



## Effects of long-term tillage systems on aggregate-associated organic carbon in the eastern Mediterranean region of Turkey

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### Abstract

The stability of aggregates plays a vital role in preserving and long term storing of soil organic carbon (SOC). In this study, the long-term (2006-2014) effects of six tillage systems on aggregate-associated SOC were investigated in a field experiment conducted under Mediterranean conditions. The tillage treatments were; conventional tillage with residue incorporated in the soil (CT1), conventional tillage with residue burned (CT2), reduced tillage with heavy tandem disc-harrow (RT1), reduced tillage with rotary tiller (RT2), reduced tillage with heavy tandem disc harrow followed by no-tillage (RNT) for the second crop, and no tillage (NT). The most frequently encountered aggregates in all tillage systems were at 4.0-2.0 mm size and the least frequently found aggregates were 1.0-0.5 mm. The mean weight diameter (MWD) value increased in the NT compared to the conventional tillage practices at the rates of 137% and 204%, respectively at 0-15 cm soil depth. Aggregate-associated SOC contents in 0-15 cm depth were higher under conservation tillage systems. However, the highest SOC at 15-30 cm depth were greater mainly in conventional tillage systems as 9.4% for both CT1 and CT2. The results indicated that conservation tillage systems had greater aggregation and carbon storage at the soil surface.

**Keywords:** Aggregation, Mediterranean, soil organic carbon, soil tillage.

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### Introduction

Soil organic carbon (SOC) is an important indicator of soil quality because of its significant effects on soil physical, chemical and biological properties. SOC is closely linked with soil aggregate formation and stabilization (Balesdent et al., 2000) and is strongly affected by agricultural management practices such as soil tillage (Six et al., 2002).

Conventional tillage systems have a series of adverse effects on soil physical, chemical and biological properties in a semi-arid Mediterranean environment which induce the degradation of the soil ecosystems (Carter and Stewart, 1996). Excess tillage and removal of crop residues disrupt macro aggregate formation and stability via exposing physically protected organic carbon to microbial decomposition (Barto et al., 2010; Shu et al., 2015). However, use of conservation tillage systems improves soil structure and SOC, reduces soil erosion and enhances soil fertility and quality (Kabiri et al., 2015).

Many physical, chemical and biological processes taking place in soil such as seedling emergence and root growth, water and gas transfer, organic matter protection and dynamics depend on the intra and inter organization of the aggregates in the soil matrix (Blanco-Canqui et al., 2005). Mechanical forces can disrupt aggregates during tillage as the machinery fractures, crushes or compacts the soil structure (Blanco-Canqui

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and Lal, 2006). Macro aggregates are more sensitive to this effect of tillage than micro aggregates (Andruschkewitsch et al., 2014). Conservation tillage systems promote macro aggregation with time by reducing soil disturbance (Six et al., 2000). Macro aggregates, with enhanced development in no-tillage areas, have higher SOC and nutrient contents and macro porosity providing higher aeration and infiltration than micro aggregates (Dexter, 1988). For this reason, enhanced macro aggregates under conservation tillage systems are more durable than under conventional tillage systems (McVay, 2006).

Reduced tillage is becoming popular in the Çukurova region despite the long-standing history of the widely used conventional tillage systems throughout Turkey. However, research is limited concerning the effects of tillage systems on the SOC contents of the different sizes of aggregates in the soils of the country. In this respect, the objective of this study was to determine the long-term (8-year) effects of conventional, reduced and no tillage practices on the soil structural indicators. The indicators studied were the aggregate size distribution, SOC contents and mean weight diameters of the aggregates in wheat-corn and wheat-soybean rotations conducted on a heavy clay (mean 50% clay) soil in the eastern Mediterranean region of Turkey.

## Material and Methods

### Experimental site

A field experiment was conducted from 2006 to 2014 at the Experimental Farm (37°00' 54" N, 35°21' 27" E; 32 m above sea level) of the Çukurova University located in Adana, Turkey. The soils of the study were the clayey Arık soils, classified as fine, smectitic, active, mesic Typic Haploxererts (Soil Survey Staff, 1999) with a pH of 7.82, CaCO<sub>3</sub> of 244 g kg<sup>-1</sup>, electrical conductivity of 0.15 dS m<sup>-1</sup> and particle size distribution of 50% clay, 32% silt and 18% sand at the surface horizon (0-30 cm) (Celik et al., 2011).

The prevailing climate of the study area is Mediterranean with a long-term (30 years) mean annual temperature of 19.2 °C. The summers are hot and dry, and winters are wet and mild. The long-term mean annual precipitation is 639 mm, about 75% of which falls during the winter and spring (from November to May) and the long-term mean annual potential evapotranspiration is 1557 mm.

### Experimental design and tillage systems

The experiment was conducted in a randomized complete block design where similar experimental units were grouped into blocks or replicates. The treatments with three replications were conventional tillage with residue incorporated in the soil (CT1), conventional tillage with residue burned (CT2), reduced tillage with heavy tandem disc-harrow (RT1), reduced tillage with rotary tiller (RT2), reduced tillage with heavy tandem disc harrow followed by no-tillage (RNT) for the second crop, and no tillage (NT). The tillage plots were 12 m wide and 40 m long (480 m<sup>2</sup>). A buffer-zone of 4 m was reserved around each plot for tractor and tillage equipment operations. The detailed information on treatments within each practice and sowing methods are shown in Table 1.

The rotations of winter wheat (*Triticum aestivum* L.)-corn (*Zea Mays* L.), winter wheat (*Triticum aestivum* L.) - soybean (*Glycine max.* L.) were applied in all treatments from 2006 to 2014. In each growing season, the first crop was winter wheat and the second crop was corn and soybean.

Two weeks prior to sowing, the total herbicide (500 g Glyphosate ha<sup>-1</sup>) was used to control weeds in the NT and RNT treatments. Compound NP-fertilizers were applied in the seedbed at the rates of 172 kg N<sup>-1</sup> ha and 55 kg P ha<sup>-1</sup> for wheat, 250 kg N ha<sup>-1</sup> and 60 kg P ha<sup>-1</sup> for corn, and 120 kg N ha<sup>-1</sup> and 40 kg P ha<sup>-1</sup> for soybean. Winter wheat was sown in the first week of November from 2006 to 2013 at a seeding rate of 240 kg ha<sup>-1</sup>, and harvested in the first week of June 2007 to 2014. The second crops (corn and soybean) were sown in the third week of June from 2007 to 2014, and harvested in the second week of October from 2007 to 2014. Corn and soybean seeding rates were 8.4 and 23.6 plants per m<sup>2</sup>, respectively. Soybean and corn were nine times irrigated by sprinklers in 13 day intervals. The amount of water applied for each irrigation was identical for all treatments and no irrigation water was applied to the wheat.

### Soil sampling and analysis

Soil samples (108) were collected at three sites of each individual plot (nine samples per tillage treatment) from 0-15 and 15-30 cm depths in October 2014. Field-moist samples were gently/ manually crumbled and sieved (<8 mm) to remove root material in the field and transferred to the laboratory. Soil samples were air-dried at room temperature (≈20°C) and dry sieved through 4, 2, 1 and 0.5 mm mesh for aggregate size

distribution in the laboratory. Mean weight diameter (MWD) as a soil aggregation indicator was measured by using an instrument similar in principle to the Yoder wet sieving apparatus involving 4, 2, 1 and 0.5 mm meshes in samples initially sieved from an 8 mm mesh (Kemper and Rosenau, 1986). After sieving through an 8 mm sieve, 50 g soil sample was inserted on the first sieve (4 mm) and slowly moistened to avoid a sudden rupture of aggregates. Moistened soil was sieved in distilled water at 30 oscillations per minute. The soil above each sieve was dried after 10 minutes of oscillation, and then sands and aggregates were separated (Gee and Bauder, 1986).

Table 1. Tillage methods, depth of tillage, and equipment used in the study

Tillage Methods	Soil Tillage for Winter Wheat	Soil Tillage for Second Crop Corn and Soybean
Conventional tillage with residue incorporated (CT1)	<ul style="list-style-type: none"> <li>• Stover chopping of second crop</li> <li>• Mouldboard plough (30-33 cm)*</li> <li>• Disc harrow (2 passes, 13-15 cm)</li> <li>• Float (2 passes)</li> <li>• Drill (4 cm)</li> </ul>	<ul style="list-style-type: none"> <li>• Stubble chopping of wheat</li> <li>• Heavy tandem disc harrow (18-20 cm)</li> <li>• Disc harrow (2 passes, 13-15 cm)</li> <li>• Float (2 passes)</li> <li>• Planter (8 cm)</li> </ul>
Conventional tillage with residue burned (CT2)	<ul style="list-style-type: none"> <li>• Stover burning of second crop</li> <li>• Moldboard plough (30-33 cm)</li> <li>• Disc harrow (2 passes, 13-15 cm)</li> <li>• Float (2 passes)</li> <li>• Drill (4 cm)</li> </ul>	<ul style="list-style-type: none"> <li>• Stubble burning of wheat</li> <li>• Chisel plow (35-38 cm)</li> <li>• Disc harrow (2 passes, 13-15 cm)</li> <li>• Float (2 passes)</li> <li>• Planter (8 cm)</li> </ul>
Reduced tillage with heavy tandem disc harrow (RT1)	<ul style="list-style-type: none"> <li>• Stover chopping of second crop</li> <li>• Heavy tandem disc harrow (2 passes, 18-20 cm)</li> <li>• Float (2 passes)</li> <li>• Drill (4 cm)</li> </ul>	<ul style="list-style-type: none"> <li>• Stubble chopping of wheat</li> <li>• Rotary tiller (13-15 cm)</li> <li>• Float (2 passes)</li> <li>• Planter (8 cm)</li> </ul>
Reduced tillage with rotary tiller (RT2)	<ul style="list-style-type: none"> <li>• Stover chopping of second crop</li> <li>• Rotary tiller (13-15 cm)</li> <li>• Float (2 passes)</li> <li>• Drill (4 cm)</li> </ul>	<ul style="list-style-type: none"> <li>• Stubble chopping of wheat</li> <li>• Rotary tiller (13-15 cm)</li> <li>• Float (2 passes)</li> <li>• Planter (8 cm)</li> </ul>
Reduced tillage with heavy tandem disc harrow + no-tillage (RNT)	<ul style="list-style-type: none"> <li>• Stover chopping of second crop</li> <li>• Heavy tandem disc harrow (18-20 cm)</li> <li>• Float (2 passes)</li> <li>• Drill (4 cm)</li> </ul>	<ul style="list-style-type: none"> <li>• Stubble chopping of wheat</li> <li>• Herbicide treatment</li> <li>• No-till planter (8 cm)</li> </ul>
No-tillage (NT)	<ul style="list-style-type: none"> <li>• Stover chopping of second crop</li> <li>• Herbicide treatment</li> <li>• No-till drill (4 cm)</li> </ul>	<ul style="list-style-type: none"> <li>• Stubble chopping of wheat</li> <li>• Herbicide treatment</li> <li>• No-till planter (8 cm)</li> </ul>

\*Figures in parentheses are the average working depths of the equipment

The mean weight diameter was calculated as follows:

$$MWD = \sum_{i=1}^n (X_i W_i)$$

Where, MWD is the mean weight diameter of water stable aggregates,  $X_i$  is the mean diameter of each size fraction (mm) and  $W_i$  is the percentage of the total sample mass in the corresponding size fraction after the mass of sands deducted. SOC in aggregates was measured by the wet combustion method (Schlichting and Blume, 1966).

### Statistical analysis

To assess the effects of different tillage practices on the soil properties determined, the JMP statistical programme was used for one-way analysis of variance (ANOVA). The least-significant difference (LSD) method was used for mean comparisons among different treatments. Moreover, the correlation test was conducted in order to determine the relationships between soil properties.

## Results and Discussion

### Soil aggregate size distribution

Long term tillage practices had statistically significant effects on aggregate size distribution (Table 2). In all soil tillage practices, the amount of 4.0-2.0 mm aggregate fraction was determined to be highest and the >4.0, 2.0-1.0 and 1.0-0.5 mm aggregate fractions followed this in the 0-15 and 15-30 cm depths, respectively. For the 0-15 cm depth, the highest aggregate fraction of 4.0-2.0 mm was obtained in NT which was 24% higher than of the RT1. For the 15-30 cm depth, the 4.0-2.0 mm aggregate fraction was 14% higher in NT than in RT1. Similar to the NT system, [Gelaw et al. \(2015\)](#) reported that continuous addition of leaf litter and biomass cover in open pasture lands provide habitat for soil biota which enhance the soil aggregation.

Table 2. Effects of different tillage treatments on aggregate size distribution

Tillage treatments	Aggregate size distribution (%)			
	> 4.0 mm	4.0-2.0 mm	2.0-1.0 mm	1.0-0.5 mm
0-15 cm				
CT1	30.7 ± 5.1 <sup>c</sup>	56.9 ± 4.6 <sup>b</sup>	9.1 ± 1.4 <sup>b</sup>	1.0 ± 0.5 <sup>a</sup>
CT2	30.8 ± 2.1 <sup>c</sup>	57.3 ± 2.0 <sup>ab</sup>	11.8 ± 1.4 <sup>a</sup>	1.0 ± 0.5 <sup>a</sup>
RT1	41.6 ± 5.5 <sup>a</sup>	49.1 ± 5.4 <sup>c</sup>	7.0 ± 2.0 <sup>c</sup>	1.1 ± 0.7 <sup>a</sup>
RT2	35.3 ± 3.3 <sup>b</sup>	55.3 ± 2.2 <sup>b</sup>	7.8 ± 2.0 <sup>bc</sup>	0.9 ± 0.3 <sup>a</sup>
RNT	31.2 ± 3.8 <sup>bc</sup>	57.0 ± 1.7 <sup>b</sup>	8.1 ± 1.4 <sup>bc</sup>	1.4 ± 0.8 <sup>a</sup>
NT	30.6 ± 2.3 <sup>c</sup>	60.8 ± 1.3 <sup>a</sup>	8.0 ± 1.1 <sup>bc</sup>	1.1 ± 0.3 <sup>a</sup>
LSD <sub>till</sub>	4.22 <sup>**</sup>	3.55 <sup>**</sup>	1.73 <sup>**</sup>	ns
15-30 cm				
CT1	38.4 ± 5.8 <sup>a</sup>	56.3 ± 2.7 <sup>ab</sup>	7.1 ± 1.5 <sup>c</sup>	0.9 ± 0.1 <sup>c</sup>
CT2	37.4 ± 3.1 <sup>a</sup>	52.7 ± 3.7 <sup>cd</sup>	8.4 ± 1.9 <sup>abc</sup>	1.7 ± 0.7 <sup>ab</sup>
RT1	38.6 ± 5.4 <sup>a</sup>	51.0 ± 3.7 <sup>d</sup>	9.9 ± 1.9 <sup>a</sup>	1.5 ± 0.5 <sup>bc</sup>
RT2	34.4 ± 3.3 <sup>a</sup>	55.0 ± 1.5 <sup>bc</sup>	8.0 ± 1.6 <sup>bc</sup>	2.3 ± 0.9 <sup>a</sup>
RNT	29.4 ± 3.4 <sup>b</sup>	58.0 ± 1.8 <sup>ab</sup>	8.3 ± 1.7 <sup>abc</sup>	1.3 ± 0.4 <sup>bc</sup>
NT	28.0 ± 2.3 <sup>b</sup>	58.3 ± 3.4 <sup>a</sup>	9.4 ± 1.1 <sup>ab</sup>	1.3 ± 0.6 <sup>bc</sup>
LSD <sub>till</sub>	4.44 <sup>**</sup>	3.19 <sup>**</sup>	1.76 <sup>*</sup>	0.67 <sup>**</sup>

Mean values ± standard deviation. Values followed by the same letters in a column are not significantly different ( $P < 0.05$ ).

\*: Difference is significant at  $P < 0.05$  level, \*\*: Difference is significant at  $P < 0.01$  level, ns: Difference is not significant. CT1: Conventional tillage with residue incorporated, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow followed by no tillage for the second crop, NT: No tillage

Generally, conventional tillage practices of this study increased the amount of smaller aggregate fractions by breaking larger macro aggregates in the 0-15 cm depth. Microaggregates are attached to form macroaggregates by a labile fraction of soil organic matter which is highly sensitive to the soil disturbance ([Ashagrie et al., 2005](#)). Breaking larger aggregates into smaller ones increases the surface area for microorganisms to oxidize the organic carbon stored in macroaggregates. [Hou et al. \(2013\)](#) reported that the amount of >0.25 mm aggregate fraction decreased with conventional tillage practices in the 0-20 and 20-40 cm depths. This decreasing of >0.25 mm aggregate fraction in soil with conventional tillage could be mainly due to the mechanical disruption of macro aggregates from frequent tillage operations and reduced aggregate stability ([Hou et al., 2013](#)). Conservation tillage practices (reduced and no-till) receives higher crop residue input than the conventional practices. Formation and stabilization of aggregates in soil mainly depend on the amount of biomass input and the rate of organic matter mineralization ([Blanco-Canqui and Lal, 2004](#)). Similarly, the increased amounts of 4.0-2.0 mm aggregates in the NT tillage practice was also reported by [Zhang et al. \(2012\)](#) and [Du et al. \(2013\)](#) in long term experiments. Moreover, [Zhang et al. \(2012\)](#) found that the >2.0 mm aggregate size in a clay loam soil was higher under no-tillage in comparison to conventional tillage.

### Soil organic carbon accumulation in different aggregate sizes

Concentration of SOC associated to different aggregate sizes at both soil depths are presented in Table 3. Tillage practices had statistically significant effects on the SOC of different aggregate sizes in surface soils ( $P < 0.01$ ). Conservation tillage systems in general provided significantly higher SOC accumulation than conventional tillage practices in 0-15 cm soil depth for all aggregate sizes (Table 3). For conventional

practices, this may be due to tillage causing the destruction of the aggregates conserving organic matter and in turn the increased temperature and aeration of the soil. Many studies reported that higher SOC contents in aggregates were found in conservation tillage systems in comparison to conventional tillage practices (Pinherio et al., 2004; Bhattacharyya et al., 2009; Zhang et al., 2012; Andruschkewitsch et al., 2014).

Table 3. Effects of different tillage treatments on SOC in different aggregate sizes

Tillage treatments	SOC (g kg <sup>-1</sup> ) in Aggregates			
	> 4.0 mm	4.0-2.0 mm	2.0-1.0 mm	1.0-0.5 mm
0-15 cm				
CT1	9.6 ± 0.7 <sup>d</sup>	9.5 ± 0.6 <sup>c</sup>	8.5 ± 0.4 <sup>b</sup>	9.6 ± 0.6 <sup>d</sup>
CT2	9.7 ± 0.4 <sup>d</sup>	9.7 ± 0.5 <sup>c</sup>	8.2 ± 0.6 <sup>b</sup>	9.6 ± 0.6 <sup>d</sup>
RT1	12.6 ± 0.5 <sup>c</sup>	12.2 ± 0.6 <sup>b</sup>	11.5 ± 0.7 <sup>a</sup>	12.6 ± 0.7 <sup>c</sup>
RT2	13.5 ± 0.8 <sup>ab</sup>	13.2 ± 1.0 <sup>a</sup>	11.7 ± 1.3 <sup>a</sup>	14.4 ± 1.6 <sup>a</sup>
RNT	12.8 ± 0.6 <sup>bc</sup>	12.7 ± 0.8 <sup>ab</sup>	11.3 ± 0.8 <sup>a</sup>	13.3 ± 0.7 <sup>bc</sup>
NT	13.7 ± 1.8 <sup>a</sup>	13.5 ± 1.8 <sup>a</sup>	11.8 ± 2.0 <sup>a</sup>	14.0 ± 1.5 <sup>ab</sup>
LSD <sub>till</sub>	0.85**	0.92**	1.06**	0.97**
15-30 cm				
CT1	9.4 ± 0.4 <sup>a</sup>	9.1 ± 0.5 <sup>a</sup>	8.1 ± 0.7 <sup>a</sup>	9.4 ± 0.5 <sup>a</sup>
CT2	9.4 ± 0.7 <sup>a</sup>	9.3 ± 0.8 <sup>a</sup>	8.1 ± 0.6 <sup>a</sup>	9.2 ± 0.4 <sup>a</sup>
RT1	8.7 ± 0.6 <sup>b</sup>	8.5 ± 0.7 <sup>a</sup>	7.9 ± 0.8 <sup>a</sup>	8.7 ± 0.7 <sup>a</sup>
RT2	8.9 ± 0.7 <sup>ab</sup>	8.6 ± 0.6 <sup>a</sup>	7.8 ± 0.5 <sup>a</sup>	8.7 ± 0.5 <sup>a</sup>
RNT	8.8 ± 0.5 <sup>ab</sup>	8.5 ± 0.7 <sup>a</sup>	7.9 ± 0.4 <sup>a</sup>	8.9 ± 0.6 <sup>a</sup>
NT	8.5 ± 1.0 <sup>b</sup>	8.4 ± 0.9 <sup>a</sup>	7.6 ± 0.9 <sup>a</sup>	8.7 ± 0.8 <sup>a</sup>
LSD <sub>till</sub>	0.63*	ns	ns	ns

Mean values ± standard deviation. Values followed by the same letters in a column are not significantly different ( $P < 0.05$ ).

\*: Difference is significant at  $P < 0.05$  level, \*\*: Difference is significant at  $P < 0.01$  level, ns: Difference is not significant. CT1: Conventional tillage with residue incorporated, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow followed by no tillage for the second crop, NT: No tillage

Concentration of SOC followed a different trend in 15-30 cm soil depth. The SOC only slightly significant ( $P < 0.05$ ) in >4.0 mm aggregates, lowest in NT treatment and non-significant for other aggregate sizes. With increasing depth, the SOC contents of the different sizes of aggregates in the soils under conventional tillage were determined to be lower than the SOC contents of the aggregates of the soils under conservation tillage. This can be attributed to the shallow or no-till practice of the conservation systems when compared to the conventional practices, where the crop residues are not mixed under the surface (15-30 cm). In contrast to conservational practices, burying crop residues to subsurface layer resulted in higher SOC of conventional practices at all aggregate sizes. The SOC contents of macroaggregates (> 4.0 mm) in all tillage practices at both soil depths were higher than 4.0-2.0 mm and 2.0-1.0 mm size aggregates, and very similar to 1.0-0.5 mm size aggregates. Gelaw et al. (2015) found the highest SOC content of surface soils associated with macroaggregates (20.0 g kg<sup>-1</sup>), in open pastures, whereas the highest SOC content was reported in agroforestry land.

### Mean weight diameter (MWD)

Conservation tillage practices provided significant statistical development on soil structure in comparison to conventional tillage ( $P < 0.01$ ). Also, no-tillage enhanced soil structure development more than the other conservation tillage practices.

In two soil depths, the highest MWD value was obtained in the no-till system whereas the lowest was obtained in the conventional tillage systems (Table 4). In the 0-15 cm soil depth, the highest MWD values were obtained under NT (0.76 mm). On the contrary, the lowest MWD values were obtained under the CT2 (0.26 mm) and CT1 (0.32 mm). Similarly, the lowest aggregation index was found under CT2 (0.32 mm) and CT1 (0.42 mm) at 15-30 cm soil depth. When numerically considered, the NT method in 0-15 cm depth provided higher development of soil structure compared to CT2 by 204 % and CT1 by 137%. The NT practice also had higher contribution to soil structure development compared to CT2 (by 66 %) and CT1 (by 29 %) in 15-30 cm soil depth.

The reason for the high MWD values in conservation tillage compared to conventional tillage is most likely due to the high organic carbon contents obtained in the former (Table 4). SOC is the major cementing factor

in aggregate formation in soil and moreover, according to most researchers, is significantly correlated with aggregate stability. (Spaccini et al., 2004; Tejada and Gonzales, 2006).

Table 4. Effects of different tillage practices on the mean weight diameter

Tillage treatments	Mean weight diameter (mm)	
	0-15 cm	15-30 cm
CT1	0.32 ± 0.07 <sup>d</sup>	0.42 ± 0.05 <sup>b</sup>
CT2	0.26 ± 0.04 <sup>d</sup>	0.32 ± 0.06 <sup>c</sup>
RT1	0.48 ± 0.11 <sup>c</sup>	0.48 ± 0.05 <sup>ab</sup>
RT2	0.66 ± 0.14 <sup>b</sup>	0.55 ± 0.13 <sup>a</sup>
RNT	0.48 ± 0.07 <sup>c</sup>	0.45 ± 0.06 <sup>b</sup>
NT	0.76 ± 0.10 <sup>a</sup>	0.53 ± 0.08 <sup>a</sup>
LSD <sub>till</sub>	0.088**	0.073**

Mean values ± standard deviation. Values followed by the same letters in a column are not significantly different ( $P < 0.05$ ).

\*\* Difference is significant at  $P < 0.01$  level. CT1: Conventional tillage with residue incorporated, CT2: Conventional tillage with residues burned, RT1: Reduced tillage with heavy tandem disc harrow, RT2: Reduced tillage with rotary tiller, RNT: Reduced tillage with heavy tandem disc harrow followed by no tillage for the second crop, NT: No tillage

Above explained results relation to effects of tillage systems on soil structure were significantly similar to results in other studies. Compared to conventional tillage, soil aggregates under conservation tillage systems were found more stable (Pagliai et al., 2004). Celik et al. (2012) found that MWD values under no-tillage and reduced tillage were higher than conventional tillage. Abdollahi and Munkholm (2014) reported that reduced tillage systems increased MWD values, penetration resistance and water-stable aggregates.

#### Correlation between MWD and SOC in different aggregate sizes

The correlation test between MWD and SOC contents in different aggregate sizes showed that SOC contents were statistically significant ( $P < 0.01$ ) correlations with MWD in the surface soils (0-15 cm) (Table 5). Moreover, the effect of the SOC contents of the >4.0 mm aggregates was higher on MWD pointing out to a higher contribution on the stability of the aggregates of these sizes compared to the others.

Table 5. Correlation between mean weight diameter and SOC in different aggregate sizes

	0-15 cm	MWD	SOC in Different Sized Aggregate			
			>4.0 mm	4.0-2.0 mm	2.0-1.0 mm	1.0-0.5 mm
	MWD	1.000				
SOC in Different Sized Aggregate	>4.0 mm	0.684**	1.000			
	4.0-2.0 mm	0.669**	0.967**	1.000		
	2.0-1.0 mm	0.569**	0.873**	0.884**	1.000	
	1.0-0.5 mm	0.650**	0.940**	0.932**	0.883**	1.000
	15-30 cm					
	MWD	1.000				
SOC in Different Sized Aggregate	>4.0 mm	-0.251	1.000			
	4.0-2.0 mm	-0.275*	0.860**	1.000		
	2.0-1.0 mm	-0.253	0.650**	0.724**	1.000	
	1.0-0.5 mm	-0.187	0.784**	0.861**	0.717**	1.000

\* Difference is significant at  $P < 0.05$  level, \*\* Difference is significant at  $P < 0.01$  level

In spite of the strong relation between the aggregation index of the surface soils and the SOC contents of the different aggregate sizes, there was no important relation between MWD and SOC contents in different sized aggregates in the subsurface (15-30 cm) soils (Table 5). This showed that the cementing components other than organic carbon were responsible for the aggregation, though organic carbon might have been effective for the endurance of the aggregates in the subsurface layer. The major component effective in aggregation and the endurance of the aggregates is humus which is most durable to decomposition after mineralization. Garcia-Orenes et al. (2009) also indicated that the amount of biomass incorporated to soil had a strong impact on stability of aggregates and the associated SOC content. Thus, higher correlation of MWD and SOC in surface soils is mainly associated to the residue input in surface soil.

## Conclusion

The results indicated that the tillage systems significantly influenced soil aggregation and organic carbon contents in the aggregates. At the two sampling depths, the amount of 4.0-2.0 mm aggregates was determined highest in all treatments. Consequently, no-tillage was found to be the best practice for the improvement of the soil structure via the increased mean weight diameter among all other tillage systems. Conservation tillage systems provided higher organic carbon accumulation than conventional tillage practices in 0-15 cm soil depth for all aggregate sizes. The intensity of soil tillage and the amount of crop residue added to the soil significantly impacted SOC in surface soils. However, the soils of the conventional tillage practices were found to contain higher soil organic carbon than the conservation tillage system soils in the 15-30 cm depth. The relationship between soil aggregation and soil organic carbon was also supported by the correlation test performed in the 0-15 cm soil depth. However, there was no relationship between soil aggregation and soil organic carbon in 15-30 cm soil depth. Finally, our results suggest that conservation tillage systems could be useful to carbon sequestration and reduce soil erosion together with the crop residues on the soil surface in a high clay content soil under Mediterranean climatic conditions.

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