Soil & Tillage Research 155 (2016) 381–389

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Soil organic matter fractions as affected by tillage and soil texture under semiarid Mediterranean conditions

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ARTICLE INFO

Article history:
Received 16 April 2015
Received in revised form 31 July 2015
Accepted 17 August 2015

Keywords:
Soil organic carbon
Particulate organic matter
Mineral-associated organic matter
Conservation tillage
Rainfed agriculture

ABSTRACT

The inherent complexity of soil organic matter (SOM) and its stabilization processes make suitable the identification of SOM fractions that reflect the management-induced changes in soil organic carbon (SOC) dynamics. This is of special interest in semiarid regions where the capacity of soil for agricultural production is limited. This study aims to evaluate the effect of different tillage and soil management practices on the distribution of C among SOM fractions and determine the influence of soil texture on the protection of SOC in a semiarid Mediterranean region (Aragon, NE Spain). Under on-farm conditions, pairs of adjacent fields under long-term no tillage (NT) and conventional tillage (CT) were compared in five different cereal production areas. In all cases, a nearby undisturbed soil under native vegetation (NAT) was included. Results indicate that the two isolated mineral-associated OM (Min) fractions, d-Min and μagg-Min (outside and within stable microaggregates, respectively), constituted the main part of total SOC (mean contributions of 54 and 26%, respectively) and were not consistently affected by soil management. Soil clay was a determinant factor for d-Min-C and total SOC (r^2 = 0.60–0.70; P < 0.001), indicating that chemical stabilization, through clay–organic complexes, seems to be a main preservation mechanism in the studied soils. Physical protection seems to be another SOC stabilization process in these soils due to strong correlation found between μagg-Min-C and the mass of water-stable microaggregates (r = 0.900; P < 0.0001). With smaller contributions to total SOC, the two labile fractions, coarse and fine particulate OM (cPOM and fPOM) were sensitive to soil management and their concentrations decreased as soil disturbance increased (NAT > NT > CT). The highest differences between NT and CT corresponded to fPOM at the soil surface where this fraction was 1.2–3 times higher under NT. Higher soil stratification ratios in NT, always >2 for the POM fractions, indicate an improvement in soil quality with long-term NT adoption in this semiarid Mediterranean region.

1. Introduction

Soil organic matter (SOM) has been described as the most complex and least understood component of soils (Magdoff and Weil, 2004). The complexity is due to the fact that SOM is a heterogeneous mixture of organic substances with different chemical composition and turnover rates. This is one reason why total soil organic carbon (SOC) is not always the best indicator of changes in soil management, especially in semiarid regions where low precipitation and high temperature are limiting factors for SOC storage (Chan et al., 2003; Melero et al., 2012). Under these conditions, significant increments in SOC are only to be expected several years after adoption of sustainable management practices (Laudicina et al., 2012).

With the aim of elucidating the complex composition of SOM and understanding its dynamics and mechanisms of stabilization, the scientific community has made considerable efforts to develop techniques to separate SOM into fractions of different composition and stability (see reviews by Wander, 2004; von Lützow et al., 2007). These advances have allowed differentiate labile and recalcitrant SOC pools and identify those that can serve as early indicators of changes in soil quality. This seems to be the case of the particulate organic matter (POM, >53 μm in size) since it has been reported to be a sensitive labile fraction to management-induced changes in soil (Cambardella and Elliot, 1992; Wander, 2004).

Abbreviations: cPOM, coarse particulate organic matter fraction (>250 μm in size); fPOM, fine particulate organic matter fraction (250–53 μm); d-Min, easily dispersed mineral-associated organic matter fraction (<53 μm, outside water-stable microaggregates); μagg-Min, mineral-associated organic matter fraction in water-stable microaggregates (<53 μm); μagg, microaggregate fraction (250–53 μm in size).

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http://dx.doi.org/10.1016/j.still.2015.08.011
0167-1987/

Increments in POM with the adoption of conservation tillage and, specially, with no tillage (NT) have been reported in several studies (Six et al., 1999, 2000; Dou and Hons, 2006; Virto et al., 2007; Álvaro-Fuentes et al., 2008; Martín-Lammerding et al., 2013). However, the magnitude of these increments is variable and the POM effectiveness as soil indicator seems to depend on different factors such as quantity and quality of crop residues, management historical and soil texture (Domínguez et al., 2009; Martín-Lammerding et al., 2013; Blanco-Moure et al., 2013).

As POM decomposes and fragments into finer organic matter, it becomes physically and/or chemically stabilized within the soil mineral component as mineral-associated organic matter (Min, <53 μm in size). The long persistence of Min-C in the soil and its high contribution to total SOC, make this fraction of particular interest in the context of the global C cycle (Schmidt et al., 2011; Feng et al., 2013). Considerable progress has been made in the characterization of this fraction and, however, our knowledge is still limited due to its heterogeneity and to the different stabilization mechanisms involved and their interactions (von Lützow et al., 2007; Moni et al., 2010; O'Brien and Jastrow, 2013). Although there is evidence that SOC in the Min fraction is controlled by soil texture and particularly by clay content, the literature reveals that there is not always a close and direct relationship between clay and SOC concentration (McLauchlan, 2006; Sleutel et al., 2006; Zhao et al., 2006). The reason seems to be complex and can involve not only many influential factors, such as the clay mineralogy (and specific surface area) or the composition of organic C inputs, but also mechanisms other than simple monolayer sorption of SOM onto mineral surfaces as recent studies have shown (O'Brien and Jastrow, 2013; Vogel et al., 2014).

All the above information suggests that more research is necessary to advance in the characterization of SOC fractions and their dynamics, and thus, to develop soil management strategies to increase the quantity and stability of SOM. No tillage can be a sustainable strategy due to its potential to increase SOC (Govaerts et al., 2009; Cerdà et al., 2009). This is of special relevance to the Mediterranean region where a 74% of land has a surface soil horizon with less than 20 g kg^{-1} of SOC (Van-Camp et al., 2004). In Aragon (NE Spain), as in the rest of Spain, the interest of farmers in NT has been increasing (López et al., 2012; Gonzalez-Sanchez et al., 2015). However, there is still little available information on SOM and its fractions in agricultural soils of the region and it comes from small research plots and single soil types. The objectives of this study were to (1) determine the effect of soil tillage on the distribution of C among SOM fractions by comparing traditional tillage with long-term NT and with undisturbed soils under native vegetation, and (2) evaluate the influence of soil texture, and other basic soil properties, on SOC protection, giving special attention to the Min-C pool. The study was conducted under on-farm conditions in different cereal production areas of Aragon across different soils, microclimates and agronomic practices.

2. Materials 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 Aragon (NE Spain) and located in areas receiving a mean annual precipitation ranging from 350 to 740 mm (Table 1). These fields were selected from a previous study where 22 soils under NT were characterized across different rainfed cereal areas of the region (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 conducted in the 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 (2008), the present

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	41º44′30″ N 0º46′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	41º44′22″ N 0º46′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	41º43′22″ N 0º21′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 shrubs
Torres de Alcanadre	41º57′52″ N 0º05′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	42º33′43″ N 1º07′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 shrubland and *Pinus halepensis*
Artieda	42º35′46″ N 0º59′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] World Reference Base for Soil Resources, 2007.