



Characterization of the heavy, hydrolysable and non-hydrolysable fractions of soil organic carbon in conventional and no-tillage soils

Ravindra Ramnarine*, Robert P. Voroney, Kari E. Dunfield, Claudia Wagner-Riddle

School of Environmental Sciences, University of Guelph, 50 Stone Road East, Guelph, Ontario, N1G 2W1, Canada

ARTICLE INFO

Keywords:

Soil organic carbon
Heavy fraction
Hydrolysable fraction
Non-hydrolysable fraction
Conventional tillage
No-tillage

ABSTRACT

Quantification of soil organic carbon (SOC) pool fractions under different tillage systems is important in understanding SOC dynamics and storage. Two major pools of SOC that can be isolated are the light (LF) and heavy fractions (HF). Few studies have quantified the effect of tillage systems on the hydrolysable (HYF) and non-hydrolysable fractions (NHF) which comprise the HF. The objective of this study was to evaluate if there were significant changes in the quantity and $\delta^{13}\text{C}$ of the HF, HYF, and NHF fractions of SOC after six years of no-tillage (NT), on arable soils that were previously under conventional tillage (CT). Our study used ^{13}C natural abundance (rotation of C_3 and C_4 crops) on a calcareous Typic Hapludalf soil in southern Ontario, Canada. The HF ($> 1.7 \text{ g cm}^{-3}$) was isolated using density fractionation and separated into its HYF and NHF using acid hydrolysis (6 M HCl) for three soil depths: 0–10, 10–20, and 20–30 cm. The HF pool (90–93% of SOC) was significantly greater ($P < 0.05$) in the NT (28.9) than the CT system (25.5 Mg C ha^{-1}) only for the 0–10 cm depth. The dominant SOC fraction from the HF pool was the NHF (62–65% of SOC) for both tillage systems. However, the HYF (25–30% of SOC) was significantly greater in the NT (9.3) than the CT system (7.0 Mg C ha^{-1}) only for the 0–10 cm depth. Additionally, there was a significantly higher proportion of C_4 -derived C in the HF only at the 0–10 cm depth of NT soils. Differences in the $\delta^{13}\text{C}$ of the whole soil and SOC fractions show a preservation of newly derived C in the HF, HYF and NHF of NT soils. We conclude that the adoption of NT systems on arable soils increases the quantity of HF and HYF in the 0–10 cm depth only, but there is no difference in carbon sequestration potential when treatments are compared over the 0–30 cm depth in the short-term.

1. Introduction

Soil organic carbon (SOC) pools, dynamics and storage are affected by conventional (CT) and no-tillage (NT) systems (Angers et al., 1995; Six et al., 1999; Lupwayi et al., 2004; Huggins et al., 2007; Schjøning et al., 2007; Alvarez and Steinbach, 2009; Beyaert and Voroney, 2011). SOC is the carbon stored in soil organic matter (SOM), which refers to the organic fraction of soil that consists of a mixture of plant and animal residues in various stages of decomposition, microbial biomass, and substances made microbiologically or chemically from by-products (Schnitzer, 2000; Weil and Brady, 2016). Lehmann and Kleber (2015) provides empirical evidence that SOM is a continuum of progressively decomposing organic carbon-containing substances but argues against the formation of stable humic substances. According to Schnitzer (2000), there will be decomposition and synthesis of products during SOM formation.

Decomposition of crop residues by the soil microbial biomass results

in the residue organic C being oxidised to CO_2 by soil organisms and microbial products becoming stabilized by sorption to mineral surfaces and forming humus (Jenkinson and Rayner, 1977; Voroney et al., 1989). During this continuum of decomposition, two major pools of SOM can be identified. Firstly, there is a transitory intermediate pool known as the light fraction (LF) consisting of plant and microbial residues in various states of decomposition (Gregorich and Beare et al., 2008), and secondly a heavy fraction (HF) pool that consists of more stable, low molecular weight organic compounds and high molecular weight humified organic matter (Christensen, 1996). These pools are normally recovered by density fractionation, which is the physical separation of SOM using a liquid of known specific gravity, into a low- and high-density fraction, known as the LF and HF, respectively (Strickland and Sollins, 1987; Angers et al., 1997; Sohi et al., 2001; Tan et al., 2007; Cerli et al., 2012).

There have been many studies on the physical separation of the SOC pool into the LF and HF (Janzen et al., 1992; Cambardella and Elliot,

Abbreviations: $\delta^{13}\text{C}$, isotopic signature of carbon; CT, conventional tillage; HF, heavy fraction; HYF, hydrolysable fraction; LF, light fraction; NHF, non-hydrolysable fraction; NT, no-tillage; SOC, soil organic carbon; SOM, soil organic matter

* Corresponding author at: Department of Food Production, Faculty of Food and Agriculture, The University of the West Indies, St. Augustine, Trinidad and Tobago.

E-mail address: Ravindra.Ramnarine@sta.uwi.edu (R. Ramnarine).

1993; Hassink, 1995; Gregorich et al., 1996; Leifeld and Kögel-Knabner, 2005; Jacobs et al., 2010; Ramnarine et al., 2015). However, the HF pool includes the majority of the SOM (Christensen, 1992; 1996) and its importance in SOM dynamics may have been under estimated. There have also been relatively fewer studies on the chemical fractionation of the HF pool into its hydrolysable (HYF) and non-hydrolysable fractions (NHF). There is also a paucity of data on the HYF and NHF and this study aims to fill this knowledge gap.

The HF is composed of highly decomposed organic material and has a higher specific density than the LF as it is more closely bound to soil mineral surfaces (Gregorich et al., 1996). It also has a slower turnover rate and lower C concentration than the LF (Christensen, 1996). The HF can be separated into its HYF and NHF when subjected to chemical fractionation methods such as acid hydrolysis (Leavitt et al., 1996).

The HYF consists mainly of sugars, polysaccharides, amino acids and peptides that are formed during the breakdown of cellulose, hemicellulose and proteins from the crop residues (Schnitzer and Preston, 1983; Rovira and Vallejo, 2002). The NHF (recalcitrant) is comprised of stable aromatic and long chain compounds synthesized during microbial decomposition (Baldock et al., 1997; Paul et al., 2001) and inherent plant litter components which are highly resistant to degradation (e.g. lipids, cutin, suberin, tannin, and lignin), and charcoal (Rovira and Vallejo, 2002). Acid hydrolysis thus removes labile components and is useful in isolating a stable older soil C fraction (Leavitt et al., 1996; Paul, 2016). Variations in the acid hydrolysis procedure are mainly due to temperature and reflux time. Conditions range from 6 M HCl at 96 °C for 18 h (Plante et al., 2006) to 6 M HCl at 116 °C for 16 h (Collins et al., 2000; Paul et al., 2001; 2006).

Researchers have attributed three mechanisms responsible for the stabilization of organic matter in temperate soils (Voroney et al., 1989; Christensen, 1996; Six et al., 2002; Krull et al., 2003; von Lützow et al., 2006; Conceição et al., 2013). These include:

- (i) Biochemical recalcitrance of SOM to microbial (enzymatic) activity and non-enzymatic chemical reactions (Krull et al., 2003; von Lützow et al., 2006).
- (ii) Physical protection or occlusion of SOM to microbes by micro- and macroaggregates (Hassink et al., 1997). A recent study suggests that SOM stability is governed by accessibility to microbial degradation rather than recalcitrance (Dungait et al., 2012).
- (iii) Chemical stabilization due to interaction of SOM with mineral (silt and clay) surfaces (organo-mineral complexes) and formation of organo-metal complexes (Schrumpp et al., 2013). Stabilization processes determine the decomposition rates, mean residence time, and the quantity and quality of the substrate in soil carbon pools (Sollins et al., 1996).

Soil organic matter stability is considered not only as a function of molecular structure but also as an ecosystem property, arising from complex interactions between biotic and abiotic factors (Schmidt et al., 2011). SOM dynamics and modeling have conceptually divided the SOM fractions into compartments or pools of different C mineralisation rates, stability and mean residence time (Jenkinson and Rayner, 1977; Parton et al., 1987). As an example, the CENTURY model (Parton et al., 1987) shows SOM as part of three kinetic pools with varying turnover times. There is an 'active' SOM pool conceived as consisting mainly of the soil microbial biomass, microbial products, and root exudates (turnover time 1–5 y). There is a 'slow' pool consisting of physically protected or SOM more resistant to microbial degradation, with an intermediate turnover time of 20–40 y. There is also a 'passive' pool consisting of chemically recalcitrant SOM with a turnover time of 200–1500 y. The LF is included in the conceptually defined 'active' pool, the HYF is representative of the 'slow' pool, and the NHF is analogous to the 'passive' pool (Collins et al., 2000).

Determining the nature of individual soil carbon pools as affected by tillage practices, allows for a better understanding of soil organic matter

dynamics, and its contribution to greenhouse gas emissions from soil. Due to the complex and heterogeneous nature of SOM, many techniques have been developed to study the characteristics of the different SOM pools (Stevenson, 1994; von Lützow et al., 2006). This study however, focused on measurements of the HF and its sub-fractions (HYF and NHF). The effects of tillage practices on the LF organic matter was previously reported in Ramnarine et al. (2015).

The objective of this study was to investigate the effects of conventional (CT) and no-tillage (NT) systems on the quantity and $\delta^{13}\text{C}$ signature of the heavy (HF), hydrolysable (HYF), and non-hydrolysable (NHF) fractions of SOC in arable soils. It also aims to evaluate if there were significant changes in the above SOC fractions after six years of no-tillage, on soils that were previously under conventional tillage.

2. Material and methods

2.1. Study site

This study was carried out at the Elora Research Station (43°38' N, 80°25' W), southern Ontario, Canada. The soil is a Typic Hapludalf derived from calcareous glacial till parent material. The soil is a silt loam (sand–270 g kg⁻¹, silt–560 g kg⁻¹, clay–170 g kg⁻¹) with an average pH of 7.3, total N of 1.8 g kg⁻¹ and TOC of 21.2 g kg⁻¹ in the top 0–20 cm soil depth. The site receives a mean annual precipitation of 900 mm and average monthly temperature ranges from –7.1 °C in January to 19.8 °C in July.

The research site consisted of four large-scale plots (2 CT and 2 NT), each 100 m × 150 m (1.5 ha). All plots were initially managed under conventional tillage, but in October 1999, two of the plots were converted to no-tillage. In this study, conventional tillage refers to primary tillage in the fall with a moldboard plow to a depth of 15–20 cm, followed by secondary tillage in the spring with a cultivator. From 2000, the site was planted with either a C₃ crop (soybean [*Glycine max* (L.) Merr.] or winter wheat – *Triticum aestivum* L.) in annual rotation with a C₄ crop (corn – *Zea mays* L.). Corn was grown in 2000, 2003 and 2005, winter wheat in 2002, and soybean in 2001. Historical data show that corn was first grown in 1969 in rotation with winter wheat, soybean, alfalfa (*Medicago sativa* L.), and barley (*Hordeum vulgare* L.). The corn-soybean-wheat rotation is typical and predominant for southern and eastern Canada.

The "C₄-derived" carbon from corn is an important tool that can be used to analyse soil tillage effects. Due to isotopic fractionation in photosynthesis, the tissues of C₃ and C₄ plants have specific isotopic signatures. C₃ and C₄ plants have average $\delta^{13}\text{C}$ values of –27‰ and –13‰, respectively (Smith and Epstein, 1971). Thus, soils developed under C₃ or C₄ vegetation contain SOM with a $\delta^{13}\text{C}$ signature reflecting the source of their plant inputs. The ¹³C natural abundance technique utilizes the natural differences in $\delta^{13}\text{C}$ signature of C₃ and C₄ plants as a tracer during the decomposition of plant residues in the soil (Balesdent et al., 1987, 1990; Ehleringer, 1991; Angers et al., 1995). Because of this difference in isotopic signature, the fate of these different C substrates can be traced into the various SOC pools affected by tillage systems. Corn is also one of the major C₄ crops grown in the world and have been used in other tillage-related studies as a tracer for understanding SOC dynamics (Balesdent et al., 1990; Gregorich et al., 1995; Wanniarachchi et al., 1999; Allmaras et al., 2004; Murage et al., 2007; Mishra et al., 2010; Karlen et al., 2013; Rutkowska et al., 2018).

The control ¹³C site was a native northern hardwood forest soil located adjacent to our research site. With the exception of tillage management, agronomic practices were identical for all the plots.

2.2. Soil sampling and preparation

Soil sampling was carried out in October 2005 (after corn harvest) using a hydraulic core sampler (38 mm i.d.) to obtain the top 0–30 cm soil depth. Studies on the vertical distribution of SOC is normally

Download English Version:

<https://daneshyari.com/en/article/6773031>

Download Persian Version:

<https://daneshyari.com/article/6773031>

[Daneshyari.com](https://daneshyari.com)