electrode pH meter in a 1:2.5 soil-water suspension [26]. The lime ($CaCO_3$) content of the soils was determined volumetrically by the Scheibler calcimeter method [27].

Exchangeable cations (Ca, Mg, K, and Na) were determined using an ICP-OES spectrometer after extraction with 1 N ammonium acetate solution (pH=7.0) [28]. Cation exchange capacity (CEC) was determined with the aid of ICP-OES after ammonium acetate extraction in samples saturated with sodium acetate (1 N, pH=8.2) [28]. Available phosphorus contents were determined by the spectrophotometric method in extracts obtained with sodium bicarbonate [29]. Total nitrogen contents were determined according to the Micro-Kjeldahl method after wet digestion with a salicylic acid-salt mixture [30]. Aggregate stability was determined by the single-sieve method developed by [31]. In this method, aggregates 1-2 mm in size were subjected to wet sieving on a 0.25 mm sieve; the aggregates were then dispersed using NaOH as the dispersion solution, and aggregate stability was calculated from the results obtained.

## 3. RESULTS AND DISCUSSION

Some physical and chemical properties of the 0-10 cm soil depth for different land use types are presented in Table 1. The results showed that land use type statistically affected a significant portion of the soil properties ($p \leq 0.01$). In contrast, no statistically significant differences were found among land use types in terms of silt content, pH, and available $P_2O_5$ values.

Among the soil texture components, clay content ranged from 5.28% to 16.92%, with the highest value in meadow areas (16.92%) and the lowest in oak forest areas (5.28%). Sand content ranged from 58.40% to 73.71%, with the highest value in coniferous forest areas (73.71%) and the lowest in meadow areas (58.40%). In terms of organic matter content, pasture (2.95%), meadow (3.18%), and wetland areas (2.95%) had the highest values, whereas lower values were obtained in field (1.56%), oak forest (1.48%), and recreation areas (1.54%). Similarly, $CaCO_3$ content varied significantly depending on land use, with the highest value in wetlands (13.13%) and the lowest in coniferous forest areas (0.81%). The electrical conductivity (EC) values of the soils ranged from 0.09 to 1.03 dS $m^{-1}$, with the highest EC value in wetlands (1.03 dS $m^{-1}$). In terms of aggregate stability, coniferous forest areas (0.67), pasture (0.63), and meadow areas (0.63) had the highest values, whereas wetlands (0.34) and field areas (0.38) had the lowest aggregate stability. This indicates that soil structure is more stable in areas with natural vegetation. When exchangeable cations were examined, Ca content ranged from 6.91 to 20.61 me 100 $g^{-1}$ soil, with the highest value in meadow areas. The highest K content was found in wetlands (1.92 me 100 $g^{-1}$ soil) and the highest Mg content in meadow areas (3.84 me 100 $g^{-1}$ soil). In terms of Na content, wetlands (2.91 me 100 $g^{-1}$ soil) showed significantly higher values than all other land use types. Cation exchange capacity (CEC) ranged from 8.90 to 27.31 me 100 $g^{-1}$ soil, with the highest value in meadow areas and the lowest in field areas.


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**Table 1.** Soil Properties at 0-10 cm Depth under Different Land Uses

| Soil Properties | Land Use (0-10 cm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Pasture | Meadow | Field | Orchard | Coniferous Forest | Oak Forest | Recreation | Wetland |
| **Clay (%)**** | 5.41$^{c}$ | 16.92$^{a}$ | 10.19$^{bc}$ | 10.77$^{abc}$ | 5.82$^{c}$ | 5.28$^{c}$ | 6.41$^{c}$ | 14.2$^{a}$ |
| **Silt (%)$^{NS}$** | 22.96 | 24.68 | 21.19 | 19.61 | 20.47 | 23.54 | 22.71 | 17.78 |
| **Sand (%)**** | 71.63$^{a}$ | 58.4$^{b}$ | 68.62$^{ab}$ | 69.63$^{ab}$ | 73.71$^{a}$ | 71.17$^{a}$ | 70.88$^{a}$ | 68.00$^{ab}$ |
| **Organic matter (%)**** | 2.95$^{a}$ | 3.18$^{a}$ | 1.56$^{b}$ | 1.89$^{ab}$ | 2.28$^{ab}$ | 1.48$^{b}$ | 1.54$^{b}$ | 2.95$^{a}$ |
| **$CaCO_3$ (%)**** | 1.33$^{b}$ | 7.87$^{ab}$ | 0.95$^{b}$ | 1.37$^{b}$ | 0.81$^{b}$ | 1.69$^{b}$ | 3.54$^{ab}$ | 13.13$^{a}$ |
| **pH$^{NS}$** | 6.44 | 6.93 | 7.00 | 7.25 | 6.85 | 7.08 | 7.30 | 6.79 |
| **EC (dS/m)**** | 0.11$^{b}$ | 0.39$^{ab}$ | 0.13$^{b}$ | 0.33$^{ab}$ | 0.16$^{b}$ | 0.37$^{ab}$ | 0.09$^{b}$ | 1.03$^{a}$ |
| **$P_2O_5$ (kg/da)$^{NS}$** | 12.34 | 17.55 | 9.05 | 12.49 | 7.60 | 14.07 | 7.11 | 10.02 |
| **Aggregate Stability**** | 0.63$^{a}$ | 0.63$^{a}$ | 0.38$^{cd}$ | 0.52$^{abc}$ | 0.67$^{a}$ | 0.53$^{ab}$ | 0.44$^{bcd}$ | 0.34$^{d}$ |
| **Ca (me/100 g soil)**** | 8.41$^{b}$ | 20.61$^{a}$ | 6.9$^{b}$ | 14.14$^{ab}$ | 9.49$^{b}$ | 14.67$^{ab}$ | 9.14$^{b}$ | 14.35$^{ab}$ |
| **K (me/100 g soil)**** | 0.71$^{ab}$ | 1.54$^{ab}$ | 0.48$^{b}$ | 1.04$^{ab}$ | 0.58$^{b}$ | 1.32$^{ab}$ | 0.45$^{b}$ | 1.92$^{a}$ |
| **Mg (me/100 g soil)**** | 1.21$^{d}$ | 3.84$^{a}$ | 1.33$^{d}$ | 1.66$^{bcd}$ | 1.48$^{cd}$ | 2.74$^{ab}$ | 1.30$^{d}$ | 2.42$^{bc}$ |
| **Na (me/100 g soil)**** | 0.18$^{b}$ | 1.33$^{ab}$ | 0.18$^{b}$ | 0.10$^{b}$ | 0.15$^{b}$ | 0.12$^{b}$ | 0.12$^{b}$ | 2.9$^{a}$ |
| **CEC (me/100 g soil)**** | 10.51$^{c}$ | 27.31$^{a}$ | 8.90$^{c}$ | 16.94$^{abc}$ | 11.69$^{bc}$ | 18.84$^{abc}$ | 11.01$^{bc}$ | 21.60$^{ab}$ |

**CEC:** Cation exchange capacity, **EC:** Electrical conductivity

****:** p≤0.01; **NS:** not significant; Different letters in the same column indicate statistically significant differences at p≤0.01.

The physical and chemical properties of the 10-20 cm soil depth for different land use types are presented in Table 2. The results showed that land use type had statistically significant effects on the majority of the properties examined (p≤0.01). In contrast, no statistically significant differences were found among land use types in terms of clay, silt, pH, available $P_2O_5$, and exchangeable K contents.

When soil texture properties were examined, clay content ranged from 5.22% to 13.66%, with the highest value in meadow areas (13.66%) and the lowest in pasture areas (5.22%). In terms of sand content, the highest value was found in recreation areas (81.70%) and the lowest in meadow areas (60.48%). Significant differences in sand content were found among land use types. Organic matter content ranged from 1.46% to 3.26%, with the highest value in oak forest areas (3.26%) and the lowest in field areas (1.46%). Similarly, in terms of $CaCO_3$ content, wetlands (13.96%) showed higher values than other land use types, while the lowest value was detected in field areas (0.87%). Electrical conductivity (EC) values ranged from 0.08 to 0.71 dS $m^{-1}$, with the highest value in wetlands (0.71 dS $m^{-1}$). In terms of aggregate stability, meadow (0.73) and pasture areas (0.72) had the highest values, whereas field areas (0.43) had the lowest aggregate stability. These results indicate that aggregate stability is also higher in the subsoil layer of areas with natural vegetation. When exchangeable cation contents were examined, Ca content ranged from 6.33 to 17.46 me 100 $g^{-1}$ soil, with the highest value in meadow areas. In terms of Mg content, meadow areas (2.63 me 100 $g^{-1}$ soil) had the highest value, whereas pasture areas (1.03 me 100 $g^{-1}$ soil) had the lowest. Na content was found to be significantly higher in wetlands (7.88 me 100 $g^{-1}$ soil) than in all other land use types. Cation exchange capacity (CEC) ranged from 8.07 to 23.22 me 100 $g^{-1}$ soil, with the highest value in wetlands and the lowest in pasture areas. High CEC values were particularly notable in meadow, coniferous forest, and wetland areas.


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**Table 2.** Soil Properties at 10-20 cm Depth under Different Land Uses

| Soil Properties | Land Use (10-20 cm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Pasture | Meadow | Field | Orchard | Coniferous Forest | Oak Forest | Recreation | Wetland |
| Clay (%)$^{NS}$ | 5.22 | 13.66 | 9.03 | 9.05 | 10.82 | 7.78 | 6.41 | 11.93 |
| Silt (%)$^{NS}$ | 25.11 | 25.86 | 23.95 | 18.51 | 16.88 | 24.79 | 11.90 | 17.30 |
| Sand (%)$^{**}$ | 70.20$^{ab}$ | 60.48$^{b}$ | 67.05$^{ab}$ | 72.44$^{ab}$ | 72.54$^{ab}$ | 67.43$^{ab}$ | 81.70$^{a}$ | 70.78$^{ab}$ |
| Organic matter (%)$^{**}$ | 2.34$^{ab}$ | 3.20$^{ab}$ | 1.46$^{b}$ | 2.58$^{ab}$ | 2.57$^{ab}$ | 3.26$^{a}$ | 1.71$^{ab}$ | 2.61$^{ab}$ |
| $CaCO_3$ (%)$^{**}$ | 1.57$^{b}$ | 10.43$^{ab}$ | 0.87$^{b}$ | 1.12$^{b}$ | 0.89$^{b}$ | 1.65$^{b}$ | 1.89$^{b}$ | 13.96$^{a}$ |
| pH$^{NS}$ | 6.54 | 7.47 | 6.87 | 7.20 | 6.79 | 7.00 | 7.33 | 6.46 |
| EC (dS/m)$^{**}$ | 0.08$^{ab}$ | 0.50$^{ab}$ | 0.11$^{ab}$ | 0.18$^{ab}$ | 0.13$^{ab}$ | 0.22$^{ab}$ | 0.09$^{ab}$ | 0.71$^{a}$ |
| $P_2O_5$ (kg/da)$^{NS}$ | 4.80 | 9.00 | 13.23 | 11.20 | 5.07 | 6.41 | 8.91 | 10.75 |
| Aggregate Stability$^{**}$ | 0.72$^{a}$ | 0.73$^{a}$ | 0.43$^{b}$ | 0.57$^{ab}$ | 0.61$^{ab}$ | 0.68$^{a}$ | 0.52$^{ab}$ | 0.51$^{ab}$ |
| Ca (me/100 g soil)$^{**}$ | 6.33$^{b}$ | 17.46$^{a}$ | 7.47$^{b}$ | 10.25$^{ab}$ | 12.05$^{ab}$ | 6.66$^{b}$ | 6.72$^{b}$ | 11.77$^{ab}$ |
| K (me/100 g soil)$^{NS}$ | 0.54 | 1.03 | 0.50 | 0.75 | 1.20 | 0.36 | 0.38 | 1.32 |
| Mg (me/100 g soil)$^{**}$ | 1.03$^{c}$ | 2.63$^{a}$ | 1.48$^{bc}$ | 1.55$^{abc}$ | 1.98$^{abc}$ | 1.3$^{c}$ | 1.09$^{c}$ | 2.27$^{ab}$ |
| Na (me/100 g soil)$^{**}$ | 0.16$^{b}$ | 0.44$^{ab}$ | 0.22$^{b}$ | 0.10$^{b}$ | 0.12$^{b}$ | 0.14$^{b}$ | 0.12$^{b}$ | 7.88$^{a}$ |
| CEC (me/100 g soil)$^{**}$ | 8.07$^{b}$ | 21.56$^{ab}$ | 9.66$^{b}$ | 12.65$^{ab}$ | 15.34$^{ab}$ | 8.47$^{b}$ | 8.31$^{b}$ | 23.22$^{a}$ |

**CEC:** Cation exchange capacity**, EC:** Electrical conductivity

****:** p≤0.01; **NS:** not significant; Different letters in the same column indicate statistically significant differences at p≤0.01.

The results of the correlation analysis for the examined properties are presented in Figure 2. According to the correlation analysis, significant positive and negative relationships were identified among the soil properties examined at both soil depths. The direction and strength of the correlations varied partially with depth.

At the 0-10 cm depth, clay content showed positive relationships with $CaCO_3$, EC, Ca, K, Mg, Na, and CEC. In contrast, sand content showed negative correlations with most of these properties. The negative relationship between sand and Ca, K, Mg, and CEC was particularly marked. While positive relationships were found between organic matter (OM) and $CaCO_3$, EC, $P_2O_5$, Ca, K, Mg, Na, and CEC, a negative relationship was detected between OM and pH. $CaCO_3$ content showed strong positive correlations, especially with EC, K, Na, and CEC. Significant relationships were also identified among nutrient elements. Strong positive correlations were found among Ca, K, and Mg, and these properties were also highly positively correlated with CEC. The positive relationships between EC and Ca, K, Mg, Na, and CEC indicate that exchangeable cations are influential on electrical conductivity in surface soils. In contrast, pH showed weak relationships with many properties and a negative correlation with OM.


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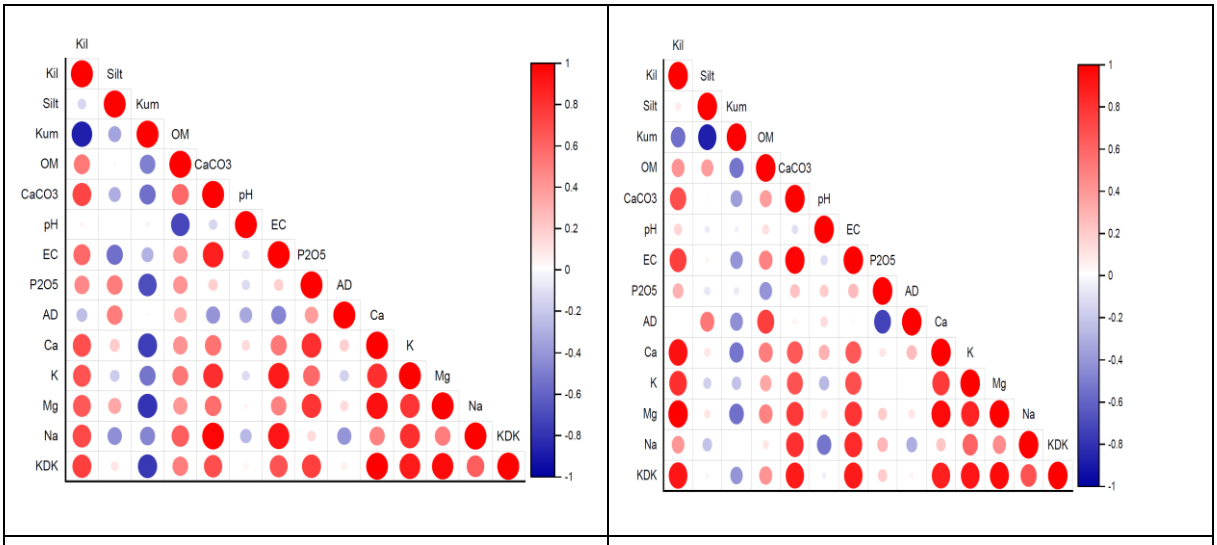


0-10 cm | 10-20 cm

**Figure 2**. Correlation plot of soil properties under different land uses

At the 10-20 cm depth, similar to the surface soil, positive correlations were found between clay content and $CaCO_3$, EC, Ca, K, Mg, and CEC. Sand content, in particular, showed negative relationships with OM, Ca, Mg, and CEC. The strong negative correlation between silt and sand revealed the natural contrast among textural fractions. In the subsoil, while positive relationships were found between OM and $CaCO_3$, EC, Ca, K, Mg, Na, and CEC, negative relationships were observed with sand and some textural properties. The positive relationships between $CaCO_3$ content and EC, Ca, K, Mg, and CEC also continued in the subsoil. Moreover, the strong positive correlation of EC with Ca, K, Mg, Na, and CEC indicates that dissolved and exchangeable cations are also important in the subsoil. When the relationships among nutrient elements were examined, Ca, K, and Mg were found to form high positive correlations among themselves and with CEC. In particular, the strong positive relationships of CEC with Ca, K, Mg, and Na revealed that cation exchange capacity is closely related to the accumulation of these basic cations. However, the negative correlation between AS (aggregate stability) and $P_2O_5$ indicates that phosphorus is controlled by different dynamics in the subsoil.

A biplot analysis showing the relationships between different land use types and soil properties at the 0-10 cm soil depth is presented in Figure 3. The first two principal components (PC1 and PC2) explained 75.2% of the total variation, of which 53.6% was explained by PC1 and 21.6% by PC2. This indicates that the biplot adequately explains the relationships among the properties in the data set. In the biplot, positive relationships were identified among properties positioned in the same direction and forming a narrow angle. Accordingly, Ca, Mg, and CEC were strongly positively related to one another, and organic matter (OM), clay, K, and $P_2O_5$ were also positioned in a similar direction to these properties. The EC, Na, and $CaCO_3$ properties were also grouped together, indicating a positive relationship among them. Sand content was positioned opposite to these properties and showed a negative relationship with them.

When the land use forms were examined, meadow areas (M) stood out in terms of $P_2O_5$ and Ca, being positioned close to these properties. Wetlands (W) were located in the region where the EC, Na, and $CaCO_3$ properties lie and were associated with these properties. Pasture areas (P) were mostly associated with silt and aggregate stability (AS). Field and recreation areas (F and R) and coniferous forest areas (CF) were positioned close to the center of the plot and did not show a distinct superiority in terms of the properties examined. Meadow and pasture areas exhibited better soil quality characteristics with higher organic matter, aggregate stability, and CEC values, whereas these properties were at lower levels in field and recreation areas. Wetlands, on the other hand, differed from other land use types owing to their high $CaCO_3$, EC, K, and Na contents. Overall, the biplot analysis

revealed that clay, organic matter, exchangeable basic cations (Ca, Mg, K), and CEC varied together in the surface soil, whereas sand content was inversely related to these properties. Moreover, land use forms were observed to cause marked differences in the physical and chemical properties of the surface soil. These findings indicate that PC1 mainly represents the balance between the soil's basic cation/fertility content and its texture, whereas PC2 represents a gradient related to salinity and lime content.

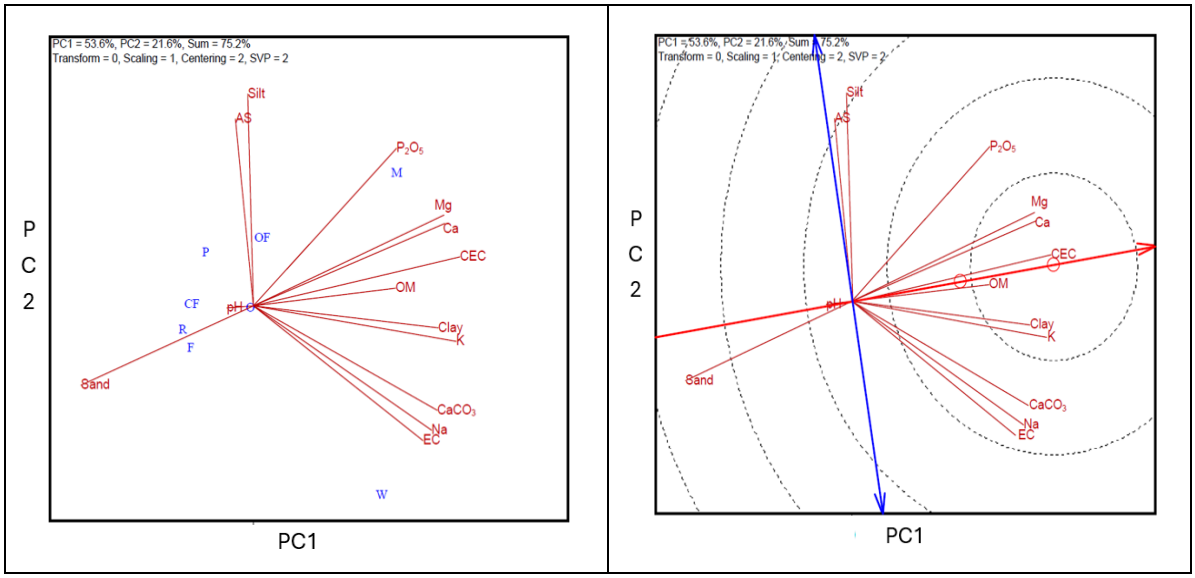


**Figure 3.** GGE biplot showing the relationships between land use forms and the physical and chemical properties of soil at the 0-10 cm soil depth

A biplot analysis showing the relationships between different land use forms and soil properties at the 10-20 cm soil depth is presented in Figure 4. The first two principal components (PC1 and PC2) explained 71.1% of the total variation, of which 49.6% was represented by PC1 and 21.5% by PC2. This result indicates that a large part of the relationships among the properties examined is explained by the first two components.

In the biplot, positive relationships were identified among properties positioned in the same direction. Accordingly, Ca, Mg, clay, K, CEC, and $CaCO_3$ were located on the same axis and showed strong positive relationships with one another. Organic matter (OM) was also positioned in a similar direction to these properties and showed a close relationship, particularly with Ca and CEC. Sand, on the other hand, was positioned opposite to these properties and showed a negative relationship, particularly with clay, CEC, Ca, Mg, and $CaCO_3$. Although $P_2O_5$ and Na contents were located in the lower part of the plot, their close positioning indicated a positive relationship between them. Silt and aggregate stability (AS) were positioned in a similar direction on the PC2 axis, and a strong relationship was found between them.


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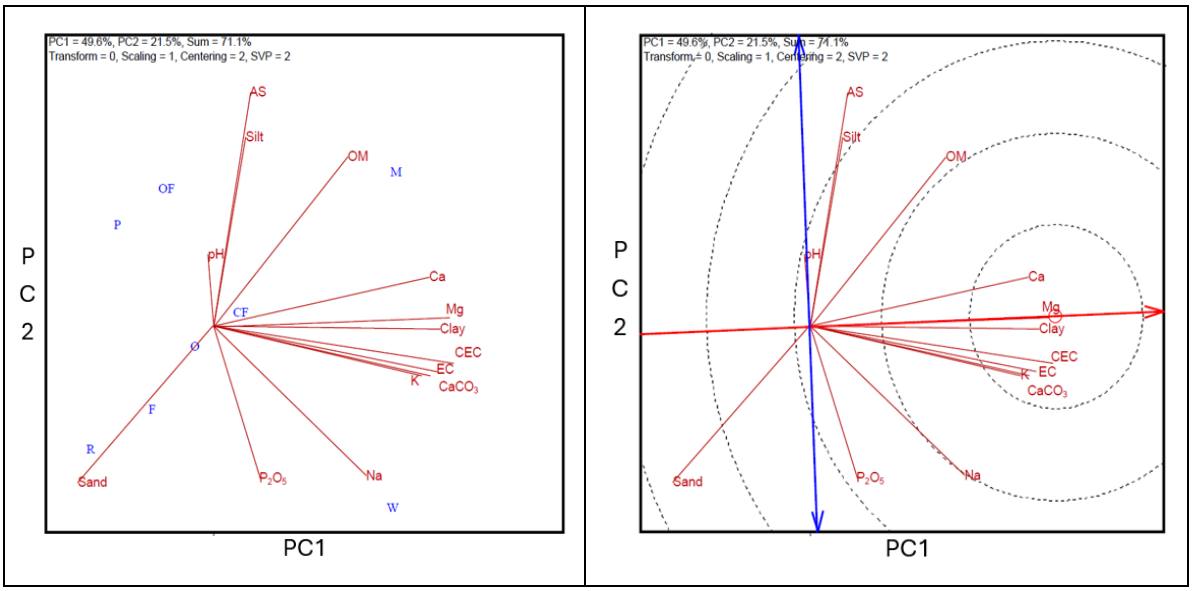


**Figure 4.** GGE biplot showing the relationships between land use forms and the physical and chemical properties of soil at the 10-20 cm soil depth

When the land use forms were examined, meadow areas (M) stood out in terms of these properties, being positioned close to organic matter and Ca. Wetlands (W) were located in the region where the Na and $P_2O_5$ properties lie and were associated with these properties. Pasture areas (P) and orchard areas (O) appear to be associated with silt and aggregate stability. Field areas (F) and recreation areas (R) were located in the region of sand content and were separated from the other soil properties. Coniferous forest areas (CF) were positioned close to the center of the plot and exhibited an intermediate character in terms of the properties examined. Overall, at the 10-20 cm depth, organic matter, clay, exchangeable basic cations (Ca and Mg), $CaCO_3$, and CEC were found to vary together, whereas sand content showed an inverse relationship with these properties. Moreover, land use forms were found to significantly affect the distribution of physical and chemical properties not only in the surface soils but also in the subsoil layers. This indicates that land use is effective at different levels in different depths of the soil profile.

This study clearly demonstrated that land use type exerts significant effects on the physical and chemical properties of soils. In particular, the high organic matter, aggregate stability, and cation exchange capacity (CEC) values found in meadow, pasture, and forest areas, and the lower levels of these properties determined in field and recreation areas, indicate that land use is one of the fundamental factors shaping soil quality. Similarly, many researchers have reported that natural and semi-natural ecosystems have higher organic matter, total nitrogen, and cation exchange capacity than agricultural areas [32,33,34].

Soil organic matter is one of the most important indicators of soil quality and plays a determining role in aggregate formation, nutrient cycling, and water-holding capacity [35,36]. In our study, the highest organic matter contents in surface soils were determined in meadow (3.18%), pasture (2.95%), and wetland areas (2.95%), whereas lower values were obtained in field (1.56%), oak forest (1.48%), and recreation areas (1.54%). These results are generally consistent with the literature. In studies conducted in Ethiopia, forest areas were reported to have the highest organic matter contents, whereas in agricultural areas organic matter decreased significantly owing to long-term tillage and the removal of plant residues [32,33]. In our study, the lower-than-expected organic matter content in oak forest areas can be explained by the sparse structure of the oak stands around Mount Erciyes, the acceleration of decomposition due to semi-arid climatic conditions, and the limited amount of organic residue on the surface. In addition, sampling from the surface soil may have made differences related to the spatial distribution of organic residues more pronounced.

The differences observed in organic matter depending on land use were also reflected in aggregate stability. In our study, the highest aggregate stability values were determined in coniferous forest (0.67), pasture (0.63), and meadow (0.63) areas, whereas the lowest values were detected in wetlands (0.34) and field areas (0.38). Because organic matter acts as a binding agent among aggregates, this result is beyond what would be expected. [37] reported strong positive relationships between organic matter and aggregate stability. Similarly, [38] and [39] reported that aggregate stability is higher in areas with natural vegetation, whereas intensive agricultural practices weaken aggregate structure. In our study, the fact that wetlands showed low aggregate stability despite their high organic matter content appears contradictory at first glance. However, in wetlands, continuous or periodic saturation conditions, high sodium content, and heavy accumulation of dissolved salts can adversely affect the physical durability of aggregates. Indeed, the high Na levels determined in wetlands may have increased the tendency of aggregates to disperse.

In terms of cation exchange capacity, the fact that meadow areas showed the highest values at both depths can be associated with the preservation of organic matter and exchangeable base cations in these areas. Thanks to its functional groups, organic matter contributes to the retention of nutrient elements by adsorbing cations [40]. In our study, the fact that CEC values ranged from 8.90 to 27.31 me 100 $g^{-1}$ at the 0-10 cm depth and from 8.07 to 23.22 me 100 $g^{-1}$ at the 10-20 cm depth indicates that land use type exerts marked effects on nutrient retention capacity. Similar results have also been reported in studies conducted in Jordan, Ethiopia, and Cameroon, where CEC was reported to be higher in natural forest and meadow areas and lower in agricultural areas [41,42,43].

In this study, no statistically significant difference in pH values was found among land use types. This can be explained by the fact that the soils in the region developed on the same parent material and that the volcanic-origin characteristics suppressed the effect of land use. However, some studies have reported that changes in land use have significant effects on pH [44]. Similarly, available phosphorus contents did not show statistically significant differences among land use types. While fertilization practices in agricultural areas increase phosphorus levels, the recycling of phosphorus through the decomposition of organic matter in natural areas may have balanced these differences.

Wetlands were clearly distinguished from other land use types in the study. In particular, the high EC, $CaCO_3$, Na, and CEC values indicate that the accumulation of dissolved ions is influential in these areas. The fact that, at the 0-10 cm depth in wetlands, EC reached 1.03 dS $m^{-1}$, Na reached 2.91 me 100 $g^{-1}$ soil, and CEC reached 21.60 me 100 $g^{-1}$ soil indicates that these areas have a strong nutrient- and ion-storage capacity. Similarly, [45,46,47] reported that wetlands are important nutrient reservoirs owing to their high organic matter accumulation and cation exchange capacity. The high EC and Na values in wetlands are also associated with hydrological processes, the influence of groundwater, and the accumulation of dissolved salts [48,49] .

When evaluated overall, the research results show that natural and semi-natural ecosystems play an important role in preserving soil quality. The high organic matter, aggregate stability, and CEC values determined in meadow, pasture, and forest areas revealed that these areas are more advantageous in sustaining soil functions. In contrast, the low values observed in agricultural and recreation areas indicate that intensive human activities may adversely affect soil quality in the long term. Therefore, the dissemination of sustainable land management strategies aimed at increasing organic matter, conservation tillage systems, cover crops, and the protection of natural vegetation is of great importance [50,51,52].

## 4. CONCLUSION

This study demonstrated that different land use forms have significant effects on soil quality in and around Mount Erciyes. Meadow and pasture areas exhibited better soil quality characteristics with high organic matter, aggregate stability, and cation exchange capacity values. In contrast, these properties were found to be lower in field and recreation areas. Wetlands, on the other hand, were distinguished from other land use types by their high EC, $CaCO_3$, Na, and CEC values.

In conclusion, the physical and chemical properties of soils were observed to be better


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preserved in areas where natural vegetation is maintained. These findings also point to concrete applications for land management. In particular, the low organic matter and aggregate stability in field and recreation areas indicate that practices such as the use of cover crops, reduced tillage, and organic fertilization should be given priority in these areas. The high EC and Na values determined in wetlands indicate that these areas should be monitored in terms of salinity management and drainage. The preservation of the existing natural vegetation of meadow, pasture, and forest areas is critically important for the sustainability of the soil quality advantages these areas provide. Therefore, it is recommended that sustainable land management practices be disseminated, that practices aimed at increasing organic matter be encouraged, and that measures for the protection of natural ecosystems be strengthened.

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This work is original.

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***3. Ethics approval:***

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The author declares no competing interests.

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Generative AI was used only for translation purposes during the preparation of this study.

***7. Sustainable Development Goals:***

☐ 1 NO POVERTY ☒ 2 ZERO HUNGER ☐ 3 GOOD HEALTH AND WELL-BEING ☐ 4 QUALITY EDUCATION ☐ 5 GENDER EQUALITY ☐ 6 CLEAN WATER AND SANITATION ☐ 7 AFFORDABLE AND CLEAN ENERGY

☐ 8 DECENT WORK AND ECONOMIC GROWTH ☐ 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE ☐ 10 REDUCED INEQUALITIES ☐ 11 SUSTAINABLE CITIES AND COMMUNITIES ☐ 12 RESPONSIBLE CONSUMPTION AND PRODUCTION ☒ 13 CLIMATE ACTION ☐ 14 LIFE BELOW WATER

☒ 15 LIFE ON LAND ☐ 16 PEACE AND JUSTICE STRONG INSTITUTIONS ☐ 17 PARTNERSHIPS FOR THE GOALS THE GLOBAL GOALS For Sustainable Development

## REFERENCES

[1] Zhang, R., Zhao, X., Zhang, C., & Li, J. (2020). Impact of Rapid and Intensive Land Use/Land Cover Change on Soil Properties in Arid Regions: A Case Study of Lanzhou New Area, China. Sustainability, 12(21), 9226. https://doi.org/10.3390/su12219226

[2] Peng, L., Tang, C., Zhang, X., Duan, J., Yang, L., & Liu, S. (2022). Quantifying the Effects of Root and Soil Properties on Soil Detachment Capacity in Agricultural Land Use of Southern China. Forests,


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13(11), 1788. https://doi.org/10.3390/f13111788

[3] Arévalo-Gardini, E-, Canto, M., Alegre, J., Loli, O., Julca, A., & Baligar, V. (2015). Changes in Soil Physical and Chemical Properties in Long Term Improved Natural and Traditional Agroforestry Management Systems of Cacao Genotypes in Peruvian Amazon. PLoS ONE, 10(7), e0132147.

[4] Dixit, M., Ghoshal, D., Lal Meena, A., Ghasal, P. C., Rai, A. K., Choudhary, J., & Dutta, D. (2024). Changes in soil microbial diversity under present land degradation scenario. Total Environment Advances, 10, 200104. https://doi.org/10.1016/j.teadva.2024.200104

[5] Li, L., Awada, T., Zhang, Y., & Paustian, K. (2024). Global Land Use Change and Its Impact on Greenhouse Gas Emissions. Global Change Biology, 30(12), e17604. https://doi.org/10.1111/gcb.17604

[6] Yono, A., Mokua, R. A., & Dube, T. (2025). Remote sensing of land cover change dynamics in mountainous catchments and semi-arid environments: a review. Geocarto International, 40(1). https://doi.org/10.1080/10106049.2025.2476602

[7] Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W. H., Simberloff, D., & Swackhamer, D. (2001). Forecasting agriculturally driven global environmental change. Science, 292(5515), 281–284. https://doi.org/10.1126/science.1057544

[8] Winkler, K., Fuchs, R., Rounsevell, M., & Herold, M. (2025). Six decades of global crop yield increase and cropland expansion from 1960 to 2020. Environmental Research Communications, 7(5), 055013. https://doi.org/10.1088/2515-7620/add3cd

[9] Bojko, O., & Kabala, C. (2016). Transformation of physicochemical soil properties along a mountain slope due to land management and climate changes—A case study from the Karkonosze Mountains, SW Poland. Catena, 140, 43-54.

[10] Nabiollahi, K., Golmohamadi, F., Taghizadeh-Mehrjardi, R., Kerry, R., & Davari, M. (2018). Assessing the effects of slope gradient and land use change on soil quality degradation through digital mapping of soil quality indices and soil loss rate. Geoderma, 318, 16-28.

[11] Van Berkum, S. (2023). How Urban Growth in the Global South Affects Agricultural Dynamics and Food Systems Outcomes in Rural Areas: A Review and Research Agenda. Sustainability, 15(3), 2591. https://doi.org/10.3390/su15032591

[12] Birhanu, L., Mekonen, Y., Tilahun, A., Amsalu, N., & Balzter, H. (2024). Impact of Land Use and Land Cover Change on Soil Erosion in Dondor Watershed, Blue Nile Basin, Northwestern Ethiopia. Sustainability, 16(23), 10421. https://doi.org/10.3390/su162310421

[13] Zajícová, K., & Chuman, T. (2019). Effect of land use on soil chemical properties after 190 years of forest to agricultural land conversion. Soil & Water Research, 14(3), 14, 2019 (3): 121–131.

[14] Khan, M. T., Aleinikovienė, J., & Butkevičienė, L.-M. (2024). Innovative Organic Fertilizers and Cover Crops: Perspectives for Sustainable Agriculture in the Era of Climate Change and Organic Agriculture. Agronomy, 14(12), 2871. https://doi.org/10.3390/agronomy14122871

[15] Deribew, K. T., & Dalacho, D. W. (2019). Land use and forest cover dynamics in the North-eastern Addis Ababa, central highlands of Ethiopia. Environmental Systems Research, 8(1), 8.

[16] Regasa, M., Nones, M., & Adeba, D. (2021). A Review on Land Use and Land Cover Change in Ethiopian Basins. Land, 10(6), 585. https://doi.org/10.3390/land10060585

[17] Sang, C. C., Olago, D. O., Nyumba, T. O., Marchant, R., & Thorn, J. P. R. (2022). Assessing the Underlying Drivers of Change over Two Decades of Land Use and Land Cover Dynamics along the Standard Gauge Railway Corridor, Kenya. Sustainability, 14(10), 6158.


CC: BY-NC-ND

https://doi.org/10.3390/su14106158

[18] Soil Survey Staff (2010). Keys to Soil Taxonomy, 11th ed. USDA-Natural Resources Conservation Service, Washington, DC.

[19] MTA (1961). Türkiye Jeoloji Haritası, 1/500.000 ölçekli Erzurum Paftası, Maden Teknik Arama Enstitüsü, Ankara.

[20] Keskin M (2003). Magma generation by slab steepening and breakoff beneath a subduction-accretion complex: An alternative model for collision-related volcanism in Eastern Anatolia, Turkey. Geophysical Research Letters, 30(24). https://doi.org/10.1029/2003GL018019

[21] Mora ML, Schnettler B, Demanet R (1999). Effect of liming and gypsum on soil chemistry, yield, and mineral composition of ryegrass grown in an acidic Andisol. Communications in Soil Science and Plant Analysis, 30(9–10).

[22] Dingil, M., Şenol, S., Akça, E., & Öztekin, M. E. (2012). Türkiye'de Volkan Külleri Üzerinde Oluşmuş Toprakların Andik Özellikleri ve Sınıflandırılmaları. Yuzuncu Yıl University Journal of Agricultural Sciences, 22(2), 108-112.

[23] Kara Z, Saltalı K, Yakupoğlu T (2022). Erciyes Dağı Civarındaki Volkanik Ana Materyal Üzerinde Oluşan Toprakların Bazı Fiziksel Özelliklerinin Araştırılması. KSÜ Tarım ve Doğa Dergisi, 25(4), 901-908. https://doi.org/10.18016/ksutarimdoga.vi.911270

[24] Nelson, D.W. and Sommers, L.E. 1982. Total carbon, organic carbon, and organic matter. In: Methods of Soil Analysis. Page, A.L. (Ed) Part 2, 2nd ed. Agron. Monogr. 9. ASA. And SSSA, Madison, WI, pp. 539-579.

[25] Bouyoucos, G. J. (1928). The hydrometer method for studying soils. Soil Science, 25(5), 365-370.

[26] Mclean, E.O. 1982. Soil pH and Lime Requirement. Methods of Soil Analysis Part2. Chemical and Microbiological Properties Second Edition. Agronamy. No: 9 Part 2 . Edition, 199-224.

[27] Nelson, R. E. (1982). Carbonate and gypsum. Methods of soil analysis: Part 2 Chemical and microbiological properties, 9, 181-197.

[28] Rhoades, J. D. (1982). Cation exchange capacity. Methods of soil analysis: Part 2 chemical and microbiological properties, 9, 149-157.

[29] Olsen, S.R., Sommers, L.E. 1982. Phosphorus. Methods of Soil Analysis Part2. Chemical and Microbiological Properties Second Edition. Agronamy. No: 9 Part 2. Edition, 403-427.

[30] Bremner, J.M., Mulvaney, C.S. 1982. Nitrogen Total. Methods of Soil Analysis Part2. Chemical and Microbiological Properties Second Edition. Agronomy. No: 9 Part 2. Edition, 597-622.

[31] Kemper, W.D. and Rosenau, R.C. 1986. Aggregate stability and size distribution. In: Methods of Soil Analysis, part 1. Agronomy Monographs, 9 (ed. A. Klute). AmericanSociety of Agronomy, Madison, WI.

[32] Adugna, A., & Abegaz, A. (2016). Effects of land use changes on the dynamics of selected soil properties in northeast Wellega, Ethiopia. SOIL, 2(1), 63–70. https://doi.org/10.5194/soil-2-63-2016

[33] Fentie, S. F., Jembere, K., Fekadu, E., & Wasie, D. (2020). Land Use and Land Cover Dynamics and Properties of Soils under Different Land Uses in the Tejibara Watershed, Ethiopia. The Scientific World Journal, 2020(2), 1–12. https://doi.org/10.1155/2020/1479460

[34] Gubila, M., Regassa, A., Legess, G., & Mulatu, K. (2024). Land Use Land Cover Change and Its Effect on Selected Soil Physico-Chemical Properties in Southwest Ethiopia. American Journal of Environmental Science and Engineering, 8(3), 65–78.


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https://doi.org/10.11648/j.ajese.20240803.12

[35] Fageria, N. K. (2012). Role of Soil Organic Matter in Maintaining Sustainability of Cropping Systems. Communications in Soil Science and Plant Analysis, 43(16), 2063–2113. https://doi.org/10.1080/00103624.2012.697234

[36] Weil, R., & Magdoff, F. (2004). Significance of Soil Organic Matter to Soil Quality and Health (pp. 13–56). Crc. https://doi.org/10.1201/9780203496374-5

[37] Chaney, K., & Swift, R. S. (1984). The influence of organic matter on aggregate stability in some British soils. Journal of Soil Science, 35(2), 223–230. https://doi.org/10.1111/j.1365-2389.1984.tb00278.x

[38] Li, M., Wang, K., Ma, X., Fan, M., & Song, Y. (2024). Effects of Land Use Change on Soil Aggregate Stability and Erodibility in the Karst Region of Southwest China. Agronomy, 14(7), 1534. https://doi.org/10.3390/agronomy14071534

[39] Hamza, A., Karčauskienė, D., Mockevičienė, I., Repšienė, R., Tahir, M. A., Manzoor, M. Z., Kousar, S., Lodhi, S. S., Rasool, N., & Ullah, I. (2025). Soil Aggregate Dynamics and Stability: Natural and Anthropogenic Drivers. Agriculture, 15(23), 2500. https://doi.org/10.3390/agriculture15232500

[40] Murphy, B. (2015). Key soil functional properties affected by soil organic matter - evidence from published literature. IOP Conference Series: Earth and Environmental Science, 25(1), 012008. https://doi.org/10.1088/1755-1315/25/1/012008

[41] Khresat, S., Al-Bakri, J., & Al-Tahhan, R. (2008). Impacts of land use/cover change on soil properties in the Mediterranean region of northwestern Jordan. Land Degradation & Development, 19(4), 397–407. https://doi.org/10.1002/ldr.847

[42] Miheretu, B. A., & Yimer, A. A. (2017). Spatial variability of selected soil properties in relation to land use and slope position in Gelana sub-watershed, Northern highlands of Ethiopia. Physical Geography, 39(3), 230–245. https://doi.org/10.1080/02723646.2017.1380972

[43] Tellen, V. A., & Yerima, B. P. K. (2018). Effects of land use change on soil physicochemical properties in selected areas in the North West region of Cameroon. Environmental Systems Research, 7(1). https://doi.org/10.1186/s40068-018-0106-0

[44] Ewunetu, T., Selassie, Y. G., Molla, E., Admase, H., & Gezahegn, A. (2025). Soil properties under different land uses and slope gradients: Implications for sustainable land management in the Tach Karnuary watershed, Northwestern Ethiopia. Frontiers in Environmental Science, 13. https://doi.org/10.3389/fenvs.2025.1518068

[45] Li, Z., Jin, Z., & Li, Q. (2017). Changes in Land Use and their Effects on Soil Properties in Huixian Karst Wetland System. Polish Journal of Environmental Studies, 26(2), 699–707. https://doi.org/10.15244/pjoes/65360

[46] Nair, V. D., Graetz, D. A., Reddy, K. R., & Olila, O. G. (2001). Soil development in phosphate-mined created wetlands of Florida, USA. Wetlands, 21(2), 232–239. https://doi.org/10.1672/0277-5212(2001)021[0232:sdipmc]2.0.co;2

[47] Ballantine, K., & Schneider, R. (2009). Fifty-five years of soil development in restored freshwater depressional wetlands. Ecological Applications, 19(6), 1467–1480. https://doi.org/10.1890/07-0588.1

[48] Sheng, Y., Luan, Z., Yan, D., Li, J., Xie, S., Liu, Y., Chen, L., Li, M., & Wu, C. (2022). Effects of Spartina alterniflora Invasion on Soil Carbon, Nitrogen and Phosphorus in Yancheng Coastal Wetlands. Land, 11(12), 2218. https://doi.org/10.3390/land11122218


CC: BY-NC-ND

[49] Zhang, D., Qi, Q., Tong, S., Wang, X., An, Y., Zhang, M., & Lu, X. (2019). Soil Degradation Effects on Plant Diversity and Nutrient in Tussock Meadow Wetlands. Journal of Soil Science and Plant Nutrition, 19(3), 535–544. https://doi.org/10.1007/s42729-019-00052-9

[50] De Alencar, G. V., Gomes, L. C., Barros, V. M. D. S., Ortiz Escobar, M. E., De Oliveira, T. S., & Mendonça, E. D. S. (2024). Organic farming improves soil carbon pools and aggregation of sandy soils in the Brazilian semi-arid region. Soil Use and Management, 40(3). https://doi.org/10.1111/sum.13097

[51] Li, H., Chang, L., Wei, Y., & Li, Y. (2023). Interacting Effects of Land Use Type, Soil Attributes, and Environmental Factors on Aggregate Stability. Land, 12(7), 1286. https://doi.org/10.3390/land12071286

[52] Regasa, A., Haile, W., & Abera, G. (2024). Soil acidity and fertility status of surface soils under different land uses in Sayo district of Oromia, western Ethiopia. PloS One, 19(12), e0316009. https://doi.org/10.1371/journal.pone.0316009

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