Effects of Land-Use Change on the Soil Organic Carbon and Selected Soil Properties in the Sultan Marshes, Turkey

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Abstract
This study aims to assess the effects of land-use changes on the carbon storage capacity and some soil properties of The Sultan Marshes, a wetland partially drained and converted to other land uses during the middle of the last century. Undisturbed soil sampling was performed in different land-use types (rangelands, shrubs, marsh, agriculture, and dried lake area) in the wetland area at depths of 0–50 cm, and soil organic carbon (SOC), bulk density, and carbon stocks of soils for each land use type were calculated at 10 cm soil depth levels. Furthermore, disturbed soil samples were taken at two soil depths (0–20 cm and 20–40 cm), and the particle size distribution, pH, electrical conductivity (EC), aggregate stability and dispersion ratio (DR) properties of the soils were analyzed. Data were processed using ANOVA, Duncan’s test, and Pearson’s correlation analysis. The soil properties affected by the land-use change were SOC, carbon stock, pH, EC, aggregate stability, clay, silt, sand contents, and bulk density. SOC and carbon stocks were high in rangeland, marsh, and shrub land, while low in agriculture and drained lake areas. As the soil depth increased, SOC and carbon stock decreased. The organic carbon content of the soils exhibited positive relationships with aggregate stability, clay, and carbon stock, while it showed a negative correlation with bulk density, pH, and DR. The results showed that s drainage and conversion of the wetland caused a significant decrease in the carbon contents of the soils.

Keywords Sultan Marshes · Land-use change · SOC · Carbon stock

Özet
Bu çalışmanın amacı, kısmen drene edilerek farklı arazi kullanımlarına dönen Sultan Sazlığı örneğinde arazi kullanımı değişimlerinin sulak alan ve civarı topraklardaki karbon depolama kapasitesi ve bazı toprak özellikleri üzerindeki etkilerini ortaya koymaktır. Bu amaçla sulak alan ekosisteminde bulunan farklı arazi kullanım şekillerinden (mera, tarım, çalılık, sazlık ve kurugöl), doğal yapısı bozulmuş toprak örneklemesi yapılmış (0–50 cm) ve 10 cm’lik derinlik kademesine ayrılarak her bir derinlik kademesindeki organik karbon miktarı (TOK), hacim ağırlığı belirlenmiş ve karbon depolama kapasiteleri hesaplanmıştır. Ayrıca her bir arazi kullanım şeklinden iki derinlik kademesinden (0–20 cm ve 20–40 cm) alınan toprak örneklerinin toprak testürü, tane yoğunluğu, pH, elektriksel iletkenlik (EI), agregat stabilitesi ve dispersiyon oranı (DO) belirlenmiştir. Arazi kullanımındaki değişimin toprak özellikleri ve karbon depolama kapasitesini etkileyip etkilemediği Varyans analizi; gruplar arasındaki farklılaşmalar ise Duncan testi ile belirlenmiştir. Toprak özellikleri arasındaki ilişkiler Pearson korelasyon analizi ile bulunmuştur. Arazi kullanım değişimlerinden etkilenen toprak özellikleri; organik karbon, karbon depolama kapasitesi, tane yoğunluğu, pH, EI, agregat stabilitesi, kum, toz içeriği ve hacim ağırlığıdır. Organik karbon ve karbon depolama kapasitesi mera, sazlık ve çalılık alanlardaki topraklarda yüksek iken tarım ve kurugöl alanlarında düşüktür. Toprak derinliği arttıkça organik karbon ve karbon depolama kapasitesi azalmıştır. Toprakların organik karbon içeriği; agregat stabilitesi, kum ve karbon depolama kapasitesi ile pozitif; tane yoğunluğu, pH, DO ve hacim ağırlığı ile negatif ilişki göstermiştir. Araştırma sonuçları sulak alan drenajı ve arazi kullanımındaki değişimlerin toprakların karbon içeriğinde azalma neden olduğunu göstermiştir.

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Introduction

Wetlands, the largest and effective carbon reservoirs in the world (IPCC 2005; Bedard-Haughn et al. 2006), are also the source of many ecosystem functions such as improving water quality, flood protection, and supporting biodiversity, and they are an important component of water and nutrient cycles (Mitra et al. 2005; Mitsch and Gosselink 2015). However, their roles as the atmospheric gas cycle and carbon pool are less acknowledged. It is effective to benefit from natural systems to control greenhouse gas emissions into the atmosphere. Although wetlands occupy a small area of 2–6% globally, they cover a significant part of terrestrial soil sinks that store carbon (Whiting and Chanton 2001; Stockmann et al. 2013). According to estimations, 20–30% of the 2,500 Pg carbon in the world soils (Lal 2008) is accumulated in wetlands (Bridgham et al. 2006). Wetland functions depend on the strong relationships between wetland water and soils. Therefore, soil conditions are among the most critical components of wetland intervention (improvement, restoration, etc.). Soil organic matter in wetlands is associated with various soil properties (Brady and Weil 2002), and it has functions such as controlling the hydrological properties of the soil, removing multiple contaminants from water, carrying nutrients and elements necessary for plants (Craft et al. 1988; Hogan et al. 2004). The fertility, productivity, and quality of wetland ecosystems can be affected by soil organic carbon and nitrogen (Bridgham et al. 2003; Gebrehiwot et al. 2018).

Human activities may affect carbon stocks and greenhouse gas exchanges with the atmosphere in wetlands (Roulet 2000). Wetland drainage, reclamation, and conversion to agriculture, the transformation of saturated conditions (primarily anaerobic) to unsaturated conditions (aerobic) disrupt the critical properties of wetlands and change the cycle of matter in the wetland system (Jacob and Otte 2003; Kløve et al. 2010; Yang et al. 2013; Yuan et al. 2019; Zhu et al. 2021).

Although there are ecosystems with such a high ecological value in the world, wetlands are under extreme pressure to be converted into agricultural areas for the last century (Wang et al. 2006; Chen et al. 2015; Reis et al. 2017; Chemada et al. 2017, Mao et al. 2018). Global estimates show that the most significant conversions are 6% in temperate (Armentano and Menges 1986) and 50% in tropical regions (Moser et al. 1996). Approximately 84% of human activities that cause land-use change in wetlands, such as development and utilization for various purposes, are in Ramsar areas (Dugan and Jones 1992). Practices such as the drainage of wetlands, reclamation, and conversion to agriculture may cause a rapid decrease in soil organic matter in the cultivation zone (Oehl et al. 2004; Zhang et al. 2007; Page and Dalal 2011). The decomposition and accumulation of soil organic carbon in wetlands affect the stability of the soil carbon pool and CO₂ emissions (Santin et al. 2008).

Various studies have been recently carried out on land-use changes in wetlands (Wang et al. 2002; Liu et al. 2004; Zhang et al. 2004; Bian and Lin 2005). However, such studies aim to analyze and understand the dynamics of wetlands using remote sensing techniques, mainly in large areas (Treitz and Rogan 2004). More studies are needed in less known regions to evaluate carbon storage changes through field sampling.

In Turkey, many wetlands have been degraded in the last century, and drainage for conversion to agriculture was the major reason. Especially between 1950 to 1970, 21 wetlands (93 582 ha) were entirely drained by government agencies to open up agricultural areas, prevent flooding, and combat malaria. Seventeen wetlands, covering 143 956 hectares of land, were left to dry due to interventions in the flood prevention and water regime regulations (Erdem 2004). The Sultan Marshes was selected as a study area because it is one of the most important and internationally attractive wetlands in our country, where the pressure of anthropogenic processes on wetlands is well observed. The Sultan Marshes was included in the Wetland of International Importance category according to the Ramsar Convention in 1994 and was included within the scope of national parks in 2006 (Meriç and Çağırımkaya 2013). The Sultan Marshes consist of habitats with different characteristics, such as fresh and saltwater ecosystems, vast marshes and swamp areas, meadows, valuable bird habitats, rangelands, and steppe areas (Karadeniz 2000) (Fig. 1). In the flora studies conducted between 2002 to 2004, 428 species belonging to 73 families were identified in the area, and 48 of them are endemic to Turkey (Aksoy 2004). This important ecosystem has been exposed to drainage activities since the 1950s, and dams and ponds were built on some of the feeding streams, and some parts were opened to agriculture (Fig. 1). The wetland and its surrounding ecosystem experience various environmental problems such as drought, changes in the hydrological system, opening to agriculture, and reed cutting. Various studies have been conducted to the present day on the ecosystem features of the Sultan Marshes (Özesmi et al. 1993; Kızıroğlu 1998), its flora (Yıldırımli and Öztekin 2000; Hamızağlı and Aksoy 2006), environmental problems (Somuncu 1987), the human and economic characteristics of the region (Tuńcel 1994), and the culture-environment relationship (Karabaşa 2006). Previous studies conducted in the Sultan Marshes region are mostly ecological and hydrological studies (Dadaş-Celik et al. 2006; Dadaş-Celik et al. 2007; Dadaş-Celik et al. 2008a; Gürer 2004; Karadeniz 1995; Karadeniz 1997). Furthermore, recent studies aim to determine land-use changes by remote sensing techniques (Dadaş-Celik et al. 2008b; Kesikoğlu et al. 2015; Sönmez and Somuncu, 2016; Jouma and Dadaş-Celik 2021),
and no study that coincides with the subject of this study was encountered. The IPCC’s Land Use, Land Use Change and Forestry (LULUCF) sector strives to identify carbon changes resulting from land-use changes and attempts to develop policies and recommendations to control and predict carbon emissions/removals (IPCC 2003, 2005, 2006, 2013). These issues are among the major points of recent studies on global climate change. If we know how much carbon is retained in wetland soils, we can better understand the role of these areas as a carbon pool and direct the conservation efforts of these valuable ecosystems (url 1 https://www.salt-marshapp.com/science/#science). It is extremely important to determine the effects of land-use changes in wetlands on soil organic carbon in revealing the reaction of wetlands in terms of the organic matter cycle to human impacts. It is necessary to have information about the effects of land-use conversions on soils' physical and chemical properties to make appropriate soil sustainability and agricultural productivity recommendations (Tufa et al. 2019).

There are uncertainties regarding the estimates of carbon storage in wetlands and the effects of land-use conversions on this accumulation. Information on how many wetlands have been converted to various human uses on a global scale is quite insufficient, and country-level estimates are mostly lacking. Knowing the effects of land-use changes on the carbon budget and the amount of carbon stored in different terrestrial ecosystems, such as the Sultan Marshes, will positively contribute to carbon management and the global carbon balance, and studies on sustainable ecosystem management in the world. The effects of wetlands on

Fig. 1 Water system of the study site and sampling locations (modified from Paşaoğlu 1994)
greenhouse gases in many areas under human influence are largely unknown.

To contribute to the knowledge on wetland-carbon nexus, this study aims to reveal the effects of land-use changes, one of the important interventions that threaten wetlands, on the carbon stocks and some soil properties with the Sultan Marshes example.

Materials and Methods

Site Description

The Sultan Marshes is a wetland ecosystem in the Develi Basin within the boundaries of Kayseri province, with a surface area varying between 8000–13,000 ha, depending on the season. Its altitude varies between 1070–1150 m. The Sultan Marshes is located between 38°12' 14''- 38°25' 49'' north latitudes and 35°09' 20''-35°22' 20'' east longitudes (Fig. 1). Its average slope is 2% (DSI 1995; Gürer 2004). The Sultan Marshes has "semi-arid subtropical Mediterranean terrestrial" climate characteristics with cold winters and hot summers (Aksoy and Demirezen 2003; Karadeniz 1995). The annual mean temperature in the basin is 11 °C, and the long-term mean annual precipitation is 363 mm (Özesmi and Gürer 2003). The soils in the Develi Closed Basin are usually alluvial and exhibit salty and alkaline characteristics in some places (Ulusoğlu et al. 2003). Thick, dark-colored hydromorphic alluvial soils rich in organic matter are located in areas with temporary lakes and marshes (Topraksu General Directorate 1984). In the southeast of the Develi Plain, there are brown calcareous soils around Musahacılı and Yerköy (Karadeniz 1995; Yıldız 2007). The lands in the Sultan Marshes Nature Protection Area are used for settlement, agriculture, and grazing purposes.

Agricultural areas are cumulated in the southern and northern parts of the plain, and agricultural products include sugar beet, sunflower, barley, and fruits (UDGP 2008–2012). Overgrazing damages flora and fauna around the Sultan Marshes (Fig. 2) (Özesmi and Gürer 2003). Some parts of this wetland have been subjected to land-use changes in the form of opening to agriculture by draining for similar purposes mentioned above. In the studies conducted using remote sensing techniques in the Sultan Marshes and its immediate surroundings, it was stated that various changes occurred in the land use/cover of the study area from the past to the present (Sönmez and Somuncu 2016; Jouma and Dadaser-Celik 2021). These studies emphasized that especially agricultural activities increased significantly, and consequently, natural vegetation areas and water areas decreased.

Experimental Design and Soil Sampling

Several interventions related to land drainage activities in the area have been collected from the literature (DSI 1970; Gürer 2004; Gürer and Yıldız 2008) and summarized in Table 1:

According to this information, it is thought that the strongest intervention in the area was the opening of the wetland to agriculture by exposing it to drying activities, which began in the 1940s-1950s. Furthermore, according to the information obtained from the local people, some of these areas, which were drained for agricultural purposes, have turned into rangelands for many years due to low agricultural productivity.

The collected information was checked by field studies, and land use patterns and soil sampling plots were determined. A completely randomized block design was selected as the sampling design. Land use types sampled according to the land conditions are as follows: 1. Rangeland areas 2. Shrubland areas, 3. Örtülüakar (southern) marshes, 4. Kepir (northern) marshes, 5. Lands that have been previously wetlands and opened to agriculture at different times (orchards and agricultural areas), 6. The dry-lake area formed by the withdrawal of water due to drought (Fig. 3).

The field studies and soil sampling were conducted in the summer and autumn months of 2019, starting with 2018 autumn.

Three sampling plots were determined (20 × 30 m) from each of the land-use patterns, and from each sampling plot, samples of the soil with the undisturbed natural structure were taken with the help of sampling tubes from three points. Samples of the soil with the disturbed structure were obtained with the help of a hand earth auger at two depths (0–20 cm; 20–40 cm) (Fig. 4). Although the soil sampling depth is specified as 30 cm in the IPCC (2006) for wetlands in carbon stock calculations, it was planned to take samples up to 50 cm to see the storage status in the subsoils and changes in the soil characteristics taken from different land-use patterns. However, sampling up to 50 cm from some points could be made with sampling tubes for samples with the undisturbed natural structure during field studies, and sampling up to 50 cm from some of them could not be performed due to some negativities in soil conditions and field conditions (excessive wetness or dryness, excessively sticky soil, swamp, etc.). In such cases, soil sampling was performed up to 30 cm or up to a depth at which samples could be taken. Due to unfavorable land conditions, soil samples were taken from shallow marshes in the marshland area. These samples taken were preserved by taking the necessary protection measures and transported to the laboratory. Then, soil organic carbon, bulk density, and carbon stock were determined for each depth level by separating soil samples into 10-cm levels in the laboratory.
The locations where soil sampling was performed were marked as regional according to their land use on the map (Fig. 1).

Some descriptive characteristics and coordinates of the regions where soil sampling plots were taken are presented in Table 2.

### Laboratory Analysis

The soil organic carbon, bulk density, carbon stock, pH, electrical conductivity (EC), aggregate stability, particle size distribution (texture), and dispersion ratio (DR) of the soils were determined. Air-dried soil samples were passed through a 2 mm sieve. The pH and EC were measured in a 1:5 H₂O soil–water mixture using a Hach-Lange multiparameter instrument. The core method was used to find soil bulk density (Blake and Hartge 1986). The hydrometer method was used to determine particle size distribution (Bouyoucos 1962). The soil organic carbon (SOC) was determined using the Walkley–Black method (Walkley and Black 1934). The dispersion ratio was defined according to Middleton (1930). Aggregate stability was calculated according to Kemper and Rosenau (1986). The carbon stocks of the soils were calculated as follows (Pluske et al. 2013):

\[ \text{SOCs} = \text{SOC} \times \text{soildepth} \times \text{bulkdensity} \times 10^{4} \]  

### Statistical Design

Experimental design factors were sampling depth ((0–10 (1st depth), 10–20 (2nd depth) and 20–30 cm (3rd depth), 30–40 cm (4th depth), 40–50 cm (5th depth) for SOC, bulk density, carbon stock and (0–20 (1st depth), 20–40 (2nd depth) for the other soil properties and land use (rangeland, cropland, shrubland, marshland, and dry-lake area). IBM SPSS Statistics version 24.00 was used to perform statistical analyses. The analysis of variance (ANOVA) was conducted to reveal the effects of land use and soil depth on soil properties, and Duncan’s test (α = 0.05) was used to determine significant averages. Pearson’s correlation analysis was conducted to determine the correlations between soil properties (α = 0.05) (Zar 1996).

### Results and Discussion

Descriptive statistics regarding the general characteristics of the study area soils are presented in Table 3. The results of the analysis of variance for soil depth and land use factors
and their interactions are shown in Tables 4 and spatial evolu-
tions for SOC and CS are given in Table 5. Furthermore, 
Pearson's correlation analysis results showing the rela-
tionships between soil properties are presented in Table 6.

**Soil Organic Carbon**

The SOC in the study area varied between 0.09–7.41% (Table 3). According to different land-use types, the average 
SOC can be listed in descending order as rangeland > marsh-
land > shrubland > cropland > dry-lake area (Fig. 5). The 
average SOC content of the study area was statistically 
significantly affected by the land-use change (P < 0.05) (Table 4). While the organic carbon content of rangeland 
and marshland soils was statistically similar, it was different 
from other land-use types. The SOC in the dry-lake area was 
lower and statistically different from other land uses. The 
SOC in the shrubland and cropland also showed statistical 
similarity (Fig. 5). The SOC content in rangeland, marsh-
land, and shrubland areas was found to be higher than other 
land uses. Similar to our study, Tangen and Bansal (2020) 
found approximately 6% SOC in inner natural marshland 
soil at 0–15 cm depth. The high SOC content in the range-
land, marshland and shrubland areas could be explained by 
the continuous input of organic material from their above-
ground plant biomass than the other land uses. The amount 
of organic carbon, nitrogen, and phosphorus in wetland soils 
depends on organic matter accumulation (Frolking et al. 2001; Avnimelech et al. 2001). Plants in the growth process 
affect organic carbon by changing the environment of the 
soil (Santin et al. 2008). In the study conducted by Compton 
and Boone (2000), high productivity and perennial flood-
ing in the two marshes indicated the high rate of carbon 
and nutrient accumulation in wetland soils, leading to the 
formation of large amounts of organic residues in the soil 
and slow decomposition of soil organic matter. According
to the results of this study, the draining of the wetland and converting it to agriculture affected the SOC adversely. It is thought that the low SOC in the dry-lake area may be due to the decomposition of the organic matter in that region and the absence of new organic matter input in its place.

The statistical analysis results according to the soil depth factor showed that the average SOC was affected by the change in soil depth ($P < 0.05$) (Table 4). As the soil depth increased, SOC decreased. The SOC contents at the 1st and 2nd depth levels were 2.62% and 2.05%, respectively, and statistically similar, higher, and different from other depths (Fig. 5). The SOC at the 2nd, 3rd, and 4th depth levels was statistically identical. The SOC at the 5th depth layer was both the lowest and different from the other depths (Fig. 5).

As in this study, Luo et al. (2014) determined the highest SOC values at 0–10 cm depth, while SOC decreased considerably at depths below 20 cm. The distribution of plant roots in our sampling plots decreased with the increasing soil depth. This distribution explains the high amount of organic matter from plant biomass and belowground biomass in the topsoil (Dong et al. 2010). Again, Zhu et al. (2021) stated that the organic matter was the highest in soybean fields at 20–40 cm and 40–60 cm depth and at 0–20 cm in the drained wetland. They found that organic matter varied significantly depending on the depth in only natural wetlands and drained wetlands. In addition, Xia et al. (2021) reported that SOC decreased with increasing soil depth.

When a local evaluation is made, the SOC of the soils in the agricultural areas in the southern part of the research area (around Karamadazı, İlyaslı, Mustafabeyli, Yuları, Senirköy) was found to be lower than the agricultural areas in the north-northeastern section (around Sindelhöyük) (Table 5). The high SOC content of the soils around Sindelhöyük compared to other sites may be due to the application of animal manure. In addition, it has been stated by the local people that the agricultural areas here are covered with the material transported as a result of the marsh area overflowing during the periods when the water is high. SOC height may also be related to this. As a matter of
| Location                  | Land use       | Latitude      | Altitude     | Grazing | Land cover and management applications                                                                 |
|---------------------------|----------------|---------------|--------------|---------|----------------------------------------------------------------------------------------------------|
| Mustafabeyli              | Cropland       | 38.15 59° 21" | 35.37 25° 72"| –       | Apple orchard, 3 × 5 m, soil tillage is available between rows, cattle manure and chemical fertilization is available |
| Karamadazi                | Cropland       | 38 18 60 56   | 35. 28 44 80 | –       | Apple orchard, 3 × 5 m, soil tillage is available between rows, cattle manure and chemical fertilization is available |
| Yuları                    | Cropland       | 38.16 66 76°  | 35.33 17 16" | –       | Apple orchard, 3 × 5 m, soil tillage is available between rows, cattle manure and chemical fertilization is available |
| Yuları                    | Rangeland      | 38 17 12 27   | 35.33 30 31  | Yes     | Couch grass, jungus, vegetation cover 45%                                                                 |
| Ovaçifliği                | Rangeland      | 38.25 25 20°  | 35.18 85 97° | Yes, heavy | Couch grass, vegetation cover 60%, salt crystals are available on the soil surface                        |
| Between Ovaçifliği and Kuşçu | Rangeland   | 38.22 00 76°  | 35.23 38 74° | Yes, heavy | Couch grass, salt crystals are available on the soil surface, vegetation cover 30–60%                        |
| Ovaçifliği                | Shrubland      | 38.25 46 28°  | 35.18 53 55° | Yes, heavy | Tamarix, couch grass, salt crystals are available on the soil surface, vegetation cover 60%                  |
| Ovaçifliği                | Shrubland      | 38.24 70 67°  | 35.19 58 05° | Yes, heavy | Tamarix, couch grass, salt crystals are available on the soil surface, vegetation cover 50%                  |
| Ovaçifliği                | Marshland      | 38.25 58 75°  | 35.19 14 97° | Yes       | Phragmites sp., Mean vegetation height: about 1.5 m., vegetation density 95%                             |
| Between İlyaslı and Musahacılı | Cropland   | 38.19 04 23°  | 35.31 46 16° | –       | Apple orchard, 3 × 5 m, soil tillage is available between rows, cattle manure and chemical fertilization is available |
| Between İlyaslı and Yerköy | Cropland      | 38.18 17 32°  | 35.31 51 57° | –       | Apple orchard, 3 × 5 m, soil tillage is available between rows, cattle manure and chemical fertilization is available |
| İlyaslı                   | Cropland       | 38.17 36 37°  | 35.31 10 94° | –       | Apple orchard, 3 × 5 m, soil tillage is available between rows, cattle manure and chemical fertilization is available |
| Between Senirköy and Yeşilova | Cropland   | 38.21 44 43°  | 35.22 50 96° | –       | Sunflower, barley, cattle manure and chemical fertilization available                                     |
| Senirköy-Ovaçifliği-Yerköy | Cropland      | 38 22 00 76   | 35 23 88 74  | –       | Sunflower, barley, cattle manure and chemical fertilization available                                     |
| Between Senirköy and Musahacılı | Cropland   | 38.19 38 73°  | 35.26 77 58° | –       | Sunflower, barley, cattle manure and chemical fertilization available                                     |
| Between Senirköy and Yeşilova | Cropland   | 38.21 48 48°  | 35.22 75 88° | –       | Sunflower, barley, cattle manure and chemical fertilization available                                     |
| Çöl lake                  | Rangeland      | 38.46 22 89°  | 35.20 47 39° | Yes, heavy | Yabani kekik, vegetation cover %25, salt crystals are available on the soil surface                       |
| Between Yenihayat and Sindelhöyük | Rangeland | 38.31 58 98°  | 35.34 99 16° | Yes, heavy | Vegetation cover 15%, groundwater level is near surface                                               |
| Yenihayat                 | Drylake        | 38.29 78 06°  | 35.30 68 89° | Yes      | Vegetation cover 15%, groundwater level is near surface, dried lake area                              |
| Between Sindelhöyük and Soysallı | Cropland   | 38.36 33 22°  | 35.38 06 62° | –       | Maize, sunflower, barley, cattle manure and chemical fertilization available, There is a hard soil layer up to 15 cm deep |
| Between Sindelhöyük and Kepir | Cropland      | 38.38 65 47°  | 35.31 99 73° | –       | Maize, sunflower, barley, cattle manure and chemical fertilization available, There is a hard soil layer up to 15 cm deep |
| Between Sindelhöyük and Kepir | Marshland    | 38.36 48 01°  | 35.33 64 95° | Yes      | Phragmites sp., Mean vegetation height: about 1.5 m., vegetation density 90% feeding by Soysallı freshwater source, |
fact, there is a tight soil layer consisting of thin material on the surface of the agricultural areas in this region. In the pasture areas, the highest SOC values were determined in the pastures around Senirköy, and the lowest SOC values were in the pastures around Yenihayat. The denser vegetation can explain this situation in the pasture areas in the Senirköy region. SOC is lower in Kepir Marshes than in Örtülüakar Marshes (Table 5). The high organic carbon content in Örtülüakar Marshes can be explained by the fact that conservation activities are more effective in this region and, therefore less exposed to human impacts. In our study, the SOC content was generally lower in croplands compared to rangelands and marshlands. Wetland losses for agricultural purposes reduce SOC and carbon sequestration (Wang et al. 2010; Liu et al. 2019). Considering the possible future effects of climate change, as reported by a study conducted in Develi Plain, the minimum and maximum temperatures will generally increase; there is also predicted a decreasing trend in annual precipitation (Jouma 2019). It is thought that this situation may cause adverse effects on wetland hydrology and ecosystem, accelerating the degradation process in the wetland, and thus negatively affecting the organic carbon storage ability of wetland soils. Tillage activities disrupt the underlying ecosystem and expose it to aerobic aeration, increase the organic matter decomposition rate, and cause a decrease in the organic matter content of the soils (Reicosky and Lindstrom 1993; Gesch et al. 2007). Microorganism communities of different structures are responsible for organic matter decomposition and carbon and nitrogen cycles in the soil (Ansola et al. 2014). Various studies have shown that when land-use changes, the structure of the soil microbial community also alters (Zhang et al. 2013a, b; Sui et al. 2019). Conversion from wetland to other land uses, especially agriculture, changes the soil nutrient and

| Soil property                  | N  | Minimum | Maximum | Mean  | Standard deviation |
|-------------------------------|----|---------|---------|-------|--------------------|
| SOC %                         | 309| 0.09    | 7.41    | 2.00  | 1.65               |
| Carbon stock t/ha             | 309| 0.18    | 69.81   | 21.17 | 16.77              |
| Bulk density g/cm³            | 309| 0.22    | 2.54    | 1.26  | 0.36               |
| pH                            | 268| 7.51    | 9.51    | 8.48  | 0.46               |
| Electrical conductivity µS/cm | 268| 105.00  | 16,170.00| 2143.31| 2597.30           |
| Aggregate stability %         | 268| 0.52    | 100.00  | 29.81 | 18.49              |
| Dispersion ratio %            | 268| 5.20    | 122.83  | 43.10 | 17.22              |
| Clay %                        | 268| 1.08    | 100.00  | 34.40 | 23.86              |
| Silt %                        | 268| 0.00    | 81.23   | 30.43 | 17.18              |
| Sand %                        | 268| 0.00    | 87.79   | 35.16 | 18.48              |

| Source of variation | SOC | CS | BD | pH | EC | AS | DR | Clay | Silt | Sand |
|---------------------|-----|----|----|----|----|----|----|------|------|------|
| Land use            | P   | 0.000 | 0.000 | 0.023 | 0.000 | 0.000 | 0.000 | 0.000  | 0.000  | 0.000 |
| Soil depth          | P   | 0.000 | 0.000 | 0.000 | 0.015 | 0.699 | 0.908 | 0.008  | 0.003  | 0.270 |
| Land use Soiland depth| P   | 0.454 | 0.909 | 0.833 | 0.010 | 0.005 | 0.419 | 0.387  | 0.592  | 0.288 |

| Location      | Land use   | SOC %         | CS t/ha      |
|---------------|------------|---------------|--------------|
| Karamadazı    | Farmland   | 0.85 ± 0.36   | 12.63 ± 5.88 |
| İlyaslı       | Farmland   | 1.22 ± 0.74   | 15.27 ± 9.95 |
| Mustafabeyli  | Farmland   | 1.22 ± 1.13   | 17.16 ± 16.58|
| Yuları        | Farmland   | 1.37 ± 0.50   | 20.34 ± 6.91 |
| Senirköy      | Farmland   | 0.82 ± 0.92   | 11.08 ± 12.67|
| Sindelhöyük   | Farmland   | 3.25 ± 0.42   | 17.85 ± 8.12 |
| Ovaçiftliği    | Rangeland  | 2.47 ± 1.30   | 29.08 ± 16.50|
| Yuları        | Rangeland  | 2.85 ± 1.98   | 32.95 ± 22.58|
| Senirköy      | Rangeland  | 4.76 ± 1.50   | 42.9 ± 14.46 |
| Çölgölü       | Rangeland  | 0.79 ± 0.65   | 7.9 ± 6.51   |
| Yenihayat     | Rangeland  | 1.2 ± 0.48    | 11.6 ± 6.22  |
| Kepir         | Marsh      | 1.44 ± 1.03   | 12.87 ± 9.17 |
| Örtülüakar    | Marsh      | 2.96 ± 1.71   | 31.38 ± 18.44|

SOC Soil organic carbon, CS Carbon stock, BD Bulk density, EC Electrical conductivity, AS Aggregate stability, DR Dispersion ratio

Table 3 Some descriptive statistics of general soil properties in the study site

Table 4 ANOVA results for testing land use, soil depth and their interactions on selected soil properties

Table 5 Spatial changes in SOC and CS according to land use types
soil hydrothermal conditions, changing the distribution of the microorganism community. The decomposition of soil organic carbon can be accelerated in the microbial community, which adapts to these changes caused by human influences (Zhang et al. 2013a, b).

The reason for the higher organic carbon content in the cropland compared to the northern marshland may be the use of animal manure. Indeed, fertilization and tillage affect soil chemical properties (Gesch et al. 2007; Wright et al. 2007). Changes in water conditions in wetlands...
due to drainage activities may affect the accumulation of organic matter in the wetland. Wetland drainage decreases wetland productivity and accelerates the decomposition of more organic matter by ensuring its contact with air (Page and Dalal 2011). A study conducted in Northeast Germany stated that the organic carbon loss in a peat field drained 40 years ago was 37% (Kluge et al. 2008). Again, a study in the Sanjiang Plateau in China stated that deterioration in water-temperature conditions could accelerate decomposition. Agricultural production activities might also cause a sharp decrease in the amount of organic matter returned to the soil, and this might cause a significant loss in SOC and nutrients in the cultivated areas (Song et al. 2004).

The SOC was positively correlated with aggregate stability, clay and carbon stock and negatively correlated with pH, DR, and bulk density (Table 6). Likewise, Luo et al. (2014) and Xia et al. (2021) noted that bulk density affected the organic carbon accumulation of the soil. Low bulk density makes the soil looser and ensures better permeability and water holding capacity. This creates the desired environment in terms of organic carbon accumulation (Sakin 2012). Similar to the results of this study, Gebrehiwot et al. (2018) and Adesuyi et al. (2019) also found a negative correlation between soil pH and organic carbon. Likewise, Zhang et al. (2011) noted that the mechanical composition of the soil, bulk density, salinity, and nutritional status could affect the dynamics of soil carbon since it would directly affect the capacity of vegetation.

**Carbon Stocks**

The carbon stock of the soils varied between 0.18–69.81 ton/ha (Table 3). The average carbon stocks of the soils according to land use patterns were listed in descending order as rangeland > marshland > shrubland > cropland > dry-lake area (Fig. 5). As land use changed, the carbon stocks of the soils also changed statistically significantly (Table 4).

The carbon stocks of the soils in the rangeland were similar to the carbon stock measured in the marshland area but were higher and statistically different from the values measured in other land use soils. The carbon stocks of cropland and shrubland soils were statistically similar. Again, the carbon stocks of shrubland and marshland soils were statistically similar (Fig. 5).

The carbon stock of the soils changed at a statistically significant level according to the soil depth (Table 4). In general, as the soil depth increased, the carbon stock of the soils decreased (Fig. 5). The carbon stocks at the 1st, 2nd, and 3rd depths were similar to each other and different from the other depths. Again, the carbon stock at the 3rd and 4th depth levels was statistically similar. The carbon stocks of the 4th and 5th depths were also statistically similar (Fig. 5).

The average carbon stock was the highest in the soils at the 1st and 2nd depth layers (25.47 ton/ha, 25.75 ton/ha, respectively) and the lowest at the 5th depth layer (2.80 ton/ha) (Fig. 5).

In the IPCC (2019) report, the default carbon stock values in hot temperate dry climate zones were 24 ton/ha in high-activity clay soils for a 30-cm soil depth and 74 ton/ha in wetland soils (IPCC 2019). In this study, the total carbon capacity stored in the 40-cm soil column was 115.68 ton/ha in the rangeland, 82.41 ton/ha in the shrubland, 81.52 ton/ha in the marshland, 53.86 ton/ha in the cropland, and 24.74 ton/ha in the dry-lake area. In the Turkey Greenhouse Gas Inventory Report (2020), it was predicted that the soil of a wetland with a carbon stock of 36.37 ton/ha for the Central Anatolian steppe conditions would store 32.14 ton/ha of carbon 20 years after its conversion to cropland.

When a general evaluation was made, the highest carbon stock was found in rangeland, marshland, and shrubland soils. A relatively lower storage capacity was detected in the soils in the cropland and dry-lake area. When the dry-lake area is examined, it can be concluded that the soils here may have lost a large part of the stored carbon after drying. Carbon stock in the cropland is thought to be contributed by fertilization resulting from agricultural activities. The highest carbon storage was determined in the agricultural areas around Yulari, and the lowest in the soils around Senirköy (Table 5). Pasture areas around Senirköy have the highest carbon stock. The carbon stock of the Ötülüakar Marshes is higher than the Kepir Marshes, which are more exposed to human activities (Table 5). The higher carbon stock in rangeland, shrubland, and marshland soils can be explained by the organic matter contribution provided by vegetation. These results show that human activities that do not have continuous vegetation, such as agricultural activities, affect the organic carbon and carbon stocks of the soil. This study revealed the importance of protecting marshlands, rangelands, and shrublands, which are an important sink for the global carbon cycle, against human effects. Yang et al. (2013) reported that total organic carbon values in the topsoil were affected by land-use changes. The researchers detected that organic carbon in natural wetlands (Humus wetland (203.5 g/kg) and wet grassland (59.2 g/kg) were higher than in other land-use patterns. They stated that draining the humus wetland caused a significant decrease in the SOC (52%). The soil organic matter decreased by 45% in the drained wet grassland.

Lands, converted after drainage, started to restore carbon. It was concluded that the soil carbon content in the dry-lake area, drained later, was lost significantly.

The carbon stock of the soils was positively correlated with aggregate stability, clay, and organic carbon content and negatively correlated with pH (Table 6).
Bulk Density

The bulk density of the soils in the study area varied between 0.22–2.54 g/cm³ (Table 3). According to land use patterns, the bulk density of the soils was listed in descending order as shrubland > cropland > dry-lake area > rangeland > marshland (Fig. 6). The average bulk densities of the soils were statistically significantly affected by the change in land use ($P < 0.05$) (Table 4). The average bulk density of the soils taken from the marshland differed statistically from the values determined in other land uses. The average bulk densities of the soils under the other four land uses were statistically similar (Fig. 6).

When examined in terms of soil depth, the bulk densities of the study area soils were statistically significantly affected by the change in soil depth (Table 4). The bulk density of the topsoil was lower and statistically different from the subsoils. In general, as the depth of the soil increased, the bulk density also increased (Fig. 6).

The reason for the low bulk density in marshlands can be explained by the continuous organic material input in these areas and, therefore, the higher amount of organic matter compared to the cropland. The grazing pressure can explain the similar bulk density of the croplands close to the rangelands and shrublands. The higher bulk density in the cropland compared to the marshland and rangeland may be due to low organic matter and soil cultivation. Likewise, Tufa et al. (2019), Yitbarek et al. (2013), and Takele et al. (2014) found that the bulk density of agricultural soils in the topsoil was higher than the bulk density in the rangeland and forest areas.

The bulk density of the soils was positively correlated with pH, EC, and silt content and negatively correlated with sand content and SOC (Table 6). SOC is a property that controls bulk density and porosity. As the organic carbon content of the soil increased, its bulk density decreased.

pH

The pH of the soils in the study area generally varied between 7.51–9.51 (Table 3). The average pH of the soils according to different land uses was listed in descending order as dry-lake area > shrubland > rangeland > cropland > marshland (Fig. 7). The pH of the soils was statistically significantly affected by changes in land use ($P < 0.05$) (Table 4). The average pH values were similar in the soils taken from dry-lake and shrubland areas and were statistically different from the soils taken from other land use patterns. The average pH of the soils taken from cropland and marshland areas was similar and different from the soils taken from other land-use patterns. The decrease in pH in cropland soils could be caused by the washing out or depletion of the basic cations in the soil or by nitrogen fertilization (Chauhan et al. 2014; Tilahun 2007). The average pH of rangeland soils differed statistically from other land-use patterns (Fig. 7). It is thought that the low pH in the marshland may have been caused by the high organic carbon content and the humic acids formed in the environment as a result of the decomposition of the vegetative material (Dube and Chitiga 2011). The average pH of the topsoils was 8.43, and that of the subsoils was 8.57, and the pH varied statistically significantly according to the soil depth (Fig. 7, Table 4). The pH can be used as an indicator for the quality of wetland soils under different land uses to assess the degradation in wetland soils. Zhu et al. (2021) also reported that the pH of 0–20 cm significantly changed between land uses converted to natural, drained soybean agricultural lands and later rice cultivation areas. Still, there was not a very significant change.

The pH properties of the soils were positively correlated with EC, DR, and bulk density and negatively correlated with sand, organic carbon, and carbon stock (Table 6).
Similar to this study, Yang et al. (2013) reported that the pH values of soils were negatively correlated with the total organic carbon.

**Electrical Conductivity (EC)**

The electrical conductivity (EC) values of the soils taken from the study area were between 105–16,170 µS/cm (Table 3). The average EC values of the soils according to different land-use patterns were listed in descending order as dry-lake area > shrubland > rangeland > marshland > cropland (Fig. 7). EC was statistically significantly affected by the change in land use \((P < 0.05)\) (Table 4). The average EC values were statistically different in the soil samples taken from the rangeland from the EC values of the samples taken from other land-use patterns. The average EC of cropland and marshland soils was similar but different from other land uses. Again, the average EC of the soils taken from the dry-lake and shrubland areas was identical, but both values were higher and statistically different from other land uses (Fig. 7). When the evaluation was made by considering only the soil depth factor, the average EC in the topsoils was determined to be 2013 µS/cm and 2083 µS/cm in the subsoils, and it was statistically similar. In other words, the soil depth did not significantly affect EC \((P > 0.05)\) (Table 4).

The salinity problem was observed in the study area, especially in the soils in the rangelands, shrubland, and dry-lake area in the Ovaçiftliği region. During the field studies, salt crystals were found in some places on the soil profile and surface in these regions (Fig. 8). It is thought that this may be related to the groundwater level close to the land surface. It is considered that irrigated farming practices in cropland soils may have reduced soil salinity by washing the topsoils.

EC was positively correlated with pH, silt, DR, and bulk density and negatively correlated with sand content (Table 6).

**Aggregate Stability**

The aggregate stability values of the soils in the study area varied between 0.52–100% (Table 3). The average aggregate
stability of the soils according to different land use patterns was listed in descending order as marshland > dry-lake area > cropland > rangeland > shrubland (Fig. 9). The aggregate stability of the soils was statistically significantly affected by land-use changes ($P < 0.05$) (Table 4). The average aggregate stability of the soils taken from the shrubland differed from the aggregate stability of the soils taken from other land-use patterns (Fig. 9).

The aggregate stability of the soils taken from the marshland was similar to that of the soils taken from the cropland and dry-lake area and different from other land-use patterns. Again, the aggregate stability of the soils taken from the rangeland was similar to the soils taken from cropland and dry-lake area and statistically different from other land uses (Fig. 9). It was observed that the aggregate stability decreased in the regions where agriculture and animal grazing were performed compared to the marshland and dry-lake area. Thus, Mainuri and Owino (2013) noted that tillage reduced aggregate stability. It is thought that the lower aggregate stability in the shrubland may be due to the higher sand content of the soil. A negative correlation was found between the aggregate stability of the soils and the sand content in the correlation analysis (Table 6).

According to the soil depth, the average aggregate stability of the topsoils (32.62%) was higher compared to the subsoils (31.02%). However, this difference was not statistically significant (Table 4).

The aggregate stability of the soils was positively correlated with clay content, SOC, and carbon stock and negatively correlated with sand content (Table 6). Mainuri and Owino (2013) found a positive correlation between aggregate stability and soil organic carbon. Thus, the high values mentioned in the marshland with the high clay and organic carbon content confirm this. The high sand content and low clay content in the shrubland probably reduced the aggregate stability.

**Dispersion Ratio (DR)**

The DR values of the soils in the study area varied between 5.20–123% (Table 3). When evaluated in general, the fact that the soils in the study area have DR $> 15$ indicates that they are sensitive to erosion (Balcı 1996). The DR values of the soils according to different land-use patterns were listed in descending order as shrubland > dry-lake area > marshland > rangeland > cropland (Fig. 9). Land-use change statistically significantly affected the DR of the soils ($P < 0.05$) (Table 4). The DR values of cropland, dry-lake area, and shrubland soils differed from each other and other land-use patterns. The average DR of rangeland and marshland soils was statistically similar (Fig. 9).

Soils that seem to be most sensitive to erosion were identified as shrubland and soils in the dry-lake area (Fig. 9). When evaluated in terms of the soil depth, it was determined that the DR values (39.67%) of the topsoils in the study area were lower and statistically significantly different than the subsoils (46.53%) ($P < 0.05$) (Table 4). The topsoils were more resistant to erosion than the subsoils.

According to the correlation analysis, DR was positively correlated with pH, EC, and silt content and negatively correlated with sand content and SOC (Table 6).

**Particle Size Distribution**

According to the evaluation made according to the International Soil Society triangle (Tommerup 1934), soils in the study area had the loam-clay texture in the cropland and marshland areas, the clay loam texture in the rangeland area, the loam texture in the shrubland area, and the clay texture in the dry-lake area.

**Clay**

The clay content of the soils varied between 1.08–100% (Table 3). According to the land-use patterns, the average clay contents were listed in descending order as dry-lake area > marshland > cropland > rangeland > shrubland (Fig. 10). The clay content of the soils was statistically significantly affected by the change in land use ($P < 0.05$) (Table 4).
The soils taken from cropland and marshland areas were similar in terms of clay content. However, the soils taken from other land uses were different. The clay content of the soils taken from shrubland, rangeland, and dry-lake areas was statistically different (Fig. 10).

According to the soil depth, the clay content of the topsoils (30.55%) was lower and statistically different from the clay content of the subsoils (38.25%) (*P* < 0.05) (Table 4, Fig. 10).

The clay content of the soils was positively correlated with aggregate stability, SOC, and carbon stock and negatively correlated with silt and sand content (Table 6).

**Silt**

The silt content of the soils generally varied between 0–81.23% (Table 3). According to different land-use patterns, the average silt contents of the soils were listed in descending order as shrubland > rangeland > cropland > marshland > dry-lake area (Fig. 10). The silt content of the soils in the study area changed statistically significantly as the land use changed (*P* < 0.05) (Table 4).

The average silt content of the soils in the dry-lake area was lower and statistically different from that determined in other land use patterns. The silt content of the shrubland soils was similar to the values in the rangeland soils, but it was statistically different from the silt content in other land use patterns. Again, the silt content of the marshland soils was statistically similar to the values determined in the cropland area, but it was different from other land-use patterns (Fig. 10).

According to the soil depth factor, silt contents did not differ statistically in the topsoil (30.74%) and subsoil (30.12%) (*P* > 0.05) (Table 4).

It was determined that silt content was positively correlated with EC, DR, and bulk density and negatively correlated with clay content (Table 6).
The sand content of the soils varied between 0–87.79% (Table 3). According to different land use patterns, the average sand contents were listed as shrubland > range-land > marshland > cropland > dry-lake area (Fig. 10). The average sand content of the soils was statistically significantly affected by the change in land use ($P < 0.05$) (Table 4).

The average sand content of the soils taken from the dry-lake area, cropland, marshland, and shrubland areas differed statistically. The sand content of rangeland soils was...
statistically similar to that of marshland and shrubland soils and was different from the soils of other land uses (Fig. 10).

When the sand content was examined in terms of soil depth, it was high in the topsoils of the study area (38.70%) and lower (31.62%) in the subsoils. This difference was statistically significant ($P < 0.05$) (Table 4, Fig. 10).

The sand content of the soils negatively correlated with EC, pH, aggregate stability, clay, DR, and bulk density (Table 6).

Abbasi et al. (2007) emphasized that the differences between the textures of soils in different land-use patterns showed the effects of varying utilization and management systems on the soil properties of land use patterns.

**Conclusion**

The changes in land use in and around the Sultan Marshes significantly affected the soil properties, including organic carbon stocks. The soil properties affected by land-use changes were SOC, carbon stock, pH, EC, aggregate stability, sand, clay, silt content, and bulk density. The soil properties affected by the change in soil depth were SOC, carbon stock, clay, sand content, and bulk density. SOC and carbon stock were higher in rangeland, marshland, and shrubland areas, while low in cropland and dry-lake areas. As the soil depth increased, the SOC and carbon stock decreased. The highest carbon stock in the 40-cm soil column was in rangeland, shrubland, and marshland areas. The organic carbon content of the soils was positively correlated with aggregate stability, clay and carbon stock and negatively correlated with pH, DR, and bulk density. The carbon stock of the soils was positively correlated with aggregate stability, clay, and soil organic carbon content and negatively correlated with pH. The soils in the study area generally showed an alkaline reaction. The highest pH values were in the dry-lake area soils, while the lowest pH values were in the marshland soils. There was a salinity problem, especially in the soils in the rangeland areas around Ovaçiftliği and Lake Çol, in the shrubland and dry-lake area soils. The rangeland soils in the study area served as an important sink in terms of carbon storage. However, since rangeland and shrubland areas were under grazing pressure due to the intensity of cattle and ovine breeding, animal husbandry activities in the region should be carried out within the grazing plan. Protecting and improving controlled livestock and vegetation are very important for sustainable carbon management. The restoration of degraded rangelands can enhance organic matter contribution to the soil.

Activities such as drainage, conversion to agriculture, and grazing, which are among the human activities in the study area, affected the soil properties significantly. The marshland soils were affected by human activities (such as drainage, opening to agriculture, and animal husbandry). The intensive use pressure should be mitigated, especially in the Northern Marshes. Thus, the study results revealed that the carbon stock of the better preserved Southern Marshes was higher than the Northern Marshes, where the human effects were more intense. Marshland areas, just like rangeland areas, are one of the most important carbon storage areas that need to be protected and improved. Especially agricultural activities have adversely affected the carbon stocks of the soils. In terms of soil carbon management in the wetland, it is recommended to stop further conversions to agriculture. The existing agricultural areas can be maintained with good agricultural practices that protect and improve the organic matter content of the soil. The Sultan Marshes, similar to other wetlands in the region, are suffering from projected changes in climatic parameters that will increase evapotranspiration. Increased drought frequency and severity are also estimated for the region. Therefore, we may observe more drastic adverse effects such as productivity loss or further depletion of carbon stocks when climate change impacts are added to the already increased land management activities.

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**Data Availability** The data that support the findings of this study are available on request from the corresponding author.

**Declarations**

**Ethics Approval** Not applicable.

**Consent to Participate** Not applicable.

**Consent for Publication** Not applicable.

**Conflict of Interest** The authors declare no competing interests.

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