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Long-term variations in soil organic matter under different tillage intensities

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ABSTRACT

Tillage practices have a major effect on soil C storage and cropping sustainability, due to their impact on soil aggregation, organic residue decomposition rate, OC dynamics, microbial abundance and diversity, N mineralization and nutrient availability.

Our research was aimed at assessing the long term effects of different tillage treatments on soil organic matter (SOM) quantity and quality and its evolution with time, in a loam textured-soil from central Italy cultivated with continuous maize. The tillage treatments included a conventional tillage (DP) by mouldboard ploughing to 40 cm depth, a ripper subsoiling (RS) to 40–45 cm, a shallow tillage by mouldboard ploughing to 20 cm depth (SP) and minimum tillage to 10 cm by disk harrowing (DH). The soil was sampled in 1999 and 2011 (after 5 and 17 years from the beginning of the trial, respectively), at depth increments of 0–10, 10–20, 20–30 and 30–40 cm and analysed for total organic C (TOC), OC recalcitrant and labile fractions by chemical hydrolysis, total N, bulk density, aggregate stability and hydraulic conductivity.

After 17 year of treatments, the different tillage systems did not affect the overall amount of OC stored in a 0–40 cm equivalent soil mass; nevertheless, they produced significant differences in soil OC vertical distribution along the soil profile and OC recalcitrance. Both DH and RS increased soil TOC in the surface layer, with predominance of labile OC under DH and recalcitrant OC under RS. Differently, DP caused a net loss of recalcitrant OC, probably due to a detrimental impact on soil aggregate stability and, subsequently, on SOM physical protection. RS showed the largest potential for OC sequestration in stable form in the considered agroecosystem.

1. Introduction

The effects of ploughing on soil physical and chemical properties are well known. Soil organic matter (SOM) depletion under conventional tillage is commonly observed (Lal and Kimble, 1997), as well as soil aggregate disruption (Pagliai et al., 2004), compaction (Hamza and Anderson, 2005) and erosion (Lal, 2003). However, most experimental results have been obtained from investigations on the surface soil layers and are anyway related to the site-specific nature and properties of the soil, climate, cropping systems and plant residue management (Paustian et al., 1997). Furthermore, few long-term studies have addressed qualitative changes of soil OC storage in response to tillage, especially under Mediterranean environment, and most of them have been focused on conventional *vs.* minimum or no-tillage practices (Franzluebbers et al., 1994; Wright et al., 2007; Chen et al., 2009; Jacobs et al., 2010; Melero et al., 2010). Among alternative tillage implements less studied is ripper subsoiling, usually used as primary field operation to break through and shatter compact soil layers without inversion (Grevers and de Jong, 1993). According to Pagliai et al. (2004), ripper subsoiling, compared to more common conservative practices, improves soil macro- and microporosity, as well as hydraulic conductivity, along the soil profile; less information is available about the long-term influence of ripper subsoiling on SOM quality and C storage potential.

Conservation tillage practices may act positively on soil C storage, by influencing SOM turnover, enhancing soil aggregate stability and soil microbial abundance and activity (Peigné et al., 2007). However, when accounting for C sequestration potential, we have to consider that it depends upon OC distribution between the labile and the recalcitrant pools and their quality. Hence, for a better understanding of mechanisms leading to C sequestration in

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arable soils, tillage systems should be investigated in relation to these two functionally-different SOM fractions. From an analytical viewpoint, SOM fractionation based on acid hydrolysis has been found to effectively dissolve the young C compounds, leaving the older resistant molecules in the residue, and is considered a useful technique to explore soil organic C stability (Leavitt et al., 1996). This approach is commonly used to isolate stable SOM because it preferentially removes young, potentially biodegradable compounds (*e.g.*, proteins, nucleic acids, and polysaccharides) while leaving the old C fraction behind (Leavitt et al., 1996; Paul et al., 1997; Paul et al., 2001). Hence, non-hydrolysable organic matter has been considered to represent recalcitrant SOM (Tan et al., 2004) and its amount has been assumed to be a measure of 'non-active' or 'passive' SOM pool (Six et al., 2002; Springob and Kirchmann, 2002).

Long-term experiments provide important and reliable information on soil quality in response to farming managements. Accordingly, we carried out a seventeen year field experiment, based on repeated soil sampling over time, with the aim to assess temporal variations in soil OC storage, as characterized by its total, labile and refractory pools, and of soil physical properties, under different tillage treatments, including conventional and conservative implements, with different working depth (from 10 to 40 cm) and intensity (with and without soil inversion).

2. Materials and methods

2.1. Experimental site

The trial was established in 1994 at the Fagna experimental farm (Scarperia, Firenze, Italy; 43°59′03″N, 11°20′34″E) of the research center for Agrobiology and Pedology (CRA-ABP, Firenze, Italy). The area extends across the Mugello valley, close to the Apennine mountains, on an alluvial soil, typical of the sedimentary plains of Central Italy, classified as *Fluventic Eutrudept* (Soil Survey Staff, 1999).

At the beginning of the trial, the soil had the following properties: loam texture (sand = 44%, silt = 40%, clay = 16%), pH 7.8, total $CaCO_3$ = 6%, total OC = 1.0%, total N = 0.12%, C/N = 8.7.

The climate classification of the area, according to Koppen (1936), is "temperate with dry summer", with a mean annual rainfall of 1024 mm.

The experiment consisted of four tillage treatments, randomly assigned to rectangular field plots of 170 m^2 with three replicates, under continuous maize (*Zea mais* L.), for a 17-year period (1994–2011). The treatments included: a minimum tillage to 10–15 cm by disk harrowing (DH), a ripper subsoiling to 40–45 cm depth (RS), a shallow mouldboard ploughing to 20 cm depth (SP) and a conventional mouldboard ploughing to 40 cm depth (DP). Before sowing, all plots received a supplementary tillage treatment by surface rotary harrowing (6–8 cm) for seedbed preparation. During the 24 years before the trial, the experimental field had always been under continuous maize cropping by conventional tillage.

Maize was not irrigated, following the most common practice in the area. Grain yield, averaged across the 1999–2011 period, was 3.4 Mg ha^{-1}, without significant differences among treatments.

Soil sampling was carried out at the end of the growing season, after five (1999) and seventeen (2011) years from the beginning of the experiment, in order to assess temporal variations in the state of selected soil parameters. Within each plot, soil pits were dug at three sites, from which disturbed soil samples were collected at depth increments of 0–10, 10–20, 20–30 and 30–40 cm. The sampling sites were the same in the two selected years.

The samples were air dried and sieved through a 2-mm mesh. For C and N quantitative analysis and C chemical fractionation, soil sub-samples were grinded and homogenized to 0.5 mm.

Undisturbed soil samples were collected from the 0–10 and 30–40 cm layers for soil macroporosity determination, according to the micromorphometric method (three samples per tillage treatment and soil depth), and from all depth increments for soil bulk density (BD) measurement. A further sample was collected from each pit at 0–10 cm depth, taking care not to compact or loosen the soil, for soil aggregate stability analysis.

2.2. Soil organic matter and chemical fractionation

Total organic C (TOC) and total N (TN) contents in the bulk soil were measured by dry combustion on a Thermo Flash 2000 CN soil analyzer. To this aim, 20–40 mg soil were weighed into Ag-foil capsules and pre-treated with 10% HCl until complete removal of carbonates.

Chemical fractionation of SOM was performed by acid hydrolysis with 6 N HCl under reflux. This is a common procedure to determine the amount of recalcitrant OC pool (ROC) in the soil. Basically, the treatment removes labile compounds, such as proteins, nucleic acids and polysaccharides, leaving in the residue the most chemically resistant fraction, mainly represented by aromatic, humified compounds and wax-derived long-chain aliphatics (Plante et al., 2006).

Table 1
Soil TOC and TN after 4 (1999) and 17 (2011) years from the beginning of treatments at 0–10, 10–20, 20–30 and 30–40 cm depth. Standard errors are reported in parenthesis.

Tillage	Depth (cm)	TOC (Mg ha^{-1})				TN (Mg ha^{-1})				C/N			
		1999		2011		1999		2011		1999		2011	
DH	0–10	13.38	(0.28)	15.76	(0.29)	1.54	(0.01)	1.52	(0.02)	8.66	(0.14)	10.36	(0.34)
	10–20	11.69	(0.72)	11.10	(0.40)	1.35	(0.07)	1.24	(0.09)	8.65	(0.08)	9.00	(0.32)
	20–30	10.02	(0.19)	8.94	(0.52)	1.29	(0.07)	0.97	(0.06)	7.82	(0.30)	9.31	(0.54)
	30–40	9.97	(0.10)	8.80	(0.19)	1.26	(0.04)	0.91	(0.06)	7.95	(0.27)	9.79	(0.70)
RS	0–10	12.42	(0.43)	13.67	(0.45)	1.40	(0.06)	1.51	(0.05)	8.88	(0.10)	9.03	(0.09)
	10–20	11.02	(0.59)	11.96	(0.75)	1.28	(0.08)	1.45	(0.10)	8.58	(0.11)	8.24	(0.21)
	20–30	10.36	(0.34)	10.33	(0.56)	1.22	(0.05)	1.26	(0.07)	8.54	(0.23)	8.22	(0.16)
	30–40	10.36	(0.07)	9.72	(0.31)	1.26	(0.04)	1.18	(0.05)	8.24	(0.31)	8.25	(0.10)
SP	0–10	11.59	(0.52)	12.38	(0.18)	1.37	(0.06)	1.38	(0.03)	8.45	(0.06)	8.96	(0.21)
	10–20	12.08	(0.50)	11.83	(0.27)	1.42	(0.06)	1.38	(0.06)	8.50	(0.06)	8.60	(0.21)
	20–30	11.96	(0.76)	12.34	(0.59)	1.40	(0.07)	1.43	(0.11)	8.53	(0.17)	8.64	(0.27)
	30–40	11.64	(0.45)	11.42	(0.68)	1.38	(0.05)	1.33	(0.09)	8.41	(0.09)	8.61	(0.16)
DP	0–10	10.45	(0.32)	10.97	(0.71)	1.28	(0.02)	1.35	(0.11)	8.17	(0.19)	8.19	(0.30)
	10–20	10.76	(0.58)	10.51	(0.59)	1.29	(0.05)	1.28	(0.08)	8.34	(0.16)	8.21	(0.14)
	20–30	10.98	(0.59)	10.59	(0.62)	1.32	(0.06)	1.23	(0.07)	8.30	(0.16)	8.62	(0.12)
	30–40	10.92	(0.67)	10.02	(0.58)	1.30	(0.06)	1.15	(0.07)	8.39	(0.18)	8.71	(0.06)