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Dynamics of aggregate destabilization by water in soils under long-term conservation tillage in semiarid Spain

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ABSTRACT

Due to particular soil and climate conditions and inappropriate agricultural practices, Aragon (NE Spain) is a region prone to land degradation by water erosion. For this reason, the adoption of conservation tillage systems has been encouraged as an alternative to preserve soil and water in this region. However, little information concerning soils on which these techniques are applied is available. The main objectives of this study were to assess the effect of long-term no tillage (NT) on water aggregate stability in five different cereal production areas of Aragon and identify the main mechanisms involved on aggregate breakdown. The study was conducted under on-farm conditions where pairs of adjacent fields under NT and conventional tillage (CT) were compared. In all cases, a nearby undisturbed soil under native vegetation was included. Soils were slightly to highly calcareous with medium textures ranging from sandy loam to silty clay loam. Results indicate that NT increased surface aggregate stability with respect to CT systems through lower soil disturbance and higher organic carbon (OC) content at the soil surface (0–5 cm depth). Slaking was the dominant disaggregation process of the cultivated soils, representing 40–80% of total soil disruption, and was strongly and negatively affected by aggregate-associated OC. This soil property together with the silt content (weak and positive effect) explained more than 80% of the slaking variation. Swelling and clay dispersion were less frequent processes and their occurrence seemed to be associated with high silt and $CaCO_3$ contents. This study shows that, under the rainfed conditions of semiarid Aragon, NT reduces the susceptibility of soil surface to crusting and water erosion as compared to CT systems.

1. Introduction

Characterization of near-surface soil water stability is essential to predict soil susceptibility to crusting and erosion. This acquires special relevance in agricultural soils where a stable soil structure is required for good water infiltration and aeration, optimal seedling emergence and root growth, and, finally, sustainable productivity (Bronick and Lal, 2005; Carter, 2004). Soil aggregate stability is being used as an indicator of soil quality since soil structural stability depends on the presence of stable aggregates (Amézketa, 1999; Nimmo and Perkins, 2002). However, the determination and interpretation of this parameter is often difficult due to the numerous factors affecting it as well as to the interactions among them. As it is detailed in the review of Amézketa (1999), these factors can be classified into soil internal and external factors. Internal factors include, among others, organic matter, texture, clay mineralogy, electrolyte and sesquioxides (Chenu et al., 2000; Kaewmano et al., 2009; Reichert et al., 2009; Six et al., 2000). Climate, biological activity and soil management are identified as external factors affecting water aggregate stability (Blanco-Canqui et al., 2009; Peng et al., 2011; Pikul et al., 2009). However, despite much research effort, there are still many contradictory results and further understanding of the different processes of soil destabilization in water is necessary. In addition, there are numerous different methods for measuring soil water stability which complicates the interpretation of results and the comparison among different studies (Amézketa, 1999; Díaz-Zorita et al., 2002; Nimmo and Perkins, 2002).

The wet sieving procedure proposed by Kemper and Koch (1966), and later improved by Kemper and Rosenau (1986), is the most widely used method to determine water aggregate stability (WAS). However, this method does not discriminate among the different destabilizing mechanisms of soil aggregates in water (slaking, swelling, clay dispersion and mechanical breakdown by abrasion). To overcome this limitation, Le Bissonnais (1996a) proposed a new method based on the use of pretreatments and wet sieving in ethanol. Although this method has been shown to be suitable in rainfall erosion studies (Amézketa et al., 1996; Legout et al., 2005), it is not a routine procedure in soil laboratories. This is probably because it is a laborious and time-consuming method, especially when there are many samples to analyze. Another approach was proposed by Zanini et al. (1998) who established an exponential equation to describe the dynamic features of soil aggregate

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breakdown as a function of wet sieving time. In this way, the loss of aggregates caused by water abrasion is separated from that due to initial wetting phase. This has not been a widely used method in spite of it has been validated and proved its usefulness to distinguish among soils and even among horizons of the same soil (Falsone and Bonifacio, 2006; Scalenghe et al., 2004).

Due to particular soil and climate conditions, Aragon (NE Spain) is a region prone to land degradation by water erosion (García-Ruiz, 2010; Lasanta et al., 1995). In addition, inappropriate agricultural practices, such as cropping systems that leave soil surfaces bare during long periods of time (fallowing), excessive tillage and overgrazing are main driving forces for agricultural soil degradation in the region. For this reason, the adoption of conservation tillage systems has been encouraged as an alternative to preserve soil and water in this region. In fact, according to previous results on soil and crop response in cereal production areas of Aragon (Álvaro-Fuentes et al., 2009; López et al., 2005; Moret et al., 2007), conservation tillage could be regarded as a viable management alternative. Furthermore, a recent survey conducted by the Department of Agriculture and Food of the Government of Aragon (Vallés, 2009) found a very positive perception of the advantages of these tillage systems by farmers and an increasing adoption in the last years, especially of no tillage (NT). However, this report also highlights the lack of knowledge about the soils on which these systems are applied.

The little available information on WAS of cultivated soils in Aragon has demonstrated the high susceptibility of these soils to surface sealing and crusting (Amézketa et al., 2003; Martí et al., 2001; Ries and Hirt, 2008). In this regard, Álvaro-Fuentes et al. (2008) showed the suitability of NT to increase wet stability of soil aggregates in semiarid Aragon. This study was carried out in small research plots and for single soil types and, however, farming practices applied by farmers in their fields can be very diverse and differ from those in experimental plots. For these reasons, direct measurements under on-farm conditions across different soils, microclimate and agronomic practices are necessary to get a broad knowledge of the potential of conservation tillage in the region (López et al., 2012). In order to remedy this lack of information, the objectives of this study were to (1) asses the effect of long-term NT on WAS compared with traditional tillage practices and undisturbed soils under native vegetation in different cereal production areas of Aragon, (2) identify the main destabilization processes of soil aggregates in water, and (3) establish relationships between WAS and aggregate-associated organic carbon (OC) to understand the role of soil OC on soil structural stability.

2. Material and methods

2.1. Description of the study sites

The study was conducted at six long-term NT fields (9–21 years) representative of the different scenarios of NT in the region and located in areas receiving a mean annual precipitation ranging from 350 to 740 mm (Table 1 and Fig. 1). These fields were selected from a previous study where 22 soils under NT were characterized across different rainfed cereal areas of Aragon to assess the potential of this practice to increase soil surface OC (López et al., 2012). With the exception of the Peñaflor site, the study was carried out under on-farm conditions (fields of collaborating farmers) where pairs of adjacent fields under NT and conventional tillage (CT) were compared. In Peñaflor, the study was carried out in research plots from a long-term tillage experiment at the dryland research farm of the Estación Experimental de Aula Dei (Consejo Superior de Investigaciones Científicas). In this case, tillage treatments (NT, CT and reduced tillage, RT) were arranged in a randomized complete block design with 3 replicates. More details about the Peñaflor site can be found in López et al. (1996). In all sites, an undisturbed soil under native vegetation (NAT) and close to the NT and CT fields was included in the study for comparison purposes.

Information on location and soil management characteristics for each site are shown in Table 1 and detailed in a previous study (Blanco-Moure et al., 2012). It should be noted, briefly, the case of Artieda, the study site located in the area with the highest rainfall and hence highest production. As a common practice in this area, farmer removes the straw from the NT and CT fields to prevent later problems with seeding. The information in Table 1 reflects the diversity of cropping systems and the reality of the conservation agriculture in the region (López et al., 2012). Therefore, following the remark made by Blanco-Canqui and Lal (2008a), the present study shows data on the effect of NT- and CT-based cropping systems on WAS rather than those of tillage alone.

The studied soils were medium-textured soils, varying from sandy loam to silty clay loam, alkaline (pH > 8; $CaCO_3$ contents of 50–560 g kg^{-1}) and generally with low OC contents (<20 g kg^{-1} for agricultural soils). Basic properties of the study soils for the first 5 cm depth are shown in Table 2 since it was the depth at which we have focused for the characterization of the water aggregate stability. In each site, both NT and CT fields were contiguous and the NAT soil close to them, thus ensuring that soil type and topography were as similar as possible. The differences observed are attributed to the soil management itself.

Table 1
Location and management characteristics of the studied sites (NT, no tillage; RT, reduced tillage; CT, conventional tillage; NAT, natural soil; CC, continuous cropping; CF, cereal-fallow rotation; CL, cereal-legume rotation; MP, mouldboard ploughing; Ch, chisel ploughing).

Site	Location	MAP[a] (mm)	Soil type[b]	Land use and management
Peñaflor CC	41° 44′ 30″ N 0° 46′ 18″ O (259 m elev.)	355	Hypercalcic calcisol	19-year NT-CC barley. 19-year CT-CC (MP) barley. 19-year RT-CC (Ch) barley. Maintenance of crop residues in the field. Straw chopped and spread in NT/RT (>30% of soil cover by crop residues) and incorporated into the soil in CT. NAT: Typical semiarid grassland.
Peñaflor CF	41° 44′ 22″ N 0° 46′ 30″ O (259 m elev.)	355	Hypercalcic calcisol	20-year NT-CF. 20-year CT-CF (MP). 20-year RT-CF (Ch). Maintenance of crop residues. Straw chopped and spread in NT/RT (>30% residue cover) and incorporated into the soil in CT. NAT: Typical semiarid grassland.
Lanaja	41° 43′ 22″ N 0° 21′ 19″ O (422 m elev.)	433	Hypocalcic calcisol	10-year NT-CL followed by 4-year NT-CC barley with maintenance of crop residues (>30% residue cover). >14-year CT-CF (MP) and straw removed. NAT: Frequently grazed area developed over an abandoned terrace (>40-year) with sparse vegetation and patches of low shurbs.
Torres de Alcanadre	41° 57′ 52″ N 0° 05′ 00″ O (431 m elev.)	468	Calcaric cambisol	9-year NT-CC cereal with maintenance of crop residues (>30% residue cover). >9-year CT-CC cereal (MP/Ch) and straw removed. NAT: Typical Mediterranean shrubland and *Pinus halepensis.* Soil surface covered with mosses and algae.
Undués de Lerda	42° 33′ 43″ N 1° 07′ 26″ O (860 m elev.)	676	Haplic calcisol	13-year NT-CF. Maintenance of crop residues (>30% residue cover). >13-year CT-CF (MP) and straw removed. NAT: Typical Mediterranean shrublandand *Pinus halepensis.*
Artieda	42° 35′ 46″ N 0° 59′ 39″ O (526 m elev.)	741	Hypocalcic calcisol	19-year NT-CC cereal followed by 2-year NT-CL and straw removed (≈10–15% residue cover). >21-year CT-CC cereal (MP/Ch) and straw removed. NAT: Typical Mediterranean shrubland.

[a] Mean annual precipitation.
[b] WRB (2007).