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Soil type and texture impacts on soil organic carbon storage in a sub-tropical agro-ecosystem

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ABSTRACT

Soil organic carbon (C) plays a fundamental role in tropical and subtropical soil fertility, agronomic productivity, and soil health. As a tool for understand ecosystems dynamics, mathematical models such as Century have been used to assess soil's capacity to store C in different environments. However, as Century was initially developed for temperate ecosystems, several authors have hypothesized that C storage may be underestimated by Century in Oxisols. We tested the hypothesis that Century model can be parameterized for tropical soils and used to reliably estimate soil organic carbon (SOC) storage. The aim of this study was to investigate SOC storage under two soil types and three textural classes and quantify the sources and magnitude of uncertainty using the Century model. The simulation for SOC storage was efficient and the mean residue was 10 Mg C ha^{-1} (13%) for n = 91. However, a different simulation bias was observed for soil with <600 g kg^{-1} of clay was 16.3 Mg C ha^{-1} (18%) for n = 30, and at >600 g kg^{-1} of clay, was 4 Mg C ha^{-1} (5%) for n = 50, respectively. The results suggest a non-linear effect of clay and silt contents on C storage in Oxisols. All types of soil contain nearly 70% of Fe and Al oxides in the clay fraction and a regression analysis showed an increase in model bias with increase in oxides content. Consequently, inclusion of mineralogical control of SOC stabilization by Fe and Al (hydro) oxides may improve results of Century model simulations in soils with high oxides contents.

1. Introduction

Soil organic carbon (SOC) storage at a location is controlled by various environmental factors including climate, vegetation, relief, parent material, soil texture, and land use (Jenny, 1994; Stevenson, 1999). Highly weathered soils are characterized by low pH, high exchangeable Al, low base saturation and phosphorus content (Caires et al., 2006; Fox, 1980; Sá et al., 2009). Overall, increasing C storage of these soils has been reported as the key to improve soil fertility, restoring soil resilience, enhancing soil quality, and sustaining agronomic productivity (Burle et al., 1997; Lal, 2015; Sá and Lal, 2009; Sá et al., 2014).

Ecosystem models have been used to study factors that drive C storage in soils and generate scenarios to study SOC dynamics at large spatial and temporal scales. Although several models have been applied in agro-ecosystems to assess SOC storage, Century is one of the most adapted model for diverse agro-ecosystems (Parton et al., 1987; Parton et al., 1988). The model was initially developed to simulate the C and nitrogen (N) dynamics of North American prairies soils in temperate zones (Parton et al., 1987; Parton et al., 1988). Century has been applied to study different soil management impacts such as fertilizer application (Cong et al., 2014), the effect of fire (Richards et al., 2011), soil plowing (Álvaro-Fuentes et al., 2009), organic manure application (Smith et al., 1997), irrigation (Liu et al., 2011), and grazing (Kelly et al., 1997) on SOC across a variety of agro-ecosystems.

Century model simulations have been widely validated in temperate agro-ecosystems (Cong et al., 2014; Kelly et al., 1997; Smith et al., 1997). The authors reported that the Century model successfully predicted C and N dynamics in various conditions but needed improvement to predict C dynamics in specific situations such as forested systems. In tropical ecosystems, Century has been used to study the SOC dynamics in Amazon Basin (Cerri et al., 2007; Silver et al., 2000), authors reported that Century was able to simulate SOC dynamics when information such as crop productivity was available, however

Abbreviations: CD, coefficient of determination; CS, crop sequence; EF, modeling efficiency; InAn, Inceptisol Anthrept; InDy, Inceptisol Dystrudept; M, average residue; RE, relative error; RH, Rhodic Hapludox; RMSE, root mean square error; SOC, soil organic carbon; SOM, soil organic matter; SSA, specific surface area; TH, Typic Hapludox; TN, total nitrogen.

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the model underestimated SOC storage specially in sandy soils. Under sugar cane plantations, and forested areas (Galdos et al., 2009a; Galdos et al., 2009b; Lima et al., 2011), authors reported higher bias in simulation results in soils with lower C contents. In southern Brazil, Tornquist et al. (2009a) reported a reasonable estimation of SOC storage under no-till (NT) cropping systems. They attributed inconsistencies between observed and simulated values to model treatment of clay mineralogy.

Several studies have demonstrated that the mineralogy of clay and silt fraction plays an important role in C stabilization (Bruun et al., 2010; Kaiser and Guggenberger, 2003; Saidy et al., 2013; Torn et al., 1997). The association of clay and silt particles with soil C, build-up clay-humic complexes that play a fundamental role in C protection against microbial oxidation (Six et al., 2002). Some authors reported that the inclusion of soil types (Bruun et al., 2010) and clay mineralogy (i.e. Fe and Al (hydro) oxides) (Bruun et al., 2010; Leite and Mendonça, 2003) can reduce the simulation bias of ecosystem models.

To simulate the soil texture effect on C storage, the Century model assumes that the decomposition of soil organic matter (SOM) by microbial biomass and the stabilization of SOC in soils have a linear relationship with clay and silt contents, and the mineralogy of the clay and silt fractions does not affect SOC stabilization. These assumptions have been made based on studies conducted in soils with 2:1 (i.e. isomorphic substitution permanent negative charges) clay mineralogy in the USA (Leite and Mendonça, 2003). For simplification, the soil minerals effect on SOC stabilization is considered as a function of the mineral specific surface area (SSA).

We hypothesized that a reliable estimate of SOC storage can be made by parameterizing the Century model for tropical soils. Additionally, we assumed a non-linear relationship of silt + clay minerals on soil C stabilization. Thus, the aims of this study were to: i) Calibrate the Century model to study the impact of soil types and clay mineralogy on SOC storage in an on-site farm managed for 30 years under no-till; ii) validate the results with measured SOC stocks; iii) quantify the magnitude and sources of uncertainties; and iv) test whether Century equations that consider the effect of silt + clay content on SOC storage (largely parameterized for temperate ecosystems) are able to simulate C storage in tropical and subtropical soils with high content of Fe and Al (hydro) oxides.

2. Material and methods

2.1. Study area

This study was conducted at Paiquerê Farm, located at Piraí do Sul city, State of Paraná, southern Brazil (24°S 20′ 20″ and 50° W 07′ 31″, Fig. 1). This site was chosen because the entire farm adopted no-till over 30 years, with high crop yields and high C input to soil through crop residues decomposition. The farm is managed in 24 plots divided in 3 crop sequences and each crop sequence comprises 33% of the farm's land area. In the winter, 2 crop sequences occupying - 66% of the area, were being cultivated with wheat (*Triticum aestivium* L.) and other crop sequence occupying 33%, with black oat (*Avena sativa* L.). In the summer, soybean (*Glycine max* L.) is cultivated after wheat and maize (*Zea mays* L.) after black oat. The crop sequence (CS) comprised by is wheat/soybean, hereafter is designated as CS1 and occupy 33% of the farm surface area; wheat/soybean for the second consecutive year (occupying 33%) is designated as CS2, and oat/maize, is designated as CS3 which also represents 33% of the farm surface area. At each year the CS is rotating from CS1 to CS2, CS2 to CS3 and CS3 to CS1.

The relief of the farm has slightly undulated landscape with slopes ranging from 3 to 10%. The soil types identified in the farm are: 1) Latossolo Vermelho, Brazillian Classification (EMBRAPA, 2013) and equivalent to Rodhic Hapludox in USDA, Soil Taxonomy classification (Soil Survey, 2014); 2) Latossolo Vermelho Amarelo, Brazillian Classification (EMBRAPA, 2013) and equivalent to Typic Hapludox (Soil Taxonomy, Soil Survey, 2014); 3) Cambissolo Húmico, Brazillian Classification (EMBRAPA, 2013) and equivalent to Inceptisol Anthrept (Soil Taxonomy, Soil Survey, 2014). This soil originally had humic characteristics, but after cultivation, the SOM was stabilized at lower contents; and 4) Cambissolo Háplico, Brazillian Classification (EMBRAPA, 2013) and equivalent to Inceptisol Dystrudept (Soil Taxonomy, Soil Survey, 2014) (Fig. 1).

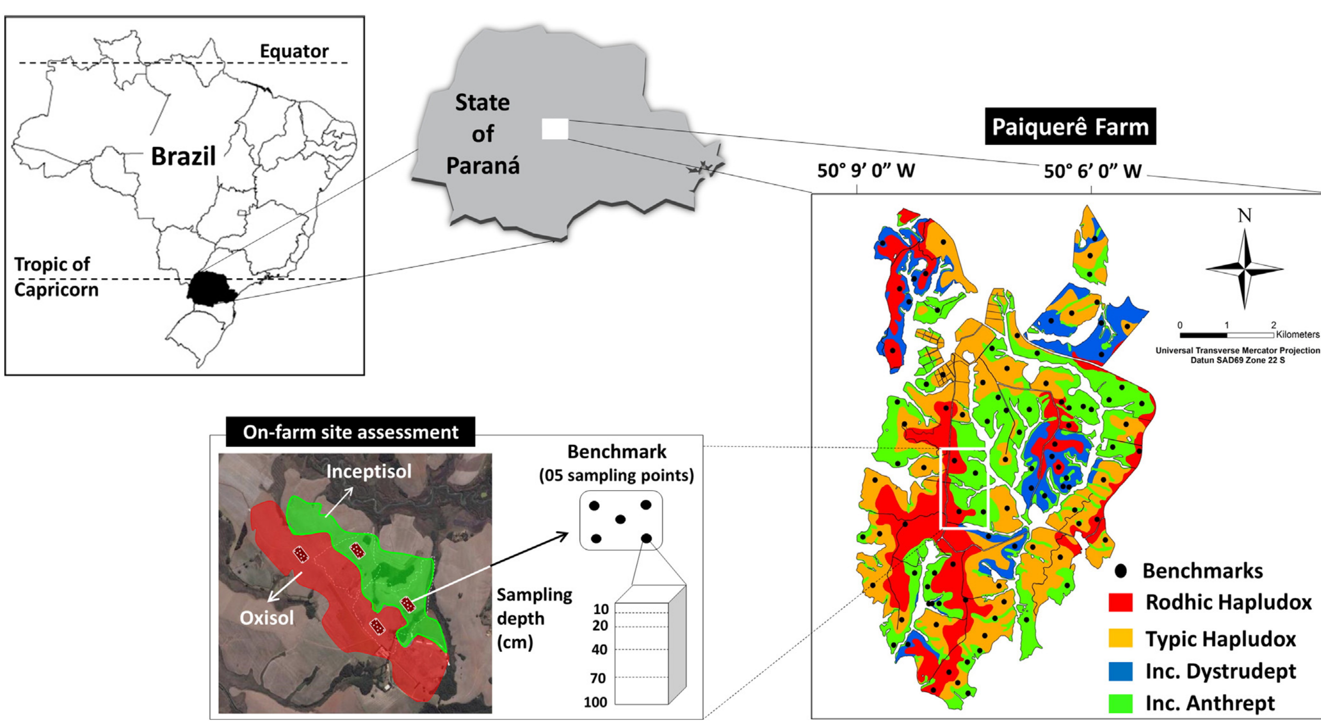

Fig. 1. Localization of the study area - Paiquerê Farm, benchmarks locals and representative scheme of a benchmark.