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Evaluation of seasonal variability of soil biogeochemical properties in aggregate-size fractioned soil under different tillages

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ABSTRACT

An augment of soil organic matter (SOM) in agricultural lands is mandatory to improve soil quality and fertility and to limit greenhouse gases emissions. A better protection of SOM from degradation is seconded to its inclusion in aggregates and to the formation of organo–mineral interactions with the clay fraction within the soil matrix. Under Mediterranean conditions, conservation agriculture (CA) has been widely related with macro-aggregates formation, SOM protection, and to an improvement of soil fertility and crop yields.

The objective of this work was to evaluate the biogeochemical properties of five aggregate-size fractions obtained by dry sieving of a Calcic Fluvisol of an experimental farm managed under three different tillages. Soil aggregates distribution, total organic carbon (TOC), labile carbon pools, and enzymatic activities were measured in 2 different periods of the same agricultural campaign. CPMAS ^{13}C NMR analyses were also performed to elucidate the structure of preserved SOM.

The results evidenced seasonal variability in aggregate distribution, labile carbon pools and *dehydrogenase* activity (DHA), whereas TOC, permanganate oxidizable carbon (POxC), and β-*glucosidase* activity demonstrated to be reliable soil quality indices for soil fractions. The NMR analyses showed a better SOM preservation under conservation tillages, due to higher plant litter inputs and/or higher amount of necromass derived compounds if compared with traditional tillage. Particularly interesting are the results of the Ø 0.5–1 mm fraction, in which different trends were found for β-Glu and several organic compound classes if compared with the other fractions. Possibly, in this fraction are concentrated most of the products from cellulose depolymerization stabilized by organo–mineral interactions.

1. Introduction

A significant part of the agricultural production in Europe, mainly fruits, vineyards, vegetables and olives, is based in countries around the Mediterranean basin (European Commission, 2014). Low organic carbon contents for the soils of this area were reported by John et al. (2005), mainly due to edaphoclimatic conditions; moreover, the intensive use of the land for agricultural and livestock jeopardizes the soil quality and enhances the risk of desertification.

Preserving soil quality is mandatory to maintain crop yields at a competitive level and to minimize the environmental impact of agricultural practices. The most used parameter to assess soil quality is the quantification of soil organic matter (SOM) via the measurement of total organic carbon (TOC) content of the soil, which has been widely and positively correlated with other chemical and biochemical parameters. The accumulation of organic matter in soil, proceeding from organic amendments and/or crop litter, stimulates microbial and fungal communities and has a positive effect on the physico-chemical properties of the soil matrix. Moreover, a depletion of SOM due to its mineralization results in higher greenhouse gases emissions. A part of the fresh organic matter added to the soil is rapidly metabolized by microbial communities, but another part is protected against the mineralization and stored into the soil matrix. The mechanisms of stabilization are still far from being unveiled. The chemical structures of the organic compounds have often been used as a discriminant factor of recalcitrance, although recent studies reported that microbial communities can metabolize, with different rates, almost all classes of organic compounds (Marschner et al., 2008; Kleber, 2010). The organo–mineral interaction between organic compounds and clays, and the inclusion of SOM into soil aggregates that impede the access of the microbes have been revealed as most effective pathways for organic matter

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storage in soil (Kögel-Knabner et al., 2008; Moni et al., 2010; Dungait et al., 2012).

To evaluate the complex interactions that occur through the soil matrix, chemical and biochemical parameters of soil are often integrated with high resolution techniques of spectrometry, such as solid state nuclear magnetic resonance (Courtier-Murias et al., 2013; Plaza et al., 2013). The ^{13}C cross polarization magic angle spinning (CP-MAS) NMR is the most used pulse sequence in soil science, since it provides information about the relative contribution of different carbon functional groups to the total SOM of the sample in its solid state without the use of solvents. However, heterogeneity and complexity of SOM lead to broad resonance lines with overlapping peaks. Several strategies are used to enhance the quality of the acquired spectra, such as (a) the obtaining of reliable composite samples that limits the variability through the field at the sampling site (Knicker et al., 2012), (b) the demineralization of the samples with HF that concentrates the organic matter and limits the signal losses provoked by paramagnetic compounds (Schmidt et al., 1997; Knicker, 2011), and (c) the isolation of specific chemical or physical fractions from the bulk soil (Schutter and Dick, 2002; Kölbl and Kögel-Knabner, 2004).

The use of intensive tillage disrupts soil aggregates and exposes SOM to the microbial degradation. Conservation agriculture (CA) globally enhances soil quality, favors soil aggregation, and improves physical and biochemical parameters of soil. For these reasons, CA adoption is increasing worldwide, even if recent studies indicated that in Europe it only accounts for 1.1% and 5% in Spain (Kassam et al., 2012). The conditions established by Gajri et al. (2002) to define the conservation tillage are, among others, the avoidance of the use of moldboard and the presence of crop residues covering at least 30% of the soil surface. The aim of this work is to unveil if SOM preservation in soil aggregates follows different pathways under different tillages. To test this, three types of tillages (traditional tillage TT, reduced tillage RT, and no-tillage NT) in two on-field experiments of different duration were compared. The traditional tillage involves moldboard plowing with soil inversion and the burial of residues. Chisel is the plowing tool used for the reduced tillage treatment, whereas direct drilling is performed in the no-tillage plots; both conservation treatments imply the retention of crop residues at surface. For each treatment, topsoil samples were collected in May and September 2010 to provide an idea on how the seasonal variability could affect the results in tillage comparison experiments. Five size-aggregate fractions per treatment were obtained by dry sieving, in order to evaluate how tillage influences the SOM storage/degradation cycles via aggregates perturbation. Aggregates distribution, chemical parameters such as total organic carbon (TOC), water soluble carbon (WSC), and permanganate oxidizable carbon (POxC), and biochemical parameters such as microbial biomass carbon (MBC), *dehydrogenase* (DHA), and β-*glucosidase* (β-Glu) activities were measured. Moreover, CPMAS ^{13}C NMR analyses were performed on each aggregate fraction to evaluate the influence of tillage on the relative abundance of organic compounds present within the soil matrix. So far in literature, few studies were performed on size aggregate fractions combining some of the above listed analyses (Schutter and Dick, 2002; Muruganandam et al., 2009; Helgason et al., 2010; Panettieri et al., 2013; Bach and Hofmockel, 2014), but none of them has taken into account the seasonal variability and the different time of establishment of two different experiments of tillage comparison.

Table 1
Total monthly rainfall and monthly mean values of average, maximum, and minimum temperatures from January to October 2010.

	Temperature (°C)			
	Average	Maximum	Minimum	Rainfall (mm)
January	10.3	14.7	6.0	193
February	11.9	16.5	7.8	245
March	13.4	19.0	8.1	90.5
April	17.6	24.4	11.4	45.9
May	19.2	26.4	11.8	13.1
June	22.4	28.8	15.8	24.9
July	27.1	35.1	19.4	1.0
August	27.7	35.7	20.2	14.5
September	23.4	31.0	16.4	6.5
October	17.2	24.7	11.0	91.5

2. Materials and methods

2.1. Experimental area

The experiment was carried out at the "La Hampa" dryland experimental farm of the "Instituto de Recursos Naturales y Agrobiología de Sevilla (IRNAS-CSIC)" (37°17′N, 6°3′W), located 13 km southwest of the city of Seville (Spain). The soil is a Calcic Fluvisol (IUSS Working Group WRB, 2007) with a sandy clay loam texture (240 g kg^{-1} clay, 180 g kg^{-1} silt and 580 g kg^{-1} sand). At a depth of 0–25 cm the soil has a high $pH_{(H2O)}$ of 7.8. The soil contains an Olsen phosphorus concentration of 18.8 mg kg^{-1}, approximately 280 g kg^{-1} of alkaline-earth carbonates and the organic carbon content is approximately 9 g kg^{-1}.

The climatic conditions are typically Mediterranean with mild rainy winters (496 mm mean annual rainfall) and very hot and dry summers. The mean annual daily temperature at the experimental site is around 19 °C, with maximum and minimum mean monthly temperatures of 33.5 °C and 5.2 °C registered in July and January, respectively. Precipitations and temperatures registered during the experiment are reported in Table 1. A wheat *(Triticum aestivum* L.) – sunflower (*Helianthus annus* L.) crop rotation was established since 1991, subsequently in 2005, a fodder pea crop *(Pisum sativum* L.) was included in the rotation. A complex fertilizer (15N–15P_2O_5–15 K_2O) was added before the wheat sowing at a dose of 100 kg ha^{-1} whereas sunflower and fodder pea crops were not fertilized. Weeds were controlled by tillage or by the application of pre-emergence herbicides depending on the tillage treatment. A rate of 2 L ha^{-1} trifluraline (18%) was applied to the sunflower crop and 4 L ha^{-1}glyphosate (18%) was applied to the wheat and fodder pea crop.

2.2. Tillage comparison experiments

For this study, we selected two contiguous tillage comparison experiments started in 1991 and in 2004, hereafter reported as long-term and mid-term experiments, respectively. The first one is an area of about 2500 m^2, divided in 6 plots of approximately 300 m^2 each in a completely randomized experimental design (3 replicates per treatment), in which traditional tillage (TTL) and reduced tillage (RTL) were compared. The second experiment is on an area of about 1500 m^2 that has been divided into 6 plots of approximately 200 m^2 each with a completely randomized experimental design in which no-tillage management (NTM) is compared to a traditional tillage (TTM).

Traditional tillage managements of both experiments consisted of a moldboard plowing (25–30 cm deep) that produces subsoil/topsoil inversion followed by two cultivator passes to 15–20 cm depth and a disc harrowing to 15 cm depth. The previous crop residues were burned until 2003, when after harvest burning started to be prohibited by the local government. For the TT plots, a special permission allowed burning in 2004 and 2005. Currently, crop residues are buried into the soil during moldboard ploughing.

The total number and depth of operation was sensibly reduced for RTL plots compared with corresponding TT ones, retaining only