Agriculture, Ecosystems and Environment 230 (2016) 68–78

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Disentangling the effects of conservation agriculture practices on the vertical distribution of soil organic carbon. Evidence of poor carbon sequestration in North- Eastern Italy

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ARTICLE INFO

Article history:
Received 11 February 2016
Received in revised form 4 May 2016
Accepted 27 May 2016
Available online xxx

Keywords:
Conservation agriculture
No-tillage
Soil organic carbon
Carbon quality
Soil carbon sequestration
Agro-environment measures
Microbial biomass
Clay minerals

ABSTRACT

Conservation agriculture is one of the agro-environment measures promoted by the Veneto Region (North-eastern Italy) to regulate and support many ecosystem services. This study compared conventional and conservation agriculture management systems in order to evaluate their effects on both SOC stocks and quality i.e. humic C and its molecular weight fractions, microbial C and N. The experiment was set up in 2010 on three farms in Veneto Region. In order to improve the monitoring procedures, a massive soil sampling programme was conducted in 2011 and 2014 in ca. 150 positions, considering the SOC stratification within a 0–50 cm profile.

Results suggested that conservation agriculture practices affected SOC distribution rather than its total amount. The retention of crop residues on the soil surface and the absence of tillage operations drove SOC dynamics in the top layer (0–5 cm) of the conservation system, while residues incorporation with ploughing was responsible for SOC accumulation at the 30–50 cm depth in the conventional one. SOC stock variation in the conservation treatment was also influenced by root C input, which was identified as a major factor able to promote SOC accumulation in the 0–30 cm profile. The role of clay on SOC dynamics was not uniform in the three farms since it depended both on the clay amount and its mineral composition. The strong interactions existing between management systems and local soil conditions were also confirmed by the C quality analyses.

This research did not demonstrate the benefits of conservation practices on SOC sequestration during the transition period. However, SOC sequestration is only one of the numerous ecosystem services provided by conservation practices. Some of these depend on the C content and quality in the top layers that, as demonstrated in our work, were strongly affected by the C stratification processes triggered by conservation agriculture.

1. Introduction

Conservation agriculture (CA) is a system of agronomic practices that minimizes mechanical soil disturbance (e.g. no-tillage, NT), maintains permanent soil cover by using crop residues and cover crops, and rotates crops.

CA regulates CO_2 emissions by increasing the C stored in soil (i.e. C sequestration) (Lal and Stewart, 2010) and reducing direct emissions through less use of agricultural vehicles (i.e. fuel saving) (Soane et al., 2012). It has been evaluated that CA can enhance soil C stocks by about 0.57 ± 0.14 t C ha^{-1} year^{-1} in the top 30 cm (West and Post, 2002). Despite the first estimates of Smith et al. (1998), suggesting that all fossil fuel C emissions from European agriculture could be mitigated through the complete conversion to NT, CA is still not recognized as a win-win option for soil C sequestration (Corbeels et al., 2016; Powlson et al., 2011; VandenBygaart, 2016). Ogle et al. (2012) argued that NT could

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http://dx.doi.org/10.1016/j.agee.2016.05.035

increase or decrease the SOC content depending on its effects (positive or negative) on crop biomass and consequent C input. The unpredictable behaviour of NT on SOC was viewed by the authors as strongly dependent on climatic conditions, which affect plant growth and soil processes and therefore play a key role in organic matter dynamics. Angers and Erik-Hamel (2008) suggested that crop residues left on the soil surface are less persistent than those incorporated by ploughing. Indeed, incorporation promotes the interaction between crop residues and soil particles and in turn enhances the physical mechanisms of SOC protection (Balesdent et al., 2000).

Baker et al. (2007) postulated that the greater C content in NT fields may be an artefact of shallow sampling and that, after considering deeper soil profiles, NT would not show any advantages in C sequestration with respect to conventional tillage. They also suggested that sampling deeper than 30 cm would be required to fully clarify the role of CA on soil C stocks. The meta-analysis by Luo et al. (2010) pointed out that NT could enhance C stocks in the top 10 cm of soil, decrease them in the deeper 10–40 cm layer and be ineffective below 40 cm.

The vertical SOC distribution in CA would be affected not only by non-inversion tillage, but also by root growth and patterns. By modifying the soil structure within the profile, NT would create a structure stratification that negatively affects root-growth and root-induced parameters (e.g. C distribution). Powlson et al. (2011) concluded that the main difference between conventional and conservation agriculture is just a matter of SOC distribution in the soil profile and not of total C stocks, and as a consequence the effects of CA on climate change mitigation might have been overestimated in the past.

Soil tillage managements were recognized to affect not only the soil C stocks but also their quality (Devine et al., 2014; Six et al., 1998). Soil organic matter (SOM) in conventionally tilled soils was usually associated to a reduction in fulvic acids, humin and labile humus substances (Kravchenko et al., 2012). On the contrary, conservation practices improved SOM quality in the top layers by leading to a higher fulvic acids content (McCallister and Chien, 2000) and lower concentrations of semiquinone free radicals and humification degree of SOM (Bayer et al., 2003).

Soil microbiota is another major driver of organic matter turnover and nutrient cycling (Schloter et al., 2003). The role of the microbial biomass in mediating soil processes and its relatively high turnover rate, logically suggests that the microbial biomass could be a sensitive indicator and early predictor of changing SOM processes in CA (Rincon-Florez et al., 2015).

In spite of its recognized benefits, “European and national administrations are still not fully convinced that the concept of CA is the most promising one to meet the requirements of an environmentally friendly farming” (Basch, 2005; cit. in Friedrich et al., 2014). Very few countries in Europe (e.g. Switzerland, Italy) promote CA with national or regional policies (Friedrich et al., 2014).

In a global change scenario and in order to advance the tools used to pursue mitigation strategies, it is important to quantify the benefits observed during the transition period from conventional to conservation practices and identify the main mechanisms driving SOC dynamics. The aim of this study was to evaluate the SOC evolution over a 3-yrs transition period in three experimental farms on the low-lying plain of Veneto Region. The impact of CA on soil quality was also quantified by monitoring the humic carbon and its molecular weight distribution, and the microbial biomass. In order to improve the monitoring procedures, a massive soil sampling programme was conducted in ca. 150 positions, considering the SOC stratification within a 0–50 cm profile.

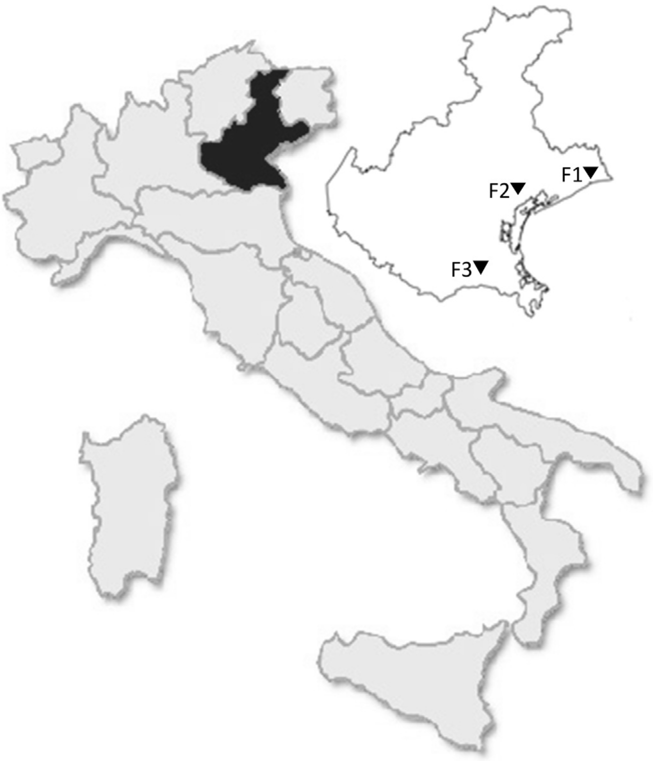

Fig. 1. Experimental sites in the Veneto Region low plain, North-eastern Italy. Farms positions are marked with triangles (F1, F2 and F3).

2. Materials and methods

2.1. Experimental sites

The experiment was set up on three farms in North-eastern Italy (Fig. 1, Table 1). Farm 1 (F1) “Vallevecchia”, is sited on the Adriatic coast (45° 38.350′N 12° 57.245′E, −2 m a.s.l.), the soil is Gleyic Fluvisols or Endogleyic Fluvic Cambisols (FAO-UNESCO, 1990) with a texture ranging from silty-clay to sandy-loam. Farm 2 (F2) “Diana”, and Farm 3 (F3) “Sasse Rami”, are located to the west, on the central (45° 34.965′N 12° 18.464′E, 6 m a.s.l.) and southern plain (45° 2.908′N 11° 52.872′E, 2 m a.s.l.), respectively. Both are characterized by Endogleyic Cambisols (FAO-UNESCO, 1990) silty-loam soil, more homogeneous in texture than F1.

The climate is sub-humid, with annual rainfall around 829 mm in F1, 846 mm in F2 and 673 mm in F3. In the median year, rainfall is highest in autumn (302, 241 and 187 mm respectively) and lowest in winter (190, 157 and 129 mm respectively). Temperatures increase from January (minimum average: −0.1, −0.9 and −0.2 °C respectively) to July (maximum average: 29.6, 29.3 and 30.6 °C respectively). Reference evapotranspiration (ETo) is 860, 816 and 848 mm, with a peak in July (4.9, 4.6 and 4.8 mm d^{-1}). ETo exceeds rainfall from May to September in F1 and F2 and from May to October in F3.

2.2. The experiment

The field experiments were established in October 2010 in order to compare conventional (CONV) versus conservation (CONS) management systems. Cultivation protocols in CONS were set up according to the Measure 214–Sub-Measure i, “Eco-compatible management of agricultural lands” of the Rural Development Programme (RDP) supported by the Veneto Region (Regione Veneto, 2013).