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The Effects of Long-Term Land Uses on Organic Carbon Associated With Aggregate Fractions in the Çarşamba Plain

Çarşamba Ovasında Agregat Fraksiyonları ile İlişkili Organik Karbon Üzerine Uzun Süreli Arazi Kullanımlarının Etkileri

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THE EFFECTS OF LONG-TERM LAND USES ON ORGANIC CARBON ASSOCIATED WITH AGGREGATE FRACTIONS IN THE ÇARŞAMBA PLAIN

ABSTRACT

Land uses and associated management practices can significantly change soil properties in agricultural areas. These changes in soil properties can cause both a decrease in soil fertility in agricultural areas and an increase in the sensitivity of agricultural soils to various processes such as climate change, erosion, and desertification. The current study investigated the effects of long-term land use types on soil properties in alluvial soils located in the Çarşamba plain. Soil properties such as aggregate size distribution, soil organic carbon (SOC) content associated with aggregates and soil organic carbon stock (SOC_{Stock}), structure stability index (SSI), aggregate stability index (ASI), unstable aggregate index (E_{LT}), mean weighted diameter (MWD) and geometric mean diameter (GMD) were measured in soil samples collected from five different land use types (vegetable, cherry, persimmon, maize, and rice) and three different soil depths (0.0-7.5 cm, 7.5-15.0 cm, and 15.0-30.0 cm). The results showed that different land use types statistically affected all the examined soil properties ($p<0.05$, $p<0.01$). The highest and lowest SSI values were obtained in persimmon land use (2.2%) and rice land use (1.8%), respectively, while the same land uses were found to have the statistically highest values (0.8) for ASI. Vegetable land use had the highest statistical impact on aggregate-associated SOC content across most of the examined aggregate sizes. Therefore, it is recommended to perform rotation cropping systems that increase organic matter (OM) input to reduce the adverse effects of land uses and soil management on aggregates-related SOC content and SOC_{Stock} in alluvial areas.

Keywords: Land Use, Aggregate Size Distribution, Soil Organic Carbon Stock, Structure Stability Index, Aggregate Stability Index.

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ÇARŞAMBA OVASINDA AGREGAT FRAKSİYONLARI İLE İLİŞKİLİ ORGANİK KARBON ÜZERİNE UZUN SÜRELİ ARAZİ KULLANIMLARININ ETKİLERİ

ÖZ

Arazi kullanımı ve onunla ilişkili yönetim uygulamaları tarımsal alanlardaki toprak özelliklerini önemli ölçüde değiştirebilmektedir. Toprak özelliklerinde meydana gelen bu değişimler hem tarımsal alanlarda toprak verimliliğinin

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azalmasına hem de tarımsal toprakların iklim değişikliği, erozyon, çölleşme gibi çeşitli süreçlere hassasiyetinin artmasına neden olabilmektedir. Mevcut çalışmada, Çarşamba ovasında yer alan alüviyal topraklarda, uzun süreli arazi kullanım tiplerinin toprak özellikleri üzerindeki etkileri incelenmiştir. Beş farklı arazi kullanım tipinden (sebze, kiraz, Trabzon hurması, mısır ve çeltik) ve üç farklı toprak derinliğinden (0.0-7.5 cm, 7.5-15.0 cm, ve 15.0-30.0 cm) alınan toprak örneklerinde agregat büyüklük dağılımı, agregatlar ile ilişkili toprak organik karbon (TOK) içeriği ve toprak organik karbon stoğu ($TOK_{Stoğu}$), strüktür stabilite indeksi (SSI), agregat stabilite indeksi (ASI), kararsız agregat indeksi ($AI_{Kararsız}$) ,ortalama ağırlıklı çap (OAÇ) ve geometrik ortalama çap (GOÇ) gibi toprak özellikleri ölçülmüştür. Elde edilen sonuçlar, farklı arazi kullanım tiplerinin incelenen bütün toprak özelliklerini istatistiksel olarak ($p<0.05$, $p<0.01$) etkilediğini göstermiştir. En yüksek ve en düşük SSI değerleri sırasıyla Trabzon hurması arazi kullanımı (% 2.2) ve çeltik arazi kullanımında (%1.8) elde edilirken, aynı arazi kullanımlarının ASI için istatistiksel olarak en yüksek değerlere (0.8) sahip olduğu bulunmuştur. Sebze arazi kullanımı, incelenen agregat büyüklük fraksiyonlarının büyük çoğunluğunda agregatlar ile ilişkili TOK **içeriği** üzerine en yüksek istatistiksel etkiyi ortaya koymuştur. Bu nedenle, alüviyal alanlarda arazi kullanımları ve toprak yönetimlerinin agregatlar ile ilişkili TOK **içeriği ve** $TOK_{\textbf{Stoğu}}$ üzerindeki olumsuz etkilerini azaltmak için organik madde (OM) girişini artıran rotasyon ekim sistemlerinin uygulanması önerilmektedir.

Anahtar Kelimeler: Arazi Kullanımı, Agregat Büyüklük Dağılımı, Toprak Organik Karbon Stoğu, Strüktür Stabilite İndeksi, Agregat Stabilite İndeksi.

1. INTRODUCTION

Soils, known as the largest carbon pool of terrestrial ecosystems, contain carbon amounts up to 2 times the current atmospheric carbon pool (750 Pg) and 2~3 times the terrestrial vegetation carbon pool (500~600 Pg) (Yousaf et al., 2017). Approximately 38.18 % of the world's land area (12.74×10^7 km^2), which includes diverse terrestrial ecosystems, is constituted by agricultural areas (4.86×10^7 km^2) that store about 8–10 % of global soil organic carbon (SOC) storage (Garten, 2002; Zomer et al., 2017). Therefore, gaining a better understanding of the factors driving changes in the organic carbon (OC) pools of agricultural soils is one of the most critical issues regarding the future of ecosystem services in terrestrial areas (Zomer et al., 2017).

The amounts of OC sequestrated in soils are controlled by various factors, including anthropogenic influences such as land use and management, as well as topography, parent material, soil properties, climatic variables, and biotic characteristics (Zdruli et al., 2017; Wenzel et al., 2022). While Alidoust et al. (2018) stated that these factors affect soil organic carbon stock (SOC_{Stock}) by influencing the SOC decomposition rates, SOC absorption, and stabilization, altering the moisture regime and the vertical redistribution of SOC in the soil profile (Akpa et al., 2016; Dorji et al., 2014). Wiesmeier et al. (2019) also reported that soil aggregation and texture, mineralogy, and the related specific surface area are considered as key variables controlling the potential of carbon storage in soils.

Sustainable management practices implemented during crop cultivation enhance the accumulation of SOC by regulating the physical, chemical, and biological processes such as aeration, temperature, moisture, compaction, soil reaction, and microbial activity in the arable soils, but poor management practices may cause OC loss in the same soils (Modak et al., 2019). The loss of soil organic matter (SOM) can also make agricultural lands more vulnerable to land degradation and desertification. Therefore, understanding the relationships between OC pools and soil management practices in agricultural ecosystems is essential for designing sustainable management strategies to enhance OC sequestration in arable soils and preserve those against land degradation and desertification.

Various soil management practices, such as reduced tillage, crop rotation, irrigation, fertilization, and organic mulching, help maintain crop residues on the soil surface, or manage primary productions that are sources of OC. Suitable management practices also promote the sustainable fertility of arable soils by enhancing SOC storage, improving aggregate structure, and providing efficient soil biological functions (Tao et al., 2018; Sekaran et al., 2021). On the other hand, unsuitable management practices across diverse land use types accelerate SOM losses in agricultural lands (Li et al., 2007) and decrease soil aggregate stability (Wakindiki et al., 2006). Consequently, these practices can lead to the deterioration of soil structure and land degradation (Haghighi et al., 2010).

Soil aggregates and OC have a synergistic interaction. Aggregates preserve and store carbon, while OC encourages the development and stabilization of aggregates. This interaction is essential for soil health because it improves soil structure, water infiltration, aeration, nutrient retention, and carbon sequestration. Density fractionation is a helpful technique for investigating the significance of OC stabilization in aggregates and minerals. The stability of OC in soil depends on its placement within the soil profile, occlusion inside aggregates, inclusion in organo-mineral complexes, and the source of plant litter (Schrumpf et al., 2013). As a result of the increased aggregate stability, the degraded sediments' particulate organic carbon (POC) and dissolved organic carbon (DOC) contents significantly increased (Chaplot et al., 2015). Aggregation of soil can improve the stability of OC in soils, which is the capacity to extend the residence period of OC in the soil relative to a benchmark or reference scenario (Berhe and Kleber, 2013).

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Soil aggregates are collections of soil particles coming together to form stable structures that are essential for plant growth and soil health (Vergani and Graf, 2016). Physical, chemical, and biological processes hold together their constituents, which include sand, silt, clay, organic materials, and microbial metabolites (Gadekar et al., 2024). Their capacity to modify important soil characteristics and processes directly impacting plant growth makes them significant. Evidence suggests that, at the species and plant community levels, soil aggregate stability rises linearly with rising root mass densities (Peres et al., 2013; Gould et al., 2016). The ability of soil to maintain its structure under various stressors is known as soil aggregate stability; it is closely related to soil shear strength. (Rillig et al., 2002) reported that the soil aggregate stability rises as root length density, microbial association diversity, and plant cover increase.

In this study, conducted in the fields of the Black Sea Agricultural Research Institute, we aimed to assess the impact of various long-term land use types and soil depths on soil aggregate fractions, SOC and SOC_{stock} associated with aggregates, and key indicators of soil structure, including the structure stability index (SSI) and aggregate stability index (ASI). It was also hypothesized that land use types with high SOC, SOC_{Stock}, SSI, and ASI values would be long-term sustainable land uses for alluvial lands.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

The study was conducted on the experimental fields at the Tekkeköy Central Campus of the Black Sea Agricultural Research Institute, located 20 km east of Samsun, Turkey (41°13′41″ N-36°30′07″ E; elevation 4 m). The long-term highest and lowest average temperatures in the region where the study was conducted were recorded in August (24.6 °C) and January (7.3 °C), respectively, and the annual average temperature are reported as 15.2 °C. Also, the region with the semi-arid climate condition has an annual rainfall of 839.6 mm and a mesic soil temperature and ustic moisture regime (Sağlam et al., 2014).

The study area is located in the Çarşamba Alluvial Delta Plain, formed by sediments carried by the Yeşilırmak River. The majority of soils in the Delta Plain are classified into the orders Vertisol, Entisol, and Inceptisol. The results regarding the basic soil properties of the experimental plots with different land use types in the study area are given in Table 1. While the textural classes of plots in other land use types, except for the cherry land use type, were determined as clay (clay contents > 40 %), the bulk density (ρ_b), organic matter (OM), pH, and electrical conductivity (EC) of soils also differed between 1.20-1.57 g cm^{-3}, 7.92-22.39 g kg^{-1}, 6.77-7.83, and 0.12-0.92 dS m^{-1}, respectively (Table 1).

Table 1. Some morphological properties of soils in the study area

Çizelge 1. *Çalışma alanında toprakların bazı morfolojik özellikleri*

Land uses	D (cm)	Clay (%)	Silt (%)	Sand (%)	Texture classes	ρ_b (g cm^{-3})	SOC (g kg^{-1})	$pH_{1:2.5}$	EC (dS m^{-1})
Vegetable*	0.0-7.5	41.4	18.9	39.7	Clay	1.20	14.63	7.67	0.92
	7.5-15.0	47.4	17.2	35.4	Clay	1.28	13.08	7.83	0.46
	15.0-30.0	51.4	15.8	32.8	Clay	1.49	11.00	7.75	0.41
Cherry	0.0-7.5	36.9	13.7	49.4	Sandy Clay	1.35	12.72	6.78	0.36
	7.5-15.0	41.2	12.7	46.1	Sandy Clay	1.47	11.38	6.91	0.15
	15.0-30.0	40.2	10.6	49.2	Sandy Clay	1.55	7.92	7.15	0.12
Persimmon	0.0-7.5	41.1	15.5	43.4	Clay	1.41	16.26	7.20	0.24
	7.5-15.0	48.3	15.0	36.7	Clay	1.57	12.36	7.61	0.18
	15.0-30.0	49.5	14.5	36.0	Clay	1.53	11.98	7.64	0.18
Maize	0.0-7.5	61.9	21.4	16.7	Clay	1.32	17.23	7.05	0.34
	7.5-15.0	67.7	22.2	10.1	Clay	1.36	16.34	7.13	0.32
	15.0-30.0	67.4	22.3	10.3	Clay	1.37	14.95	7.32	0.32
Rice	0.0-7.5	63.2	28.9	7.9	Clay	1.36	22.39	6.86	0.27
	7.5-15.0	64.0	31.6	4.4	Clay	1.39	16.71	6.91	0.16
	15.0-30.0	64.7	30.5	4.8	Clay	1.39	12.55	6.77	0.14

LUT: Land use type; D: soil depth; ρ_b : Bulk density; SOC: Soil organic carbon; EC: Electrical conductivity.

*: In the field where the cabbage-pepper-bean rotation was carried out, cabbage was planted during the soil sampling period

2.2. The history of management practices relating to each land-use system

The Black Sea Agricultural Research Institute has conducted short- and long-term research trials concerning field crops, vegetables, and orchards. While the research activities on field crops and vegetables such as rice, maize, pepper, melon, cucumber, tomato, cabbage, lettuce, leek, and spinach are performed in the summer or the winter months, those regarding orchards are generally carried out during the year. However, management practices such as tillage, irrigation, fertilization, and weed control performed during the cropping season can display considerable differences for each land-use system. As the places to be taken soil samples in the study, fields grown cabbage (vegetable rotation-annual), maize (field crop-annual), rice (filed crop-annual), cherry (orchard-perennial), and persimmon (orchard-perennial) were selected. Also, detailed information about the history of soil management practices in these fields is given in Table 2.

Table 2. The history of management practices performed in land use types

Çizelge 2. *Arazi kullanım tiplerinde gerçekleştirilen yönetim uygulamalarının geçmişi*

Land uses	**Duration/Annual or Perennial**	**Management practices**
Vegetable*	>15 years/Annual	Conventional tillage practices include plowing, disc harrow, and rotavator; irrigation with drip irrigation systems; and base fertilization (NPK).
Cherry	>35 years/Perennial	Tillage practices with a subsoil plow up to 2014; no-tillage practices after 2014; irrigation with drip irrigation systems; base fertilization (NPK); and utilizing herbicide to control weeds.
Persimmon	>35 years/Perennial	Tillage practices with a subsoil plow up to 2014; no-tillage practices after 2014; irrigation with drip irrigation systems; base fertilization (NPK); and utilizing herbicide to control weeds.
Maize	>40 years/Annual	Conventional tillage practices include plowing, rotavator, hoeing, and earthing up; irrigation with sprinkler and drip irrigation systems; and base fertilization (NPK).
Rice	4 years/Annual	Paddy-field where management practices, such as tillage, ponding, fertilizing, and utilizing herbicides, under farmer conditions were performed.

2.3. Soil Sampling and Preparation

In the fall season of 2020, soil samples were collected for four replicates from fields with different land use types (vegetable rotation, maize, rice, cherry, and persimmon). For each land-use system, a 5x5 m grid area was randomly selected, and the disturbed and undisturbed soil samples were taken from three soil depths (0.0-7.5 cm, 7.5-15.0 cm, and 15.0-30.0 cm) at the edge of the area (İç, 2024). While the disturbed samples were taken using an auger with 8 cm diameter, the undisturbed samples were collected using the stainless-steel cylinders with 5 cm diameter and 5 cm height. Also, crop residues were carefully removed from the soil surface before soil samplings.

All the distributed fresh soil samples collected from the specified land use types were divided into two parts in the laboratory. The first portion of the soil samples was passed through an 8-mm sieve to separate aggregate soil samples by removing visible plant materials and stones. During the sieving, the large clods were broken gently with hand along the natural planes of fractures, and then aggregate soil samples were air-dried. The second portion was air-dried in the laboratory and then passed through a 2-mm sieve to analyze some soil physical and chemical properties. Meanwhile, the undisturbed soil samples were used to determine ρ_b.

2.4. Soil Aggregates Fractionation

Soil aggregate samples separated with an 8-mm sieve were physically fractionated into different aggregate sizes using the dry and wet aggregate separation techniques described by Devine et al. (2014) and Elliott (1986). During both sieving methods, soil aggregates were sieved on a nest of sieves with 4.75-, 2.00-, 1.00-, 0.50-, and 0.25-mm diameters. In the dry sieving method, 50 g of soil aggregate samples were placed on the sieve set and sieved for 2 minutes using a vibratory sieve-shaker, adjusted to 3 mm shaking amplitude. Soil aggregates retained on each sieving level were collected and weighted. On the other hand, the wet sieving method was carried out by the Yoder method, using 100 g soil aggregate samples placed on the sieve set (Kemper and Rosenau, 1986). The sieving was performed for 5 minutes in a container containing distilled water. Soil aggregates were slowly wetted in the water by lowering and then raising the sieves with a stroke length of 13 mm and a frequency of 40 strokes min^{-1}. Then, soil aggregates retained on each sieve were transferred to aluminum cans, and the weight of each fraction was measured after being dried at 40 °C for 72 h. The wet-sieved soil aggregates were stored in plastic bags to analyze SOC contents.

Also, data obtained with the dry and wet sieving were used to calculate aggregate stability indices such as mean weight diameter (MWD), geometric mean diameter (GMD), ASI, and unstable aggregate index (E_{LT}) using the following equations (Okolo et al., 2020; Sekaran et al., 2021; Zhong et al., 2021).

$$MWD = \sum_{i=1}^{n} x_i w_i \tag{1}$$

$$GMD = exp\left[\frac{\sum_{i=1}^{n} log\, x_i w_i}{\sum_{i=1}^{n} w_i}\right] \tag{2}$$

$$ASI = \frac{MWD_{wet}}{MWD_{dry}} \tag{3}$$

$$E_{LT} = \frac{W_T - W_{0.25}}{W_T}\, x\, 100 \tag{4}$$

Where x_i is the mean diameter (mm) of i_{th} aggregate-size class, w_i is the proportion of total sample mass in the corresponding size fraction, $logx_i$ is the base 10 logarithm of the mean diameter for i_{th} aggregate size class, n is the number of aggregate size fractions, W_T is the total weight of the sample used for the analysis and $W_{0.25}$ is the total weight of the <0.25 mm water stable aggregates.

2.5. Laboratory Analysis

Soil texture components were determined using a hydrometer after dispersing with sodium hexametaphosphate (Gee and Bauder, 1986). ρ_b was determined in the cylindrical undisturbed soil samples dried at 105 °C up to the constant weight (Grossman and Reinsch, 2002). pH was measured using a glass electrode pH meter inside a soil: water suspension of 1:2.5 (Hendershot at al., 1993). EC was found using an EC meter inside a soil: water suspension of 1:2.5 (Rhoades, 1986). SOC contents in both bulk soil and soil aggregates were determined using the Walkley-Black method (Nelson and Sommers, 1982).

Also, the changing of SOC_{Stock} associated with aggregates for each soil layer under different land use types was calculated using the following equations (Zhong et al., 2021).

$$SOC_{Stock}\ (g\ m^{-2}) = \frac{SOC_{Ai}\ (g\ kg^{-1}) x\ w_{Ai}\ x\ \rho_b\ (g\ cm^{-3}) x\ D(cm)}{10} \quad (5)$$

Where SOC_{stock} is the soil organic carbon stock associated with aggregate fraction for each soil layer; SOC_{Ai} is the soil organic carbon content associated with i_{th} aggregate-size class; w_{Ai} is the proportion of the mass of aggregates in i_{th} size fraction to total sample mass; is soil bulk density; D is the thickness of soil layer.

SSI for the soils with different land use types was calculated using silt and clay fractions (%) with SOM (%) as defined by Pieri (1992) and Okolo et al. (2020).

$$SSI\ (\%) = \left[\frac{Soil\ organic\ matter\ (\%)}{Silt\ (\%) + Clay\ (\%)}\right] x\ 100 \quad (6)$$

2.6. Statistical Analysis

A two-way analysis of variance (ANOVA) made to determine the effects of different land use types and soil depths on all the data were performed using IBM SPSS Statistics 21.0 (IBM Corporation, Armonk, USA). All the data for variance analysis were controlled whether the conditions of normal distribution and variance homogeneity ($p<0.05$) conformed using the Kolmogorov-Smirnov test and F-test. Transformations such as square root and logarithm were performed when the data set didn't fit the normal distribution conditions. Also, mean values among treatments (land use types and soil depths) were compared using the least significant difference (LSD) test at $p \leq 0.05$.

3. RESULTS AND DISCUSSIONS

Different classifications based on aggregate sizes are commonly found because researchers cannot agree on how to classify soil aggregate fractions (Kemper and Chepil, 1965; Tisdall and Oades, 1982; Elliot, 1986; Six et al., 2000; Gartzia-Bengoetxea et al., 2009; Briar et al., 2011). The soil aggregate fractions in this study were classified using the classification system proposed by Gartzia-Bengoetxea et al. (2009) and Briar et al. (2011), which divided them into three categories: large macro-aggregates (particle size >2.00 mm), macro-aggregates (2.00-1.00 mm), and small macro-aggregates (1.00-0.25 mm). Nevertheless, the current study did not contain the classifications and findings about the micro-aggregate fraction (0.25-0.053 mm) and the clay+silt fraction (<0.053 mm).

The findings regarding the long-term impacts of different land use types and soil depths on various soil aggregate fractions are shown in Table 3. It is determined that all of the soil aggregate fractions that were investigated in the study displayed statistical differences ($p<0.01$) caused by land use types with only the soil depth having a statistical impact at the $p<0.05$ level on the macro-aggregate fraction (2.00-1.00 mm). Also, the interaction of land use types and soil depth was determined to be statistically impactful ($p<0.05$) on large macro-aggregate fractions (8.00-4.75 mm and 4.75-2.00 mm) only. Out of the various land use types, rice land use was found to have the highest statistical effect on large macro-aggregate fractions (>2.00 mm), on the other hand, the same land use had the least statistical effect on the variability of the macro-aggregate fraction (2.00-1.00 mm) and small macro-aggregate fraction (1.00-0.25 mm) (Table 3). It was determined that while land use types that had the highest statistical effect on the macro-aggregate fraction (2.00-1.00 mm) and small macro-aggregate fraction (1.00-0.25 mm) were maize and cherry land uses, respectively, vegetable land use had the least statistical effect on the macro-aggregate fraction (2.00-1.00 mm). However, only the macro-aggregate fraction (2.00-1.00 mm) among the investigated aggregate fractions showed a statistically significant change as a result of the effect of soil depths. It was found that as soil depth increased, so did the macro-aggregate fraction of soils in the study area (Table 3).

The soil aggregate size distribution results provide significant insights into the effects of soil management practices (tillage, organic fertilization, irrigation, etc.) carried out during different land use processes on soil structure (Guo et al., 2020). Reduced or no-tillage management practices during agricultural production reduce the mechanical breakdown of soil aggregates (Sithole et al., 2019). When evaluating the mechanical breakdown effects of tillage practices on soil aggregates, it has been reported that mechanical disruption affects larger aggregate sizes more than smaller aggregate sizes (Centenaro et al., 2018; Sithole et al., 2019). Additionally, the increased amount of organic materials remaining on the surface of fields managed with reduced or no-tillage practices can promote the formation of soil aggregates by enhancing microbial activity in the soil. In the current study, it was found that the vegetable and maize land uses, where more intensive tillage practices were performed, had statistically the lowest impact on the large macro-aggregates (8.00–4.75 mm and 4.75–2.00 mm). In contrast, the small macro-aggregate fraction (1.00–0.50 mm) was statistically affected the most by the same land use types. Moreover, it is suggested that the increase in the amounts of small macro-aggregate fractions (1.00-0.50 mm and 0.50-0.25 mm) in these land use types may be influenced not only by the mechanical breakdown effects of tillage practices but also by the wetting-drying cycles caused by the irrigation management practices performed in these areas.

Table 3. The variability of soil aggregate-size distributions under different land use types and soil depths

Çizelge 3. *Farklı arazi kullanım tipleri ve toprak derinlikleri altında agregat büyüklük dağılımlarının değişkenliği*

Aggregate sizes	D (cm)	LUT					
		Vegetable*	Cherry	Persimmon	Maize	Rice	Overall
8.00-4.75 mm	0-7.5	0.4 (±0.1)	3.5 (±0.1)	13.7 (±1.0)	2.8 (±0.7)	33.5 (±1.0)	10.8 (±0.6) ns
	7.5-15	5.1 (±1.2)	6.4 (±0.4)	12.1 (±1.0)	7.6 (±2.3)	24.9 (±2.4)	11.2 (±0.5) ns
	15-30	5.8 (±1.3)	2.7 (±0.4)	7.6 (±0.4)	2.3 (±0.3)	20.5 (±4.2)	7.8 (±0.5) ns
	Overall	3.8 (±0.4) C	4.2 (±0.2) C	11.2 (±0.3) B	4.2 (±0.5) C	26.3 (±1.0) A	
4.75-2.00 mm	0-7.5	4.3 (±0.3)	9.3 (±0.3)	29.2 (±1.7)	16.5 (±1.4)	38.8 (±0.8)	19.6 (±0.7) ns
	7.5-15	16.8 (±2.0)	18.9 (±1.7)	23.9 (±2.0)	19.3 (±2.1)	29.0 (±2.0)	21.5 (±0.4) ns
	15-30	15.9 (±2.0)	10.3 (±1.0)	24.5 (±2.5)	13.9 (±0.6)	30.3 (±1.8)	19.0 (±0.5) ns
	Overall	12.3 (±0.7) B	12.8 (±0.5) B	25.9 (±0.7) A	16.6 (±0.5) B	32.7 (±0.6) A	
2.00-1.00 mm	0-7.5	10.9 (±0.6)	16.2 (±0.6)	18.0 (±0.6)	38.2 (±0.9)	11.5 (±0.4)	19.0 (±0.5) b
	7.5-15	19.2 (±1.3)	18.3 (±0.4)	20.6 (±1.1)	30.7 (±1.0)	23.6 (±2.6)	22.5 (±0.3) ab
	15-30	18.7 (±1.4)	20.9 (±2.1)	25.3 (±0.9)	35.3 (±1.0)	22.9 (±3.0)	24.6 (±0.4) a
	Overall	16.3 (±0.5) B	18.5 (±0.4) B	21.3 (±0.4) B	34.7 (±0.4) A	19.3 (±0.9) B	
1.00-0.50 mm	0-7.5	25.9 (±0.7)	25.1 (±1.3)	14.1 (±1.2)	24.3 (±1.2)	5.1 (±.0.6)	18.9 (±0.5) ns
	7.5-15	18.8 (±1.3)	22.5 (±0.7)	14.6 (±0.4)	21.7 (±2.1)	8.7 (±0.9)	17.3 (±0.3) ns
	15-30	18.9 (±1.7)	23.5 (±1.8)	15.2 (±1.1)	22.8 (±0.9)	8.8 (±1.3)	17.8 (±0.4) ns
	Overall	21.2 (±0.5) A	23.7 (±0.4) A	14.6 (±0.3) B	22.9 (±0.5) A	7.6 (±0.3) C	
0.50-0.25 mm	0-7.5	36.2 (±1.7)	31.5 (±1.8)	15.7 (±0.7)	10.5 (±1.0)	3.4 (±0.4)	19.5 (±0.7) ns
	7.5-15	23.4 (±2.3)	24.0 (±1.6)	19.5 (±2.5)	10.5 (±1.4)	4.9 (±0.6)	16.4 (±0.5) ns
	15-30	24.4 (±2.0)	30.5 (±2.9)	17.7 (±1.2)	12.8 (±0.8)	6.9 (±0.9)	18.4 (±0.5) ns
	Overall	28.0 (±0.8) A	28.7 (±0.7) A	17.6 (±0.5) B	11.3 (±0.3) BC	5.1 (±0.2) C	

LUT: Land use type; D: soil depth; Mean values are followed by standard errors in the parentheses. Mean values indicated with different uppercase letters in the same row of the same soil property are significantly different at the $p<0.05$ level; Mean values indicated with different lowercase letters in the same column are significantly different at the $p<0.05$ level; ns: Not significant at $p< 0.05$.

When the effects of land use types and soil depths on organic carbon content associated with soil aggregate fractions were examined, it was observed that vegetable land use was land use type that exhibited the highest statistical effect in more than one aggregate fraction (8.00-4.75 mm, 4.75-2.00 mm, 2.00-1.00 mm, 1.00-0.50 mm) (Table 4).

Table 4. The variability of organic carbon content associated with aggregates under different land use types and soil depths

Çizelge 4. *Farklı arazi kullanım tipleri ve toprak derinlikleri altında agregatlarla ilişkili organic karbon içeriğinin değişkenliği*

Aggregate sizes	D (cm)	LUT					
		Vegetable*	Cherry	Persimmon	Maize	Rice	Overall
		Organic carbon content associated with soil aggregate-sizes (g kg^{-1})					
8.00-4.75 mm	0-7.5	15.3 (±0.8)	10.9 (±0.4)	13.4 (±0.8)	11.2 (±0.5)	10.0 (±0.4)	12.1 (±0.1) a
	7.5-15	11.4 (±0.3)	8.9 (±0.2)	9.2 (±0.4)	8.6 (±0.7)	9.7 (±0.2)	9.6 (±0.1) b
	15-30	13.2 (±0.9)	8.1 (±0.5)	10.2 (±0.4)	9.8 (±0.6)	7.1 (±0.5)	9.7 (±0.1) b
	Overall	13.3 (±0.2) A	9.3 (±0.2) B	10.9 (±0.2) B	9.8 (±0.2) B	8.9 (±0.2) B	
4.75-2.00 mm	0-7.5	13.4 (±0.3)	10.5 (±0.5)	15.0 (±0.8)	9.8 (±0.2)	8.8 (±0.9)	11.5 (±0.2) a
	7.5-15	11.6 (±0.1)	10.3 (±0.5)	9.3 (±0.4)	8.6 (±0.3)	8.9 (±0.2)	9.7 (±0.1) b
	15-30	11.7 (±0.3)	8.1 (±0.4)	9.9 (±0.3)	7.7 (±0.1)	6.0 (±0.6)	8.7 (±0.1) b
	Overall	12.2 (±0.1) A	9.6 (±0.2) B	11.4 (±0.3) A	8.7 (±0.1)B	7.9 (±0.2) B	
2.00-1.00 mm	0-7.5	13.7 (±0.5)	12.4 (±0.7)	17.8 (±1.0)	9.0 (±0.1)	12.0 (±0.2)	13.0 (±0.2) a
	7.5-15	13.3 (±0.2)	11.6 (±1.0)	9.3 (±0.3)	9.4 (±0.6)	8.7 (±0.4)	10.5 (±0.1) b
	15-30	12.6 (±0.2)	9.4 (±0.6)	10.6 (±0.1)	9.4 (±0.4)	7.2 (±0.1)	9.8 (±0.1) b
	Overall	13.2 (±0.1) A	11.1 (±0.3) AB	12.6 (±0.4) A	9.2 (±0.1) B	9.3 (±0.2) B	
1.00-0.50 mm	0-7.5	14.0 (±0.2)	11.7 (±0.5)	16.2 (±0.9)	8.7 (±0.2)	13.3 (±0.4)	12.8 (±0.2) a
	7.5-15	13.1 (±0.2)	10.1 (±0.8)	9.2 (±0.2)	9.5 (±0.4)	9.4 (±0.3)	10.2 (±0.1) b
	15-30	11.2 (±0.8)	7.4 (±0.6)	9.9 (±0.3)	8.9 (±0.2)	8.1 (±0.3)	9.1 (±0.1) b
	Overall	12.8 (±0.2) A	9.7 (±0.2) BC	11.8 (±0.3) AB	9.0 (±0.1) C	10.3 (±0.2) BC	
0.50-0.25 mm	0-7.5	10.3 (±0.1)	7.2 (±0.5)	9.2 (±0.8)	9.5 (±0.2)	14.6 (±0.1)	10.2 (±0.1) a
	7.5-15	7.5 (±0.2)	6.9 (±0.2)	5.4 (±0.2)	9.8 (±0.3)	10.0 (±0.1)	7.9 (±0.1) b
	15-30	9.1 (±0.6)	4.7 (±0.3)	5.8 (±0.3)	9.4 (±0.1)	9.1 (±0.0)	7.6 (±0.1) b
	Overall	9.0 (±0.2) B	6.2 (±0.1) C	6.8 (±0.2) C	9.5 (±0.1) B	11.2 (±0.2) A	

LUT: Land use type; D: soil depth; Mean values are followed by standard errors in the parentheses. Mean values indicated with different uppercase letters in the same row of the same soil property are significantly different at the $p<0.05$ level; Mean values indicated with different lowercase letters in the same column are significantly different at the $p<0.05$ level; ns: Not significant at $p< 0.05$.

Although the rice land use exhibited the highest statistical impact on the OC content associated with the small macro-aggregate fraction (0.50-0.25 mm), the same land use was found to have the lowest statistical impact on the large macro-aggregate fractions (8.00-4.75 mm and 4.75-2.00 mm). It was also determined that the maize land use had the lowest statistical impact on the OC content associated with the 2.00-1.00 mm and 1.00-0.50 mm aggregate fractions, while the cherry land use had the lowest statistical impact on the 0.50-0.25 mm aggregate fraction (Table 4). The OC content associated with aggregates was shown to be significantly impacted by different soil depths for all the investigated aggregate fractions. As soil depth increased, the OC content associated with aggregate fractions decreased for all the investigated aggregate fractions (Table 4).

Table 5 shows how the SOC_{Stock} associated with aggregate fractions in the study area is affected by various land use types and soil depths. When analyzing the findings given in Table 5, it can be seen that the rice and persimmon land uses have the highest statistical impact on the SOC_{Stock} associated with large macro-aggregate fractions (8.00-4.75 mm and 4.75-2.00 mm). The other land use types investigated in the study were found to have the lowest similar statistical impact on the SOC_{Stock} associated with large macro-aggregate fractions. While the SOC_{Stock} associated with macro-aggregate fraction (2.00-1.00 mm) was shown to be most statistically impacted by the persimmon and maize land uses, rice land use had the lowest statistical effect. Furthermore, it was also found that the SOC_{Stock} associated with macro-aggregate fraction (2.00-1.00 mm) was not affected statistically by the cherry and vegetable land uses. The land use type that had the highest statistical impact for the SOC_{Stock} associated with small macro-aggregate fractions (1.00-0.50 mm and 0.50-0.25 mm) was vegetable land use, whereas the land use type with the lowest statistical impact was rice land use (Table 5). On the other hand, it was shown that the SOC_{Stock} associated with all the investigated aggregate fractions statistically increased as soil depth increased. In general, even though the OC content associated with aggregates in the study area tends to decrease with increasing soil depth (Table 4), the SOC_{Stock} associated with aggregates was found to increase with the opposite trend (Table 5). One of the primary reasons for this result is considered to be the fact that the subsoil depth (15.0-30.0 cm), which contributes to the calculation of SOC_{Stock} associated with aggregates, has a soil layer twice as thick as the other soil depths evaluated (0.0-7.5 cm and 7.5-15.0 cm) (Equation 5). However, if all the soil layers considered in the calculation of SOC_{Stock} associated with aggregates had the same depth, our results indicate that SOC_{Stock} associated with aggregates would show a decreasing trend with increasing soil depth (Equation 5, Table 5). Therefore, this study also reveals that SOC_{Stock} associated with aggregates tends to decrease with increasing soil depth. In fact, due to the reduction in the number of plant roots in deeper soil layers, values regarding SOC and SOC_{Stock} are generally expected to decrease with increasing soil depth (Sahoo et al., 2019; Korkanç et al., 2022).

Table 5. The variability of organic carbon stocks associated with aggregates under different land use types and soil depths

Çizelge 5. *Farklı arazi kullanım tipleri ve toprak derinlikleri altında agregatlarla ilişkili organic karbon stoğunun değişkenliği*

Aggregate sizes	D (cm)	LUT					
		Vegetable*	Cherry	Persimmon	Maize	Rice	Overall
		Soil organic carbon stocks associated with soil aggregate-sizes (g m^{-2})					
8.00-4.75 mm	0-7.5	0.05 (±0.0)	0.39 (±0.0)	2.05 (±0.3)	0.28 (±0.1)	3.37 (±0.1)	1.23 (±0.1) ab
	7.5-15	0.52 (±0.1)	0.63 (±0.0)	1.35 (±0.2)	0.49 (±0.1)	2.57 (±0.3)	1.11 (±0.0) b
	15-30	1.48 (±0.3)	0.53 (±0.1)	1.84 (±0.2)	0.42 (±0.0)	2.53 (±0.3)	1.36 (±0.1) a
	Overall	0.68 (±0.1) B	0.51 (±0.0) B	1.75 (±0.1) A	0.39 (±0.0) B	2.82 (±0.1) A	
4.75-2.00 mm	0-7.5	0.51 (±0.0)	1.01 (±0.1)	4.55 (±0.3)	1.60 (±0.1)	3.40 (±0.3)	2.21 (±0.1) b
	7.5-15	1.82 (±0.2)	2.11 (±0.2)	2.57 (±0.2)	1.64 (±0.1)	2.66 (±0.2)	2.16 (±0.0) b
	15-30	3.97 (±0.4)	2.03 (±0.2)	5.59 (±0.7)	2.22 (±0.1)	3.52 (±0.2)	3.46 (±0.1) a
	Overall	2.10 (±0.1) B	1.72 (±0.1) B	4.24 (±0.2) A	1.82 (±0.0) B	3.19 (±0.1) A	
2.00-1.00 mm	0-7.5	1.33 (±0.0)	2.03 (±0.1)	3.50 (±0.3)	3.37 (±0.1)	1.41 (±0.1)	2.33 (±0.1) b
	7.5-15	2.43 (±0.2)	2.36 (±0.2)	2.23 (±0.1)	2.98 (±0.2)	2.06 (±0.2)	2.41 (±0.0) b
	15-30	5.20 (±0.4)	5.01 (±0.8)	6.14 (±0.3)	6.81 (±0.3)	3.46 (±0.5)	5.32 (±0.1) a
	Overall	2.98(±0.2)AB	3.14(±0.2)AB	3.95 (±0.2) A	4.39 (±0.2) A	2.31 (±0.1) B	
1.00-0.50 mm	0-7.5	3.27 (±0.1)	3.03 (±0.3)	2.28 (±0.1)	2.07 (±0.1)	0.69 (±0.1)	2.27 (±0.1) b
	7.5-15	2.39 (±0.2)	2.47 (±0.2)	1.58 (±0.0)	2.17 (±0.3)	0.85 (±0.1)	1.89 (±0.0) b
	15-30	4.90 (±0.7)	4.20 (±0.7)	3.32 (±0.2)	4.24 (±0.3)	1.48 (±0.2)	3.63 (±0.1) a
	Overall	3.52 (±0.2) A	3.23 (±0.1) A	2.39 (±0.1) A	2.83 (±0.1) A	1.01 (±0.1) B	
0.50-0.25 mm	0-7.5	3.38 (±0.2)	2.35 (±0.2)	1.51 (±0.1)	0.97 (±0.1)	0.51 (±0.1)	1.74 (±0.1) b
	7.5-15	1.72 (±0.2)	1.75 (±0.0)	1.21 (±0.1)	1.07 (±0.2)	0.51 (±0.1)	1.25 (±0.0) b
	15-30	4.79 (±0.4)	3.18 (±0.2)	2.30 (±0.1)	2.47 (±0.2)	1.28 (±0.2)	2.80 (±0.1) a
	Overall	3.30 (±0.1) A	2.43 (±0.1) AB	1.67 (±0.1) BC	1.50 (±0.1) C	0.77 (±0.0) D	

LUT: Land use type; D: soil depth; Mean values are followed by standard errors in the parentheses. Mean values indicated with different uppercase letters in the same row of the same soil property are significantly different at the $p<0.05$ level; Mean values indicated with different lowercase letters in the same column are significantly different at the $p<0.05$ level; ns: Not significant at $p< 0.05$.

The SOC content and SOC_{Stock} are significantly influenced by land uses (Ahmad et al., 2017). Furthermore, it has been reported that there are strong relationships between SOC processes and the soil aggregate size fractions and aggregate stability, which are also significantly affected by land use (Plaza-Bonilla et al., 2013). Although no results regarding correlation relationships are provided in the article, the findings obtained in our study show significant correlations between SOC content, SOC_{Stock}, aggregate size fractions, and ASI. Soil aggregation leads to better physical conditions in the soil environment (aeration, infiltration, drainage, etc.), thereby promoting plant growth and enabling increased OM input into the soil. Moreover, soil aggregates (particularly macro-aggregates) contribute to the slower decomposition of OM in the soil through the physical protection they provide and enhance the accumulation of OC in soils through the formation of organo-mineral complexes (Dorji et al., 2014; Das et al., 2022).

In the current study, the SOC content and SOC_{Stock} associated with aggregates decreased proportionally with increasing soil depth across all the examined land use types. It was likely due to reduced OM input from plant roots with increasing soil depth (Das et al., 2022) and decreased microbial activity in subsoil layers (Bhattacharyya et al., 2011). Among the land use types where the effects in the study were investigated, the vegetable land use revealed the highest aggregate-associated OC content across all the examined aggregate fractions, except for the 0.50–0.25 mm aggregate size fraction. The high aggregate-associated OC content in the vegetable land use is likely due to greater organic material input into the soil from the cabbage-pepper-bean vegetable rotation management practiced in the area.

On the other hand, as independent of land uses and soil depths, large macro-aggregate size fractions (>2 mm) had higher SOC content compared to other aggregate size fractions (macro-aggregate and small macro-aggregate sizes) (Das et al., 2022). It has been previously stated that macro-aggregate size fractions enhance SOC's physical and biochemical protection, thereby increasing SOC concentrations. Das et al. (2022) stated that large macro-aggregate size fractions (>2.00 mm) have higher SOC content than small macro-aggregate size fractions (1.00-0.25 mm) and that this also indicates that management practices that cause the disintegration of soil aggregates in agricultural production processes may lead OC to become more unstable. In the present study, however, the highest aggregate-associated SOC content and SOC_{Stock} were determined in the macro-aggregate size fraction (2.00–1.00 mm) rather than the large macro-aggregate fractions (8.00–4.75 mm and 4.75-2.00 mm). This finding suggests that the soils in the study area may have a higher proportion of stable OC compounds associated with aggregates.

It was determined that different land use types in the study area had significant statistical effects ($p<0.05$, $p<0.01$) on SSI, ASI, and E_{LT}, while soil depth had significant statistical effects on SSI only among the specified soil properties (Table 6). The persimmon land use showed the highest statistical impact on all the mentioned soil properties. Other land use types with the highest statistical impacts included rice land use (ASI and E_{LT}), cherry land use (E_{LT}), and maize land use (E_{LT}). In contrast, land use types with the lowest statistical impacts were determined as maize and rice land uses for SSI, vegetable and cherry land uses for ASI, and the vegetable land use for E_{LT}. Additionally, the SSI values of soils in the study area decreased significantly with increasing soil depth, while no significant statistical effects of different soil depths were observed on ASI and E_{LT} values (Table 6).

Table 6. The effects of different land use types and soil depths on structure stability index, aggregate stability index and unstable aggregate index

Çizelge 6. *Strüktür stabilite indeksi, agregat stabilite indeksi ve kararsız agregat indeksi* üzerine *farklı arazi kullanım tipleri ve toprak derinliklerinin etkileri*

Soil Properties	D (cm)	LUT					
		Vegetable*	Cherry	Persimmon	Maize	Rice	Overall
SSI	0-7.5	2.4 (±0.1)	2.6 (±0.2)	2.9 (±0.2)	2.1 (±0.0)	2.4 (±0.1)	2.5 (±0.0) a
(%)	7.5-15	2.0 (±0.0)	2.1 (±0.1)	1.9 (±0.0)	1.8 (±0.0)	1.7 (±0.0)	1.9 (±0.0) b
	15-30	1.6 (±0.1)	1.6 (±0.0)	1.9 (±0.1)	1.7 (±0.0)	1.3 (±0.0)	1.6 (±0.0) c
	Overall	2.0 (±0.0) AB	2.1 (±0.0) AB	2.2 (±0.1) A	1.9 (±0.0) B	1.8 (±0.0) B	
ASI	0-7.5	0.3 (±0.0)	0.5 (±0.0)	0.9 (±0.0)	0.6 (±0.0)	0.9 (±0.0)	0.6 (±0.0) ns
	7.5-15	0.5 (±0.0)	0.6 (±0.0)	0.8 (±0.0)	0.6 (±0.0)	0.7 (±0.1)	0.6 (±0.0) ns
	15-30	0.5 (±0.1)	0.5 (±0.1)	0.6 (±0.0)	0.5 (±0.0)	0.7 (±0.1)	0.6 (±0.0) ns
	Overall	0.4 (±0.0) B	0.5 (±0.0)B	0.8 (±0.0) A	0.6 (±0.0) AB	0.8 (±0.0) A	
E_{LT}	0-7.5	77.7 (±1.3)	85.6 (±1.0)	90.7 (±1.1)	92.2 (±0.6)	92.4 (±1.0)	87.7 (±0.3) ns
(%)	7.5-15	83.1 (±0.7)	90.1 (±0.7)	90.6 (±0.7)	89.8 (±1.0)	91.1 (±0.5)	88.9 (±0.2) ns
	15-30	83.6 (±1.1)	84.4 (±1.9)	90.4 (±1.0)	87.1 (±1.1)	89.5 (±0.8)	87.0 (±0.3) ns
	Overall	81.5 (±0.4) B	86.7 (±0.4) A	90.6 (±0.3) A	89.7 (±0.3) A	91.0 (±0.3) A	

SSI: Structure stability index; ASI: Aggregate stability index; E_{LT}: Unstable aggregate index; LUT: Land use type; D: soil depth; Mean values are followed by standard errors in the parentheses. Mean values indicated with different uppercase letters in the same row of the same soil property are significantly different at the $p<0.05$ level; Mean values indicated with different lowercase letters in the same column are significantly different at the $p<0.05$ level; ns: Not significant at $p< 0.05$.

In the study area, the effects of different land use types and soil depths on the mean weight diameter (MWD) and geometric mean diameter (GMD), which are indicators of soil aggregate stability, were evaluated using two different sieving methods (Table 7). It was found that the effects of different land use types on the MWD and GMD values of the soils were similar for sieving methods, dry sieving and wet sieving. According to the results of both sieving methods, rice land use had the highest statistical impact on the MWD and GMD values of the study area soils (Table 7). All the examined land use types, except for rice land use, had the lowest similar statistical effects on both MWD_{Dry} and GMD_{Dry} in the dry sieving method. In the wet sieving method, the land use types with the lowest similar statistical effects on MWD_{Wet} and GMD_{Wet} were determined to be vegetable and cherry land uses, respectively (Table 7). On the other hand, only the MWD_{Dry} values changed statistically significantly with different soil depths and increased with increasing soil depth (Table 7).

Table 7. The variability of mean weight diameter and geometric mean diameter under different land use types and soil depths

Çizelge 7. *Farklı arazi kullanım tipleri ve toprak derinlikleri altında ortalama ağırlıklı çap ve geometric ortalama çapın değişkenliği*

Soil Properties	D (cm)	LUT					
		Vegetable*	Cherry	Persimmon	Maize	Rice	Overall
MWD_{Dry}	0-7.5	2.40 (±0.1)	2.38 (±0.1)	2.54 (±0.1)	2.68 (±0.1)	4.09 (±0.1)	2.82 (±0.0) b
(mm)	7.5-15	2.70 (±0.1)	2.82 (±0.1)	2.86 (±0.2)	2.80 (±0.1)	4.14 (±0.1)	3.06 (±0.0) ab
	15-30	3.12 (±0.1)	2.86 (±0.2)	3.19 (±0.2)	2.88 (±0.1)	4.05 (±0.1)	3.22 (±0.0) a
	Overall	2.74 (±0.0) B	2.69 (±0.0) B	2.87 (±0.1) B	2.79 (±0.0) B	4.09 (±0.0) A	
MWD_{Wet}	0-7.5	0.68 (±0.0)	1.11 (±0.0)	2.31 (±0.1)	1.54 (±0.1)	3.68 (±0.1)	1.86 (±0.1) ns
(mm)	7.5-15	1.43 (±0.1)	1.59 (±0.1)	2.08 (±0.1)	1.81 (±0.2)	3.02 (±0.1)	1.98 (±0.0) ns
	15-30	1.44 (±0.1)	1.30 (±0.1)	1.89 (±0.1)	1.39 (±0.0)	2.78 (±0.3)	1.76 (±0.0) ns
	Overall	1.18 (±0.0) C	1.33 (±0.0) C	2.09 (±0.0) B	1.58 (±0.0) C	3.16 (±0.1) A	
GMD_{Dry}	0-7.5	1.26 (±0.0)	1.28 (±0.0)	1.31 (±0.0)	1.43 (±0.0)	1.70 (±0.0)	1.39 (±0.0) ns
(mm)	7.5-15	1.32 (±0.0)	1.39 (±0.0)	1.33 (±0.1)	1.44 (±0.0)	1.74 (±0.0)	1.44 (±0.0) ns
	15-30	1.42 (±0.0)	1.40 (±0.1)	1.45 (±0.1)	1.44 (±0.0)	1.72 (±0.0)	1.49 (±0.0) ns
	Overall	1.33 (±0.0) B	1.35 (±0.0) B	1.36 (±0.0) B	1.44 (±0.0) B	1.72 (±0.0) A	
GWD_{Wet}	0-7.5	0.71 (±0.0)	0.83 (±0.0)	1.15 (±0.0)	1.03 (±0.0)	1.50 (±0.0)	1.04 (±0.0) ns
	7.5-15	0.90 (±0.0)	0.97 (±0.0)	1.08 (±0.0)	1.06 (±0.0)	1.34 (±0.0)	1.07 (±0.0) ns
	15-30	0.91 (±0.0)	0.86 (±0.0)	1.06 (±0.0)	0.96 (±0.0)	1.29 (±0.1)	1.01 (±0.0) ns
	Overall	0.84 (±0.0) D	0.89 (±0.0) CD	1.10 (±0.0) B	1.02 (±0.0) BC	1.38 (±0.0) A	

MWD_{Dry}: Mean weight diameter calculated with dry sieving; MWD_{Wet}: Mean weight diameter calculated with wet sieving; GMD_{Dry}: Geometric mean diameter calculated with dry sieving; GMD_{Wet}: Geometric mean diameter calculated with wet sieving; LUT: Land use type; D: soil depth; Mean values are followed by standard errors in the parentheses. Mean values indicated with different uppercase letters in the same row of the same soil property are significantly different at the $p<0.05$ level; Mean values indicated with different lowercase letters in the same column are significantly different at the $p<0.05$ level; ns: Not significant at $p< 0.05$.

In the study area, the effects of different land use types on indicators related to soil structure and aggregate stability (SSI, ASI, E_{LT}, MWD, and GMD) exhibited significant variability due to the effect of various management practices, such as tillage, leaving organic residues on the soil surface, and irrigation, where the land use types were carried out. The highest SSI and ASI values were found in the persimmon land use performed with reduced and zero tillage practices. The probable reason for the highest SSI and ASI values in the persimmon land use is that reduced and zero tillage practices cause less disruption to soil structure, thereby reducing OC losses and enhancing OC accumulation (Okolo et al., 2020). Consequently, these findings related to SSI and ASI values demonstrated that the persimmon land use possesses higher soil structure stability than the other land use types examined.

The E_{LT}, MWD, and GMD values related to soil aggregates can better reflect information about the transformation of aggregate size distribution, aggregation, and erosion resistance of soils (Liu et al., 2020). Soils with higher aggregation are expected to have larger MWD and GMD values and smaller E_{LT} values (Wang et al., 2013; Tang et al., 2016). Among land use types, the highest MWD_{Dry}, MWD_{Wet}, GMD_{Dry}, and GMD_{Wet} values were observed in the rice land use. These results were likely associated with the high clay content in rice fields (Table 2) and the wetting-drying cycles carried out during rice cultivation (Igwe and Obalum, 2013). In addition to the high clay content, the prolonged waterlogging of soils, as occurred in the rice land use, typically leads to repeated wetting and drying cycles that affect soil aggregation. This process promotes the formation of larger macro-aggregates (Table 3) and encourages higher large macro-aggregate formation (Okolo et al., 2020). Additionally, soil tillage practices in agricultural production processes can lead to the mechanical breakdown of soil aggregates, causing changes in the size distribution of soil aggregate fractions. Therefore, in the study area, in addition to the high clay content of the soils, the soil tillage practices and wetting-drying cycles implemented under different land use types are considered important factors influencing soil aggregation (Encyclopedia of Soil Science, ESS 2008).

4. CONCLUSIONS

The effects of different land use types and soil depths on aggregate size fractions, SOC and SOC_{Stock} associated with aggregates, and properties related to soil structure and aggregate stability (SSI, ASI, E_{LT}, MWD, and GMD) were evaluated in an alluvial plain. The results revealed that different land use types statistically influenced all the studied soil properties ($p<0.01$, $p<0.05$). Soil depths were found to statistically affect only the macro-aggregate size fraction (2.00–1.00 mm) among the aggregate size fractions, as well as the SOC content and SOC_{Stock} associated with all the evaluated aggregate size fractions. While the highest SOC contents associated with aggregates in all the examined aggregate size fractions, except for the small macro-aggregate size fraction (0.50–0.25 mm), were found in the vegetable land use, the highest SOC contents associated with aggregates in the 0.50–0.25 mm aggregate size fraction was observed in the rice land use. Compared to the other land use types, the intensive tillage practices in vegetable land use led to greater mechanical breakdown of soil aggregates. However, it was also determined that, during winter and summer cropping seasons, the long-term cabbage-pepper-bean rotation performed in the vegetable area increased OM inputs to the soil. This increase contributed to reducing the loss of OC caused by the physical breakdown of aggregates. Therefore, in alluvial areas where intensive agricultural production is practiced, such as the study site, it is recommended to promote cropping systems such as crop rotations that enhance OM inputs. Such cropping systems can help mitigate the losses of aggregate-associated SOC content and SOC_{Stock} caused by land use and soil management practices.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethics

This study does not require ethics committee approval.

Author Contribution Rates

Design of Study: AAMM (%5), EEK (%15), Sİ (%40), MS (%40)

Data Acquisition: AAMM (%5), EEK (%15), Sİ (%40), MS (%40)

Data Analysis: AAMM (%10), EEK (%60), Sİ (%20), MS (%10)

Writing up: AAMM (%25), EEK (%10), Sİ (%10), MS (%55)

Submission and Revision: AAMM (%10), EEK (%10), Sİ (%10), MS (%70)

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