Catena 163 (2018) 13–23

Contents lists available at ScienceDirect

Catena

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

How does no-till deliver carbon stabilization and saturation in highly weathered soils?

Clever Briedis[a,b], João Carlos de Moraes Sá[c,*], Rattan Lal[d], Florent Tivet[e], Julio Cezar Franchini[f], Ademir de Oliveira Ferreira[a], Daiani da Cruz Hartman[a], Rafael Schimiguel[g], Pamela Thaísa Bressan[g], Thiago Massao Inagaki[a], Jucimare Romaniw[a], Daniel Ruiz Potma Gonçalves[a]

[a] Graduate Program in Agronomy, State University of Ponta Grossa, Av. Carlos Cavalcanti 4748, 84030-900 Ponta Grossa, PR, Brazil
[b] Brazilian Agricultural Research Corporation, Agricultural Instrumentation Center, Rua XV de novembro 1452, 13560-970 São Carlos, SP, Brazil
[c] Department of Soil Science and Agricultural Engineering, State University of Ponta Grossa, Av. Carlos Cavalcanti 4748, 84030-900 Ponta Grossa, PR, Brazil
[d] School of Environment and Natural Resources, Carbon Management and Sequestration Center, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210, USA
[e] Centre de Coopération Internationale en Recherche Agronomique pour le Développement - CIRAD, U R AIDA/CSIA, Avenue Agropolis, 34398 Montpellier, France
[f] Brazilian Agricultural Research Corporation, Embrapa Soybean, Rodovia Carlos João Strass, PO Box 231, 86001-970 Londrina, PR, Brazil
[g] Undergraduate Program in Agronomy, State University of Ponta Grossa, Av. Carlos Cavalcanti 4748, Campus de Uvaranas, 84030-900 Ponta Grossa, PR, Brazil

ARTICLE INFO

Keywords:
Organo-mineral association
Labile C fraction
Mineral-associated C fraction
Physical C protection
Soil aggregation
Tropical soils

ABSTRACT

Research data on the mechanisms of C stabilization and saturation affected by soil management systems in highly weathered soils remain scarce. Past studies have revealed the fundamental role of aggregation promoted by soil conservation practices in the physical protection of C fractions. This study is based on the hypothesis that the increased physical C protection provides sufficient time to strengthen the interaction between C fractions and soil minerals, as being the pathway for C stabilization and accumulation in highly weathered soils. Thus, the objectives of this study were to: i) evaluate the C stocks including labile and mineral-associated C fractions in soil under conventional (CT), no-till (NT) and native vegetation (NV), and, ii) assess the C saturation level in different C fractions through the use of contrasting mathematical models of C accumulation. Soil samples were collected (0–100 cm depth) from agroecosystems established in tropical (Lucas do Rio Verde) and subtropical (Ponta Grossa and Londrina) regions of Brazil. The data show that all C fractions were affected by soil management systems. However, the impact was more pronounced with the labile C fractions than with the mineral-associated C fractions. The depletion of C stock of labile fractions in the 0–5 cm layer upon conversion of NV to CT accounted for 86, 89 and 72% of total C in soil of Ponta Grossa, Londrina and Lucas do Rio Verde, respectively. On the other hand, compared to CT, restoration of 89, 15 and 12% of these labile fractions was observed at these respective sites with adoption of NT. The mineral-associated C fraction was the best fit to a C saturation model at all sites. The estimated C saturation level for this fraction was 98.1, 60.2 and 39.1 g C kg^{-1} silt + clay at the Ponta Grossa, Londrina and Lucas do Rio Verde sites, respectively, which is still far from the current C content. Thus, the long-term use of NT might be the pathway for physical protection of the labile C fractions as well as strong organo-mineral associations. Together, these processes contribute to C stabilization and accumulation in highly weathered soils.

1. Introduction

The soil carbon (C) plays a key role in terrestrial ecosystems. It moderates numerous soil functions, such as increasing of aggregate stability (Carter, 1992), improving water infiltration and storage (Franzluebbers, 2002), enhancing nutrient supply and cation exchange capacity (Sá et al., 2009), and being a substrate and energy source for soil microbiota (Uchida et al., 2012). However, conversion of native

Abbreviations: NV, native vegetation; NT, no-till; CT, conventional tillage; cPOC, coarse particulate organic C; LPOC, light particulate organic C; iPOC, intra-microaggregate particulate organic C; MAOC, mineral-associated organic C; H-dMAOC, hydrolysable dispersed mineral-associated organic C; NH-dMAOC, non-hydrolysable dispersed mineral-associated organic C; H-μMAOC, hydrolysable microaggregate-derived mineral-associated organic C; NH-μMAOC, non-hydrolysable microaggregate-derived mineral-associated organic C; Σ-MAOC, mineral-associated organic C

* Corresponding author.
E-mail address: jcmsa@uepg.br (J.C. de Moraes Sá).

https://doi.org/10.1016/j.catena.2017.12.003
Received 18 May 2017; Received in revised form 2 December 2017; Accepted 5 December 2017

Table 1
Characteristics of the experimental sites.

Characteristic	Ponta Grossa site	Londrina site	Lucas do Rio Verde site
Research institute	Agronomic Institute of Paraná	Embrapa Soybean	Rio Verde Foundation
Coordinates	25°09′S and 50°09′W	23°11′S and 51°11′W	13°00′S and 55°58′W
Altitude (m)	865	620	380
Soil			
Brazilian Soil Classification System	Latossolo Vermelho distrófico	Latossolo Vermelho eutroférrico	Latossolo Vermelho-Amarelo
FAO classification	Ferralsol	Ferralsol	Ferralsol
USDA Soil Taxonomy	Oxisol, Rhodic Hapludox	Oxisol, Rhodic Eutrudox	Oxisol, Typic Haplustox
Parent material	Shale	Basalt	Shale and sandstone
Clay, silt, sand (g kg^{-1})	650, 240, 110	710, 280, 10	402, 106, 492
Clay type	Kaolinite, Hematite, Gibbsite	Kaolinite, Hematite, Gibbsite	Kaolinite, Gibbsite, Hematite
Climate			
Classification[a]	Subtropical, Cfb	Subtropical, Cfa	Tropical, Aw
Mean annual temperature (°C)[b]	18.5	20.7	25.7
Mean annual precipitation (mm)	1545	1622	1950
Mean annual potential evapotranspiration (mm)	900–1000	1250–1350	1300
Native vegetation	Herbaceous species, with shrubs and woody plants	Secondary sub-mountain vegetation and semi-deciduous forest	Cerrado, tropical savannah dominated by arboreal species

[a] Cfb – humid subtropical climate, summer and winter wet and warm summer; Cfa – humid subtropical climate, summer and winter wet and hot summer; Aw – tropical savanna climate, summer hot and very wet, winter hot and dry.

[b] Values of mean annual temperature, precipitation and potential evapotranspiration refer to the period of 1954–2001 for Ponta Grossa site, 1976–2012 for Londrina site and 1990–2009 for Lucas do Rio Verde site.

vegetation (NV) to agricultural systems based on conventional tillage (CT) leads to aggregate breakdown, exposing soil C content to microbial oxidation (Cambardella and Elliott, 1993) and decreasing the C stock (Sá et al., 2015). However, conversion of CT to a no-till (NT) system (reduction or elimination of tillage, protection of soil surface and retention of crop residues) improves soil structure, especially the formation of macroaggregates (Sundermeier et al., 2011; Tivet et al., 2013a). Improved macroaggregation in NT soils leads to effective C protection within macroaggregates, and ultimately results in larger soil C storage, thus enhancing the CO_2 sink capacity and increasing the climate mitigation potential of agricultural soils (Bayer et al., 2006; Dick, 1983; Sá et al., 2015; Sperow, 2016).

Soil C is stabilized by three principal mechanisms: i) biochemical recalcitrance of soil organic molecules; ii) physical protection by soil aggregates, and iii) chemical association among C and fine soil particles (e.g., silt, clay and Fe and Al oxides) (Sollins et al., 1996). These mechanisms protect soil C against microbial oxidation, resulting in different stabilization levels (von Lützow et al., 2007). Thus, analytical methods that integrate physical, chemical and biochemical fractions can improve the scientific knowledge of different mechanisms of C stabilization in soils, provide a better understanding of the impact of soil management practices on SOC stocks, and identify management strategies for enhancing soil C sequestration and mitigating anthropogenic CO_2 emission.

Chemical protection through interactions of C with soil minerals has been emphasized as the main mechanism controlling the maximum C sink capacity in soils (Chung et al., 2008; Stewart et al., 2008). This linkage can be explained by the high surface area of fine soil fractions, and the availability of these sorption sites could control C retention in soils (Hassink, 1997; Six et al., 2002). While studying arable and grassland soils from a wide range of temperate and tropical regions, Hassink (1997) observed significant differences in C content of bulk soils, but not in C associated with clay and silt particles. Hassink hypothesized that the fine soil particles have a finite capacity to store C by chemical protection. Subsequently, inspired by the Hassink's concept of the limit of C sorption, Six et al. (2002) proposed a fractionation scheme that isolate chemical, physical, biochemical, and non-protected C, in which C saturation model could be evaluated with measurable C pools.

Several studies were conducted to test the C saturation concept in soils containing 2:1 clay minerals (Chung et al., 2008; Gulde et al., 2008; Stewart et al., 2012; Stewart et al., 2008). However, a few studies on C saturation in long-term management systems have been conducted in tropical and subtropical environments where the dominant clay minerals in soils are Fe, Al oxides and 1:1 clay minerals (Reis et al., 2014; Santos et al., 2011). Moreover, only particulate organic carbon (POC) and mineral-associated organic C (MAOC) fractions, obtained through physical fractionation, have thus far been used to assess C saturation in these studies. Furthermore, integrating physical, chemical and density fractionation methods, as proposed by Six et al. (2002), provide a better understanding of the mechanisms which affect C sequestration and saturation level by management systems. In addition, identifying soils that are far from C saturation level create possibilities to increase C contents by management of agroecosystems with soils of a high C storage capacity.

The present study was designed to test the hypothesis that the increased physical C protection promoted by high aggregation in NT allows enough time to strengthen the C interactions with soil minerals as being the pathway for soil C stabilization and accumulation, and increasing the effective C saturation level in highly weathered soils. Thus, the objectives of this study were to: i) evaluate the C stocks and distribution among labile and mineral-associated C fractions under conventional tillage (CT), no-till (NT) and native vegetation (NV) and, ii) assess the C saturation level in different C fractions through the use of different mathematical models of C accumulation in Oxisols in some contrasting agro-ecosystems of Brazil.

2. Materials and methods

2.1. Experimental sites description

This study was conducted in conjunction with three on-going long-term tillage experiments, located in subtropical and tropical regions of Brazil and previously described by Briedis et al. (2016) and briefly presented at Table 1. These experiments were conducted at sites in: i) Ponta Grossa in Paraná State, representing the subtropical environment in southern Brazil, ii) Londrina also in Paraná State representing the transition zone between the subtropical and tropical environment, and iii) Lucas do Rio Verde in Mato Grosso State representing a tropical environment in Central Brazil (Fig. 1). Geographic location and characteristics related to soil and climate of these experimental sites are presented in Table 1.