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Soil parent material, texture and oxide contents have little effect on soil organic carbon retention in tropical highlands

Marla A. Araujo[a,c], Yuri L. Zinn[b,*], Rattan Lal[c]

[a] Depto. de Agronomia, Centro de Ciências Agrárias, Universidade Estadual de Londrina, Campus Universitário, Londrina, PR 86057 970, Brazil
[b] Depto. de Ciência do Solo, Universidade Federal de Lavras, Lavras, MG 37200 000, Brazil
[c] Carbon Management and Sequestration Center, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210-1085, USA

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ABSTRACT

In tropical humid conditions, soil organic carbon (SOC) concentrations have been reported to be proportional to clay, clay + silt and Fe/Al oxide contents. Typically, soil texture and mineralogy are strongly dependent on soil parent materials, but it is not known if SOC retention would also be affected by soil parent material. Such relationship, if established, could be useful to estimate regional SOC stocks, since geological maps are more numerous and often more accurate than soil maps. The objective of this study was to assess the effect of parent material, texture, and oxide content on SOC contents in tropical highlands. Thus, samples to 1-m depth were obtained for seven soils derived from quartzite, sericite-schist, itabirite, serpentinite, limestone, gneiss and phyllite. All soils formed under similar climate and native forest, and were located on the midslope position. Despite wide variations in soil texture and mineralogy, there were no valid correlations between SOC and clay, clay + silt or Fe/Al oxide concentrations. Similarly, SOC stocks did not differ significantly when computed for 0–20, 0–40 and 0–100 cm layers, and in all soils most SOC was associated with the clay fraction. We propose that such absence of effects of soil parent material, texture and oxide contents on SOC retention can be due to the overriding effect of altitudes of 900–1100 m a.s.l., which resulted in higher SOC stocks because of lower mean annual temperatures. These trends are in contrast to those reported for tropical lowlands where the textural and mineralogical controls of SOC retention were first described. Therefore, soils on tropical highlands (> 900 m) are likely to present similarly high SOC stocks, whereas soil parent material, by means of soil texture, mineralogy and oxide contents would affect SOC retention only at lower altitudes.

1. Introduction

Soil organic carbon (SOC) forms a continuum ranging from near intact plant materials to highly oxidized carbon forms such as carboxyl groups (Lehmann and Kleber, 2015). Each of these forms interacts differently with the various mineral components in soils, resulting not only in disparate proportions between the different carbon forms, but also in large variations in total SOC concentrations and stocks. The retention of SOC is controlled by the five state factors of soil formation, namely climate, organisms, parent material, topography, and pedogenic time (Quideau, 2006; Johnson et al., 2014). The external controls exerted by climate, topography and organisms, including agricultural practices, have been studied for decades (e.g., Jenny, 1941), and the effect of pedogenetic time has been described for some recent soils (e.g., Dümig et al., 2011). However, it has been demonstrated for different climatic regions that some soil properties, more specifically texture and clay mineralogy, exert an internal control on SOC retention (Zinn et al.,

2007; Fritzsons et al., 2008; Barré et al., 2014; Herold et al., 2014; Silva et al., 2016). The content of fine particles (clay and fine silt) is proportional to soil specific surface area, and thus plays a direct control on the amount of colloidal material or soluble SOC compounds that can be sorbed to mineral surfaces (Kaiser and Guggenberger, 2003; Zinn et al., 2007). In addition, clay mineralogy also affects SOC retention, as the various minerals present in this particle size fraction have different surface area and charge (Barré et al., 2014). Furthermore, Fe and Al oxides, hydroxides and sesquioxides (from now on, referred to as *oxides* for simplicity) show apparently more affinity than kaolinite and other phyllosilicates for sorption of colloidal SOC, across a range of oxide crystallinity, oxide species, soil types and climatic zones (Zinn et al., 2007; Moni et al., 2010; Dümig et al., 2011; Saidy et al., 2013).

Soil texture and mineralogy, even in highly weathered soils of the humid tropics, are strongly influenced by soil parent material. Jenny (1941) stressed the difficulty in studying the effect of parent materials on soil properties since it cannot be effectively expressed as a number,

as is the case for climate, topography and time. However, some authors use the total silica content in rocks as a proxy. Under a warm, humid climate, sandy soils are formed preferentially from siliceous rocks such as sandstone and quartzite (Catoni et al., 2016). By the same token, crystalline rocks containing quartz (e.g., granites and gneisses) will produce soils of coarser texture than basalt, keeping other soil formation factors constant (Spain, 1990; Gray et al., 2015). This trend can affect SOC retention, and in fact silica contents in rocks have been shown to be inversely correlated with SOC concentrations in tropical soils developed from them (Gray et al., 2016). In the humid tropics, parent material also influences clay mineralogy, since rocks richer in silica (e.g., gneiss, quartzite, phyllite, schist) tend to weather into soils where kaolinite and 2:1 minerals are predominant, in contrast to the gibbsitic or hematitic soils formed from silica-poor rocks such as gabbro, serpentinite and limestone (Araujo et al., 2014). Despite these influences, there is limited information about the specific role of soil parent materials on SOC contents and stocks (e.g., Catoni et al., 2016; Gray et al., 2016; Barré et al., 2017), especially in tropical regions. An exception is the recent paper by Silva et al. (2016), who demonstrated that granitic rocks containing more mafic minerals resulted in higher SOC stocks, due to higher soil clay contents and fertility, across a humid-semiarid climate gradient in Brazil. The authors concluded that soil parent material is a stronger control on SOC retention than climate, under those environmental conditions. If proven elsewhere, such effect of soil parent material on SOC stocks would be useful to strengthen understanding of C geochemistry, because geological maps are typically more available and accurate than soil maps in many parts of the world.

This research was aimed to study the influence of soil parent material on SOC retention in the tropical forest biome near Lavras, Brazil, by means of sampling seven soils formed from seven different rocks but under the same climate and vegetation and with similar topography, and testing mathematical relations between SOC concentrations and physical or geochemical characterization data. The hypothesis tested in this study was that soil parent material indirectly affects SOC retention, by means of textural and mineralogical controls.

2. Material and methods

Based on a 1:100,000 geological map and several field surveys, we selected seven soils formed from seven different parent materials: quartzite, sericite-schist, itabirite, serpentinite, metalimestone, gneiss and phyllite. All sites were located on a 20-km radius near Lavras, Minas Gerais, Brazil, under native tropical semideciduous forests and on the midslope position of the landscape. Mean annual temperature and precipitation are respectively 19.3 °C and 1530 mm, with wet summers and dry winters. According to the Köppen classification, the regional climate is temperate highland tropical with dry winters (Cwb). Altitudes varied from 889 m (meta-limestone) to 1064 m a.s.l. (quartzite and sericite-schist). Table 1 summarizes the classification and characterization of each soil, whereas Fig. 1 shows the sampling locations. A full mineralogical and geochemical description of parent materials and soils, including rock petrography and X-ray diffraction charts, is available in Araujo et al. (2014).

INSERT FIG. 1, Table 1 HERE.

In all soils, the litter layer was relatively sparse (< 3 cm thickness) and was removed prior to soil sampling. Pits were then dug in three random replicates to a minimal depth of 1 m. Bulk and undisturbed soil samples were obtained from the 0–5, 5–10, 10–20, 30–40, 50–60 and 90–100 cm depth intervals. Additionally, undisturbed soil samples were obtained from the top 10 cm in Kubiena boxes, aiming to provide a soil micromorphological perspective. Disturbed soil samples were air dried and sieved < 2 mm, and, when present, gravels were separated and weighed. Analyses of all soil properties were conducted without any pretreatment to remove carbonates, Fe oxides or organic matter.

Undisturbed soil bulk density (ρ_b) was determined by the core method (Blake and Hartge, 1986a), whereas particle density was determined in samples < 2 mm with a pycnometer (Blake and Hartge, 1986b), and total porosity was calculated with these data. Soil particle-size distribution was determined by the pipet method (Gee and Bauder, 1986), applying dispersion with NaOH 1 M and shaking for 16 h. Efficient dispersion in all soils was assessed by examining sand and silt separates with common and polarizing microscopes, as well as X-ray diffraction (Araujo et al., 2014), which showed that those fractions were chiefly composed by quartz, and when Fe-oxides were present, they were primary grains inherited from the rock (e.g., opaque grains in Fig. 5c,d).

The acid ammonium oxalate extraction for soil amorphous Fe and Al oxides was carried out using 0.2 M ammonium oxalate adjusted to pH = 3.0 with 0.2 M oxalic acid (Kämpf and Schwertmann, 1982). Total Fe-oxides were extracted from the soil samples using a buffer of citrate and sodium bicarbonate, immersion in a water bath at 80 °C and addition of sodium dithionite ($Na_2S_2O_4$) followed by centrifugation at 1800 rpm for five minutes, repeated until the soil sample had its color changed to light gray (Mehra and Jackson, 1958). In the extracts, Fe and Al were determined by atomic absorption using a Varian SpectrAA spectrophotometer.

Total SOC was determined in the bulk soil < 2 mm by the dry combustion method at 900 °C in a Vario MAX CN apparatus (Elemental Americas, Hanau, Germany) (Nelson and Sommers, 1996). Similarly, SOC as also determined in sand, silt (0–50 μm) and clay fractions obtained by dispersion in NaOH 1 mol L^{-1}, sieving to collect the sand and successive siphonations to separate clays from the silt, as described by Zinn et al. (2007). Efficiency of dispersion was assessed by examining silt separates in a petrographic microscope, which showed that in all soils it was composed of quartz with just traces of undispersed aggregates, with the exception of the Plinthic Acrudox, where the silt is composed by the same hematite that composes the sand and clay fractions. The results were corrected in residual moisture by oven-drying at 105 °C. Standardized SOC stocks were calculated for the 0–20 cm, 0–40 cm and 0–100 cm layers, using the following equation:

$$SOC_{stock} = \sum volume \times \rho_b \times \frac{SOC_{content}}{100},$$

where SOC_{stock} in Mg ha^{-1}; n is the number of soil layers; *volume* is the total volume of soil per depth in m^3 ha^{-1}; ρ_b is the soil bulk density in Mg m^{-3}; $SOC_{content}$ in %, correcting for the gravel contents assuming that these particles had a negligible SOC concentration.

The experimental design is completely randomized, where each soil stands for one treatment. By using JMP 5.1 software (SAS Inst., Cary, NC), SOC stocks were subjected to Bartlett's test ($P < 0.05$) in order to verify the homogeneity of the variance among treatments. Then, the data were subjected to analysis of variance ($P < 0.05$ and $P < 0.01$). According to the significance, the means were compared by the Tukey test ($P < 0.05$). Linear and logarithmic regression analyses were performed to identify relationships between SOC content and other soil factors.

The soil samples inside the Kubiena boxes were air-dried during four months, then oven-dried for 24 h at 40, 60 and 105 °C, and then impregnated with epoxy resin under vacuum conditions for three days. Resin hardening and curing were achieved by heating at 100 °C for 3 h, followed by 5 h at 140 °C. The hardened resin blocks were cut in a motorized saw, polished, glued with heated, de-aerated Hillquist® epoxy resin on glass slides, then lapped to a thickness of 30 μm using kerosene and abrasive powder of aluminum oxide (25 μm). Finally, the micromorphologic description of the slides was carried out in a petrographic microscope Zeiss®, according to Stoops (2003).