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Aggregate breakdown during tillage in a Mediterranean loamy soil

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Abstract

Long-term tillage negatively affects soil aggregation, but little is known about the short-term effects of tillage. We investigated the effects of intensive tillage (moldboard plowing) and conservation tillage (chisel plowing) on aggregate breakage during tillage in a long-term study located in the semiarid Ebro river valley (NE Spain). The type of tillage resulted in different soil aggregate distributions. In the 0–5-cm and 5–10-cm soil layers, chisel plowing decreased dry mean weight diameter (DMWD) 29% and 35%, respectively, while moldboard plowing decreased DMWD by only 2% and 16%, respectively. The decrease in DMWD was mainly due to breaking of large aggregates ranging (2–8 mm) into small aggregates (<0.5 mm). Tillage method had no effect on water stability of 1–2 mm aggregates. The differences in DMWD demonstrate that the choice of the tillage implement can be a key factor in improving soil management and productivity. The surprising result that aggregate breakdown was greater with chisel than moldboard plowing needs further research to determine the mechanisms controlling aggregate breaking during tillage.

Keywords:

Soil aggregation; Moldboard plow; Chisel plow; Mediterranean conditions

1. Introduction

Soil aggregation plays an important role in the maintenance of soil productivity and quality. Soil aggregates physically protect soil organic matter and affects root density and elongation, soil erosion, oxygen diffusion, soil water retention and dynamics, nutrient adsorption and microbial community structure ([Amézketa, 1999] and [Six et al., 2004]). Karlen et al. (1994) suggested that aggregate size distribution and stability are good indicators for evaluating soil quality in tillage experiments.

Soil aggregation is influenced by a large number of factors such as changes in soil organic matter, moisture content and microbial community, crop type, root development and tillage implementation. It is well established that long-term tillage causes a modifies the dry aggregate size distribution ([Singh et al., 1994], [Yang and Wander, 1998] and [Eynard et al., 2004]) and the water-stable aggregation ([Angers et al., 1993], [Unger et al., 1998] and [Álvaro-Fuentes et al., 2008b]). Tillage mechanically disrupts soil aggregates leading to a decrease in aggregate size. At the same time, tillage continually exposes soils to wetting/drying and freeze/thaw cycles at the surface, making aggregates more susceptible to break down. Upon aggregate disruption, aggregate-occluded SOM is released and becomes more available for decomposition (Paustian et al., 1997).

Tillage effects on soil aggregate size distribution are directly related to the degree of soil disturbance. Álvaro-Fuentes et al. (2008b), in a semiarid Mediterranean agroecosystem, found that the dry mean weigh diameter (DMWD) of soil aggregates decreases in relation with tillage intensity. In semiarid central Spain, Hernanz et al. (2002) observed that water stability of 2–1 mm aggregates decreased in the following order: no-tillage (NT) > reduced tillage (RT) > conventional tillage (CT).

The majority of these studies about tillage and soil aggregation have been focused on the study of the effects of long-term tillage on aggregate size distribution and aggregate stability. However, little information exists about the short-term effects of different tillage implements on soil aggregation and, particularly, on dry aggregate size distribution.

Historically, one of the main reasons that has been given to justify soil tillage is the achievement of an adequate seedbed preparation in order to facilitate a good seed-soil contact and thus a better crop emergence. In the last 20 years, conservation tillage systems, and specially NT, have spread out and in some areas of the world have completely displaced to CT systems. Benefits of NT have been widely compiled and reviewed ([Lal, 1989] and [Unger, 1990]) but despite those well-recognized benefits, NT has not been implemented in large areas. Ignorance of the technique, textural and soil depth limitations and weed infestations are among the factors that have reduced widespread use of NT. Therefore, in areas where intensive tillage is commonly used it is necessary to shift from this practice to a more

conservative system with chisel plow or cultivator plow in order to improve soil quality and to avoid environmental risks associated with intensive tillage systems.

Our objective was (i) to quantify the breakdown of soil aggregates during a tillage event and (ii) to evaluate the effects of a reduction in tillage intensity on the aggregate breakdown. We hypothesized that: (i) during intensive tillage a large proportion of aggregates are broken up and consequently a reduction on tillage intensity can reduce this aggregate breaking.

2. Materials and methods

2.1. Site and tillage treatments

Soil samples were collected from a long-term tillage experiment established in 1989 at the dryland research farm of the Estación Experimental de Aula Dei (Consejo Superior de Investigaciones Científicas) in the Zaragoza province, Spain (41°44'30"N, 0°46'18"W, 270 m). The soil is a loam (fine-loamy, mixed, thermic Xerollic Calciorthid) according to the USDA soil classification (Soil Survey Staff, 1975). Selected soil chemical and physical properties are shown in [Table 1](#) and precipitation and maximum and minimum temperatures recorded at the experimental site for the 2004 year are presented in [Table 2](#). The climate is semiarid, with an average annual precipitation of 340 mm and an average annual air temperature of 14.7 °C. The cropping system consisted of continuous barley (*Hordeum vulgare*, L.). In this study soil samples were taken from two tillage treatments: conventional tillage with moldboard plowing (MP) to a depth of 30–35 cm and chisel plowing (CP) to a depth of 20–25 cm. The moldboard plow consisted of three bottoms of 0.50 m width and reduced tillage and the chisel plow consisted of 5 rigid shanks spaced 20 cm apart and with a shank width of 5 cm. Although during the year considered for this study no secondary tillage was performed, during the previous years a secondary tillage was performed by passing a sweep cultivator to a depth of 10–15 cm in both MP and CP treatments. In this long-term experiment, seeding has always been made with a direct drill planter. Tillage treatments were arranged in a randomized complete block design with three replications. The size of each subplot was 33.5 m × 10 m.

2.2. Soil sampling and aggregate analyses

Soil samples were collected at five depths (0–5, 5–10, 10–20, 20–30, 30–40 cm) in November 2004 just before and after tillage implementation. Tillage was done on 10 November and soil samples were collected on 8 November (pre-tillage) and 15 November (post-tillage). From each plot and depth, a composite soil sample for aggregation analyses was prepared from two samples taken at two points

15 m apart with a flat spade and placed in crush-resistant, air-tight containers in order to avoid aggregate breaking during sample transportation. Sampling position was carefully selected in order to avoid areas with previous wheel track. At the same time, once in the laboratory, field-moist soil was passed through a 8-mm sieve. The sieved soil was air dried and stored at room temperature. Soil aggregation was characterized by the dry aggregate size distribution and water aggregate stability. The dry aggregate size distribution was attained by placing 200 g of air-dried soil (previously passed through a 8 mm sieve) on the top of a vertical electromagnetic sieve apparatus (FRITSCH *Analysette 3* PRO) equipped with a stack of seven sieves with the following screens: 4, 2, 1, 0.85, 0.5, 0.25 and 0.05 mm. In order to determine the optimum combination of sieving time and amplitude (vertical vibration height), a series of experiments testing different sieving times and amplitudes were carried out using different soils. A sieving time of 5 min and with amplitude of 0.1 mm were finally fixed for our experiment. Dry soil remaining on each sieve was collected and weighed. The dry mean weight diameter (DMWD) was used to express dry aggregate size distribution (Youker and McGuiness, 1957).

(1)

$$\text{DMWD} = \sum_{i=1}^8 X_i W_i$$

where X_i is the mean diameter of the size fraction, and W_i is the proportion of total sample weight retained on each sieve.

Dry aggregates between 1 and 2 mm diameter range were separated to determine the water aggregate stability (WAS) for this aggregate size class. The WAS was measured using the procedure of Kemper and Rosenau (1986). Briefly, 4 g of 1–2 mm air-dried aggregates were placed on the top of a 0.25 mm sieve and sieved in distilled water during 3 min with a stroke length of 1.3 cm and a frequency of 35 strokes min^{-1} . Soil retained on the sieve was transferred to an aluminum pan and dried and weighed.

Total soil organic carbon (SOC) from each plot and depth was measured in July 2005, after crop harvest. A composite sample was prepared from two samples taken from each plot and depth. A 5 g subsample was used to determine total SOC content by the wet oxidation method of Walkley and Black (Nelson and Sommers, 1982).

Daily precipitation and air temperature data were collected using an automatic weather station (Campbell Scientific Inc., datalogger CR10) located within the experimental field.

Statistical analyses of data were performed using the SAS statistical package (SAS Institute, 1990). ANOVA analyses were made in order to test the effects of tillage, sampling moment and the interaction

between factors. Interaction between tillage and sampling moment was tested with the *slice* option of the LSMEANS statement.

3. Results and discussion

3.1. Tillage effects on dry aggregate distribution

Prior to tillage, the DMWD of aggregates ranged from 2.2 to 3.0 mm with similar values between tillage treatments except for the 30–40 cm depth where greater DMWD was found under MP than under CP ([Fig. 1](#)). The similar DMWD between CP and MP can be related with the long time elapsed since the last tillage event (1 year). At the same time, low differences in C inputs between tillage treatments could have led to similar DMWD values prior to tillage. It is well accepted that soil aggregation is dependent on C inputs (Bronick and Lal, 2005). Tisdall and Oades (1982), in their aggregate hierarchy model, proposed that macroaggregates (>250 μm) are formed by the binding of stable microaggregates (20–250 μm) by temporary (fungal hyphae and roots) and transient binding agents (microbial- and plant-derived polysaccharides). Nevertheless, Elmholt et al. (2008), observed similar fungal hyphae and hot-water extractable carbohydrate-C on micro- and macroaggregates. These authors concluded that the level of C inputs controls the formation of binding agents and therefore soil aggregation. Other similar studies have corroborated that soil aggregates are formed due to the action of microbial activity stimulated by the presence of plant residues ([Golchin et al., 1994] and [Six et al., 1998]). In our study, no microbial analyses were made, but crop residue inputs were similar between tillage treatments during the previous cropping season (2003–2004) with 9160 and 9340 kg dry biomass ha^{-1} (straw + roots) in CP and MP, respectively (Álvaro-Fuentes et al., 2008a).

As stated before, the exception was found in the deepest soil layer sampled (30–40 cm) where a greater DMWD was found in MP compared with CP ([Fig. 1](#)). We consider that differences in depth implementation between CP (up to 25-cm depth with no inversion) and MP (up to 35-cm depth with soil inversion) led to these observed differences in DMWD. Therefore, a deeper placement of crop residues in the MP plots compared with the CP plots could have led to a greater DMWD in the 30–40 cm depth due to greater stimulation of soil microorganisms by a greater amount of crop residues.

In all the depths and tillage treatments, the DMWD was greater before tillage implementation (pre-tillage) than immediately after tillage (post-tillage) except in the 0–5 cm depth in MP and in the 30–40 cm depth in both CP and MP where similar values were observed ([Fig. 1](#)). The greatest decrease in DMWD was observed in the 5–10 cm depth in CP where after the pass of a chisel plow the pre-tillage DMWD value decreased by 35% ([Table 3](#)). This loss of DMWD due to CP was significantly greater than

the loss observed after the pass of MP for the same soil depth. Nevertheless, the greatest difference between CP and MP was observed in the 0–5 cm depth where the CP treatment decrease by 29% in the pre-tillage DMWD compared with the pre-tillage moment. However, in the MP treatment this loss was only a 2% ([Table 3](#)). Therefore, MP compared with CP did not reduced the DMWD in the soil surface. It has been accepted that tillage implementation produces the breakdown of aggregates ([Amézketa, 1999] and [Bronick and Lal, 2005]). However, most of these studies did not deal with dry aggregation. Yang and Wander (1998) suggested that little information exists about the temporal shifts in the characteristics of naturally occurring aggregates obtaining by dry-sieving. These authors studied tillage and crop effects (corn and soybean) on temporal dry aggregation changes in Illinois. Conversely to our results, they found an increase of DMWD after fall tillage implementation in both crops. Differences between studies can be related with differences in the time elapsed between tillage implementation and soil sampling. In this study, 2 months passed from the pre-tillage to the post-tillage sampling date. Plante and McGill (2002) studying aggregate dynamics under different simulated tillage found that aggregates were rapidly reformed between tillage events occurred every 2 weeks. Concurrently, MP causes an inversion of soil profile. The little differences in DMWD between pre- and pos-tillage at surface might be related by a distribution effect where soil from the bottom of the plough layer is brought to the surface.

In the 30–40 cm depth no differences in DMWD were found between pre- and post-tillage in both tillage treatments ([Fig. 1](#)). As mentioned before, CP was performed up to 25 cm depth. Consequently, in the CP treatment similar DMWD values were observed between pre- and post-tillage. However, the differences in the MP treatment were expected to be greater since MP was done up to 35 cm. Despite no significant differences in the DMWD were found in the MP treatment in the 30–40 cm depth between the pre- and post-tillage moment, the pre-tillage DMWD was slightly greater than the post-tillage DMWD ([Fig. 1](#)).

The dry aggregate size distributions measured prior and after CP and MP operations are shown in [Table 4](#). In both tillage treatments the greatest aggregate breakage due to tillage was observed in the large macroaggregates fractions (4–8 and 2–4 mm aggregate size classes) ([Table 4](#)). In the 0–5 cm depth, the CP treatment significantly reduced the proportion of aggregates of 4–8 mm size from 24.3% to 13.1%. However, for the same aggregate size class and soil depth, MP had a similar proportion of 4–8 mm size aggregates after tillage ([Table 4](#)). Furthermore, for the 2–4 mm aggregate size class a similar trend was observed, with a significantly decrease under CP from 23.4% to 18.3% and similar values under MP ([Table 4](#)). In the 5–10 cm and 10–20 cm depths and in both CP and MP, tillage implementation significantly reduced the 4–8 and 2–4 mm aggregate size classes except for the 2–4 mm aggregate size class in the MP treatment ([Table 4](#)). In the 20–30 and 30–40 cm depths, similar proportions of 4–8 and 2–4 mm aggregates were observed between the pre- and post-tillage samplings

except for the 30–40 cm depth in the MP treatment where tillage implementation led to a decrease of the proportion of 4–8 mm aggregate size class (Table 4). In all the soil depths and in both tillage treatments, a similar proportion of 1–2 and 0.84–1 mm aggregates was found before and after tillage. Conversely, the proportion of the 0.5–0.84, 0.25–0.5, 0.05–0.25, <0.05 aggregate size classes increased after tillage implementation in both tillage treatments and in all the soil depths. Nevertheless, this tendency diminished with depth (Table 4). The lowest increase in these aggregate fractions was observed in the deepest soil layers (20–30 and 30–40 cm). Grandy and Robertson (2006), studying the short-term response of tillage on water-stable aggregate size distribution according four size classes (2–8, 0.25–2, 0.05–0.25 and <0.053 mm), observed 60 days after tillage implementation observed a decrease in the 2–8 mm aggregate size class and an increase of the 0.05–0.25 and <0.053 size classes. In our experiment, in which the dry macroaggregate range was split into 6 classes, we detected that only the macroaggregates of the 4–8 and 2–4 mm size classes were responsible for the decrease in the DMWD observed after tillage implementation. According to Tisdall and Oades (1982), roots and hyphae are the main binding agents for macroaggregates >2 mm. These binding agents are sensible to management. Several studies have observed a decrease of hyphae and root networks after tillage ([Jansa et al., 2003] and [Castillo et al., 2006]). Consequently, tillage operations could lead to a loss of macroaggregate binding agents (hyphae and little roots), resulting in an easily breakdown of soil macroaggregates.

3.2. Tillage effects on water aggregate stability (WAS)

In the pre- and post-tillage samplings, WAS ranged from 12 to 20% (Fig. 2). In the 0–5 and 5–10 cm depths, a greater pre-tillage WAS was observed in the CP treatment compared with MP. However, below 10 cm a similar pre-tillage WAS was found between tillage treatments (Fig. 2). A reduction in tillage intensity leads to an increase in the stability of soil aggregates ([Six et al., 1998], [Hernanz et al., 2002] and [Álvaro-Fuentes et al., 2008b]). In our study, soil samples were taken from a long-term tillage experiment established in 1990. Although, more than 15 years of trial, did not lead to significant differences in total SOC between tillage treatments, a slightly greater SOC was observed under CP than under MP in the 0–5 and 5–10 cm depths (Table 5). It is well accepted that SOC acts as a binding agent (Bronick and Lal, 2005) and, concurrently, macroaggregate stability is controlled by roots and hyphae (Oades and Waters, 1991). Gale et al. (2000) proposed a conceptual model in which macroaggregates are formed around root-derived particulate organic matter (POM). In this model, the decomposition of dead roots results in an increase of microbial-binding agents and thus in a greater macroaggregate stability with time. In our study, slightly greater root inputs were measured in CP compared with MP during the previous cropping season. In the 2003–2004 cropping season, the root biomass was 931 and 871 kg dry biomass ha⁻¹ in CP and MP, respectively (Álvaro-Fuentes et al.,

2008a). Consequently, this difference in root biomass between tillage treatments could have led to different 1–2 mm macroaggregate stability prior to tillage.

Tillage implementation did not lead to differences in aggregate stability in none of the tillage treatments (Fig. 2). Watts et al. (1996), in a similar experiment, found greater aggregate stability (measured as mechanically dispersed clay) in aggregates collected after tillage than in those collected prior to tillage. They concluded that differences in dispersed clay measured prior and after tillage were related to soil water content at the time of tillage. These authors found that greater water content led to greater dispersed clay. However, this trend was not observed when tillage was carried out at a moisture content below the plastic limit. In our study, although soil water content was not measured, the rainfall collected from the previous crop harvest (June 2004) to tillage (November 2004) was less than 80 mm (Table 2). This rainfall was not enough to consider that soil water content during tillage operations was above the plastic limit. Therefore, in our conditions, tillage operations independently of their intensity did not modify the water stability of the 1–2 mm macroaggregates.

4. Conclusions

The results of this study showed that tillage implementation led to the breakdown of soil aggregates. However, this effect was different depending on both the type of tillage implement used and the soil depth considered. Interestingly, the chisel plow (CP) treatment had a greater impact on aggregate size reduction compared with the moldboard plow (MP) treatment, especially in the soil surface layer. Soil aggregation is implied in a large number of soil processes with significant effects on the productivity of semiarid agroecosystems as soil water dynamics, wind and water erosion processes and soil crusting and compaction. The findings presented in this study resulted from a single tillage event and therefore further research is needed to better understand the mechanisms controlling aggregate breaking during tillage operations and its implication on semiarid agroecosystems productivity.

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Table 1.

Soil physical and chemical soil properties at the experimental site

	Soil depth (cm)	
	0–20	20–40
Particle size distribution (g kg ⁻¹)		
Sand (2000 < Ø < 50 µm)	293	279
Silt (50 < Ø < 2 µm)	484	460
Clay (Ø < 2 µm)	223	261
pH (H ₂ O, 1:2.5)	8.3	8.3
Electrical conductivity (1:5) (dS m ⁻¹)	0.25	0.28
CaCO ₃ (g kg ⁻¹)	432	425

Table 2.

Total monthly precipitation (*P*) and mean monthly maximum and minimum air temperatures (*T*) recorded at the experimental site during 2004

	2004		
	<i>P</i> (mm)	<i>T</i> (°C)	
		Max.	Min.
January	10.3	12.7	3.1
February	43.4	9.8	0.5
March	56.4	14.3	2.0
April	42.0	17.6	4.8
May	34.9	23.3	8.7
June	5.9	32.3	14.3
July	14.5	32.1	15.9

	2004 _____		
	<i>P</i> (mm)	<i>T</i> (°C) _____	
_____	_____	Max. _____	Min. _____
August	10.5	32.3	16.7
September	25.3	29.0	14.5
October	32.9	23.8	10.2
November	8.5	13.1	2.9
December	32.7	10.9	3.0

Table 3.

Percentage reduction in the dry mean weight diameter (DMWD) during tillage chisel plowing (CP) and moldboard plowing (MP) for different soil depths

Soil depth (cm)	% DMWD	
	CP	MP
0–5	29.0a [‡]	1.8b
5–10	35.2a	15.8b
10–20	27.4a	21.3a
20–30	13.9a	14.1a
30–40	3.0a	11.2a

[‡] Different lowercase letters indicate significant differences between tillage treatments within a soil depth ($P < 0.05$).

Table 4.

Dry aggregate size distribution measured at five soil depths immediately before (pre-tillage) and after (post-tillage) chisel plowing (CP) and moldboard plowing (MP)

Soil depth (cm)	Sampling time	Tillage treatment	Aggregate proportion (%)							
			4–8 m m	2–4 m m	1–2 m m	0.84–1 m m	0.5–0.84 mm	0.25–0.5 m m	0.05–0.25 m m	<0.05 mm
0–5	Pre-tillage	CP	24.3 (2.1) ±	23.4 (1.0) *)	17.6 (2.9))	3.9 (1.4)	12.8 (0.9)	11.2 (1.1) ⁺	5.2 (1.0) ⁺	0.3 (0.02) ⁺
	Post-tillage	CP	13.1 (1.8)	18.3 (1.3))	16.8 (0.1))	2.6 (0.0 1)	13.3 (0.4)	22.1 (2.4)	11.9 (1.6)	1.3 (0.3)
	Pre-tillage	MP	21.3 (2.4)	23.2 (0.7))	20.2 (0.4))	2.7 (0.2)	14.0 (0.5) ⁺	12.0 (0.9) ⁺	6.6 (1.0)	0.3 (0.06)
	Post-tillage	MP	21.8 (1.6)	20.7 (1.0))	17.8 (0.2))	2.4 (0.1)	11.5 (0.4)	14.7 (1.3)	9.7 (1.0)	0.1 (0.1)
5–10	Pre-tillage	CP	30.3 (2.0) *)	23.9 (0.5) *)	17.9 (0.6))	2.4 (0.1)	10.4 (0.9)	9.0 (0.7) ⁺	5.6 (0.5) ⁺	0.3 (0.03) ⁺
	Post-tillage	CP	13.8 (2.1)	18.6 (0.7))	18.4 (0.7))	2.8 (0.0 8)	13.2 (0.3)	19.5 (1.7)	12.7 (1.5)	1.1 (0.1)
	Pre-tillage	MP	24.9 (2.0) *)	24.6 (0.6) *)	19.2 (0.9))	2.8 (0.2)	12.1 (0.7)	10.4 (0.7) ⁺	6.0 (0.8) ⁺	0.3 (0.06) ⁺
	Post-tillage	MP	19.3 (0.9)	20.6 (0.4))	18.7 (0.2))	2.6 (0.0 9)	12.3 (0.4)	15.4 (0.4)	10.7 (0.8)	0.9 (0.1)
10–20	Pre-tillage	CP	30.4 (1.2) *)	24.9 (1.0) *)	17.1 (0.3))	2.1 (0.0 9) ⁺	9.8 (0.6) ⁺	8.8 (0.7) ⁺	6.5 (0.5) ⁺	0.4 (0.02) ⁺

Soil depth (cm)	Sampling time	Tillage treatment	Aggregate proportion (%)							
			4–8 m m	2–4 m m	1–2 m m	0.84–1 m m	0.5–0.84 mm	0.25–0.5 m m	0.05–0.25 m m	<0.05 mm
	Post-tillage	CP	17.2 (1.9)	21.1 (0.9)	18.8 (1.0)	2.7 (0.1)	12.4 (0.5)	16.8 (1.6)	10.9 (1.3)	0.9 (0.2)
	Pre-tillage	MP	29.4 (1.0) [*]	24.3 (0.3)	18.1 (0.4)	2.2 (0.03) [*]	10.8 (0.3) [*]	9.3 (0.4) [*]	5.7 (0.5) [*]	0.3 (0.05) [*]
	Post-tillage	MP	18.9 (0.8)	22.4 (0.7)	19.6 (0.3)	2.6 (0.09)	12.4 (0.2)	14.7 (1.0)	9.2 (0.3)	0.7 (0.1)
20–30	Pre-tillage	CP	26.0 (2.0)	24.1 (1.0)	16.8 (0.3)	2.3 (0.1)	9.8 (0.3) [*]	10.1 (1.1)	10.2 (1.2) [*]	0.9 (0.1)
	Post-tillage	CP	19.0 (3.1)	22.3 (0.4)	18.5 (0.6)	2.4 (0.1)	11.7 (0.6)	14.6 (1.1)	10.9 (1.2)	1.6 (0.3)
	Pre-tillage	MP	26.3 (2.6)	23.6 (0.8)	18.7 (1.1)	2.3 (0.2)	11.2 (0.8)	10.2 (0.8)	7.5 (0.7) [*]	0.5 (0.08) [*]
	Post-tillage	MP	19.9 (1.0)	21.3 (1.0)	19.3 (0.4)	2.5 (0.1)	12.4 (0.3)	14.7 (0.8)	9.5 (0.8)	0.7 (0.1)
30–40	Pre-tillage	CP	17.9 (2.0)	21.5 (0.9)	17.4 (0.5)	2.3 (0.1)	11.3 (0.2) [*]	15.2 (2.1)	13.1 (0.8)	1.4 (0.2)
	Post-tillage	CP	15.4 (1.6)	21.4 (0.8)	18.3 (0.8)	2.3 (0.08)	12.7 (0.9)	18.4 (1.6)	11.7 (0.7)	1.1 (0.1)
	Pre-tillage	MP	24.5 (2.6) [*]	23.7 (0.4)	18.0 (0.4)	2.6 (0.2)	10.5 (0.5)	10.4 (0.7)	9.4 (0.9)	0.8 (0.1)
	Post-tillage	MP	19.7 (2.2)	21.8 (0.6)	18.9 (0.5)	2.7 (0.06)	11.9 (0.5)	14.9 (1.1)	10.1 (0.7)	0.9 (0.1)

* Indicates significant differences between pre- and post-tillage measurements within the same soil depth and tillage treatment ($P < 0.05$).

‡ Values in parenthesis are the standard errors of the mean.

Table 5.

Total soil organic carbon (SOC) under chisel plow (CP) and moldboard plow (MP) at different soil depths

Soil depth (cm)	SOC (g kg ⁻¹)	
	CP	MP
0–5	10.4	9.2
5–10	10.4	9.2
10–20	9.4	9.3
20–30	9.2	9.3
30–40	8.5	9.4

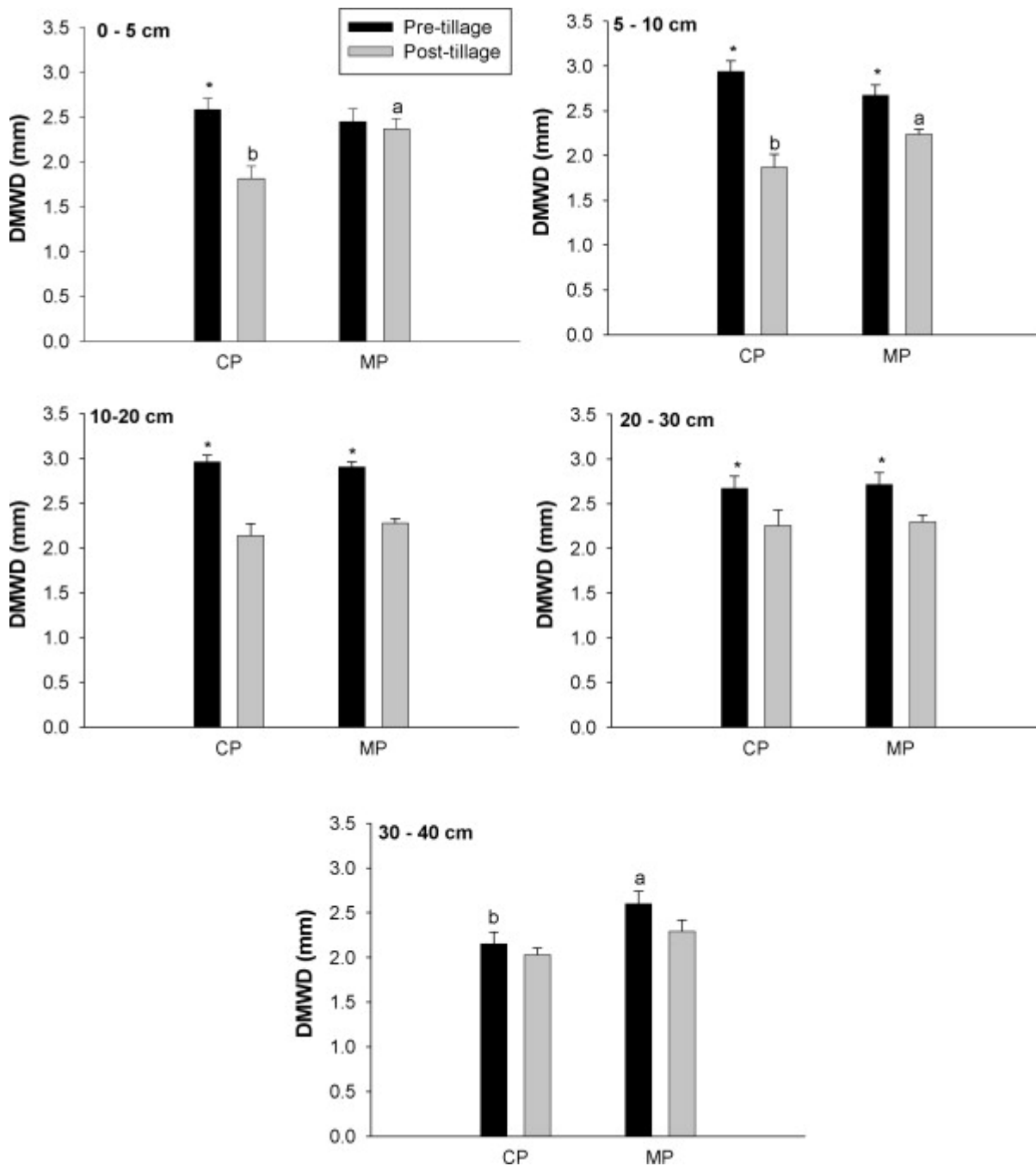


Fig. 1.

Dry mean weight diameter (DMWD) for the 0–5, 5–10, 10–20, 20–30, 30–40 cm layers of soil as affected by tillage system (CP, chisel plowing; MP, moldboard plowing) and the sampling time regarding to tillage implementation (pre- and post-tillage). Error bars represent standard errors. Different lowercase letters indicate significant differences between tillage treatments for the same moment and soil depth ($P < 0.05$). *Indicates significant differences between moments for a same soil depth and tillage treatment ($P < 0.05$).

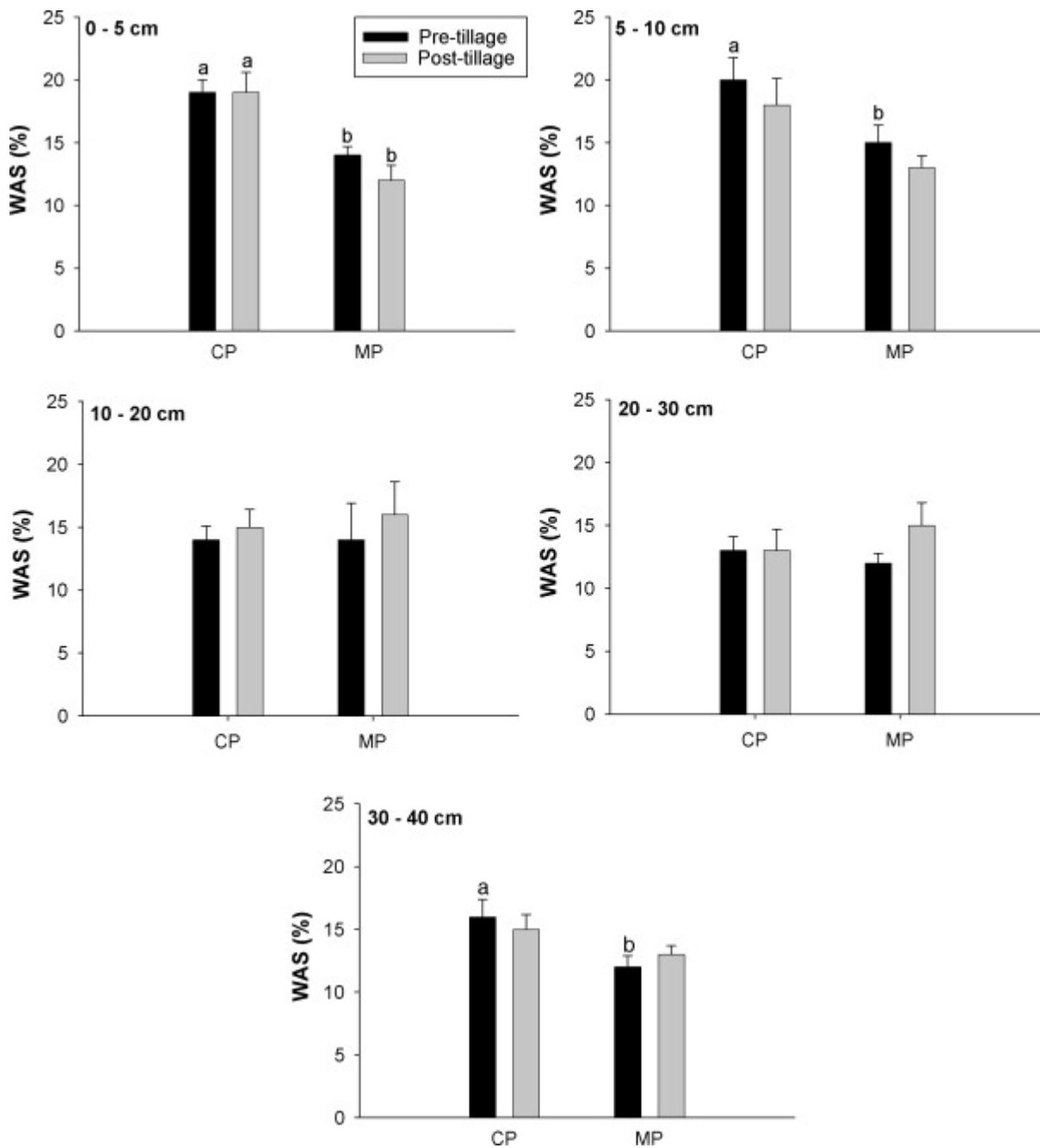


Fig. 2.

Water stability of air-dried 1–2 mm size aggregates (WAS) for the 0–5, 5–10, 10–20, 20–30, 30–40 cm layers of soil as affected by tillage system (CP, chisel plowing; MP, moldboard plowing) and the sampling time regarding to tillage implementation (pre- and post-tillage). Error bars represent standard errors. Different lowercase letters indicate significant differences between tillage treatments for a same moment and soil depth ($P < 0.05$).

