



Assessing labile organic carbon in soils undergoing land use change in Brazil: A comparison of approaches



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ABSTRACT

The labile organic C (LC) and C management index (CMI) may be useful indicators of alterations of soil organic matter (SOM) in areas undergoing land use change (LUC) for biofuels production. However, there is no consensus on which methodology is best suited for quantifying LC and CMI. The main goal of this study was to assess alterations on LC contents and CMI values in sites undergoing the LUC native vegetation (NV)-pasture (PA)-sugarcane (SC) in south-central Brazil, and evaluated the sensitivity of different methods commonly used to assess LC and CMI, in order to select a best-suited method to quantify these indicators in tropical regions. The conversion NV-PA decreased the LC and CMI, whilst the conversion of PA-SC tended to increase the CMI. Accordingly, cropping sugarcane in areas previously used as pastures, as currently has been observed in Brazil, enhance SOM quality. The methodology used to quantify the LC and the CMI is critical to infer about LUC effects. Both methods proposed by Blair et al. (1995) and Diekow et al. (2005) were highly sensitive to the conversions evaluated in this research. However, Diekow et al. (2005) is the most suitable method to estimate the LC and CMI in sites undergoing LUC in Brazil, since the approach of Blair et al. (1995) notably overestimates these SOM quality indicators. We reiterate that the SOM changes are well expressed by the total soil organic C in areas undergoing LUC and, integrated approaches, such as the CMI, are quite suitable to evaluate the effects of LUC on SOM.

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1. Introduction

Soil organic matter (SOM) is a key component of terrestrial ecosystems and its abundance and composition have important effects on processes that occur in the system (Batjes, 1996). Besides being a source for increased biogenic CO₂ emissions, decreases in the quantity and quality of SOM can reduce agricultural productivity and food security, particularly in tropical regions (Lal, 2006). Recent insights on SOM turnover assert that virtually all organic compounds can be decomposed in soil, regardless of intrinsic molecular “recalcitrance” (Lehmann and Kleber, 2015). However, organic compounds with more simple structures, such as polysaccharides, lipids and proteins, are more prone to decomposition and

to stimulate biological activity when compared to other organic compounds comprising SOM (Wang et al., 2015).

Soil labile organic carbon (LC) can be defined as the SOM fraction which fuels the soil food web and therefore greatly influences nutrient cycles and many biologically related soil properties (Zak et al., 1994). There are several techniques for LC assessment, which include procedures based on soil biological activity, chemical oxidation and physical fractionation (von Lützw et al., 2007). Chemical-based methods, such as the use of potassium permanganate (KMnO₄) (Blair et al., 1995; Lefroy et al., 1993) and potassium dichromate (K₂Cr₂O₇) (Chan et al., 2001), have been proposed. These mild oxidizing reagents are assumed to mimic the enzymatic breakdown of SOM, which is also largely an oxidative process. Physical fractionation of SOM has been used for LC assessment, generally based on particle size and degree of association with the soil mineral fraction, as a measure of its bioavailability (Cambardella and Elliott, 1992; Diekow et al., 2005).

To evaluate the effects of management and land use on LC and total soil organic carbon (SOC) in an integrated approach, Blair

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et al. (1995) proposed the carbon management index (CMI). Subsequently, the CMI has been extensively used as an indicator of soil quality in response to soil management changes (Benbi et al., 2015; Vieira et al., 2007). The CMI expresses the soil quality in terms of increments in the SOC and in the proportion of LC compared to a reference soil, generally under native vegetation, which arbitrarily has a CMI of 100.

In Brazil, the largest producer of sugarcane ethanol of the world, the area cropped to sugarcane is expanding and the most common type of land use change (LUC) is the conversion of pastures into sugarcane fields (Dias et al., 2016; Lapola et al., 2014). LUC induces modifications on SOM, which is one of the main source of uncertainty in life cycle assessments of biofuels (Qin et al., 2016). Accordingly, the LC and the CMI can be useful indicators of alterations of SOM in sites under LUC, and allow possible inferences on the sustainability of sugarcane cropping in areas previously under pastures. However, there is no consensus on which of the methods mentioned above is best suited for quantifying LC and calculating CMI in land use conversions. Thus, this study aimed to assess alterations on LC contents and CMI values in sites undergoing the LUC native vegetation-pasture-sugarcane in south-central Brazil. Moreover, we evaluated the sensitivity of different methods commonly used to assess LC and CMI, in order to select a best-suited method to quantify these indicators in tropical regions.

2. Material and methods

2.1. Description of study sites

The study sites were located in three strategic and representative locations in the south-central, main sugarcane-producing region of Brazil. The climate at all three sites has rainfall concentrated in the spring and summer (October–April), while the dry season is in the autumn and winter (May–September). The soils are typical of the Brazilian tropical region, well drained and highly weathered, with a predominance of 1:1 clay mineral kaolinite, Fe oxides (goethite and hematite), and Al oxide (gibbsite) in the clay-size fraction. The soil classification (USDA, 2014), as well as the Köppen climate classification, are presented in Table 1. For details about geology and soil characterization, see Cherubin et al. (2015).

2.2. Land use change sequence and soil sampling

In this study, we used a chronosequence approach (Bernoux et al., 2006) because there are no long-term experiments that represent this LUC sequence in the studied region. To do so, each of the three studied sites (Lat.17S; Lat.21S; Lat.23S) comprised three land uses: native vegetation (NV), pasture (PA) and sugarcane (SC), representing one of the most common LUC sequence in the south-central region of Brazil. In each site, the three land uses are located in adjacent plots, minimizing the effects of climatic, topographic and soil variations. The general description of each site is shown in Table 1. Each land use was composed of a sampling grid with nine points, 50 m apart (~4 ha). The samples were collected using an auger, at seven depths: 0–0.1, 0.1–0.2, 0.2–0.3, 0.3–0.5, 0.5–0.7, 0.7–0.9, 0.9–1.0 m. For LC analysis, the three samples on the diagonal position of the sampling grid were chosen at 0–0.1 m, 0.2–0.3 m, 0.3–0.5 and 0.9–1.0 m depth (Fig. 1). Based on our previous studies (Oliveira et al., 2016a; Oliveira et al., 2016b), these sampling points and depths are considered to fully represent the main effects of LUC on SOM in these sites in a cost-effective way. For more details about LUC sequence and sampling, see Cherubin et al. (2015) and Oliveira et al. (2016b).

2.3. Methods to quantify the LC

Although the principles of chemical oxidation and physical fractionation as an indicator of biological lability are completely different, both approaches have been promoted for measurement of the LC fraction of SOM. Accordingly, we assessed LC using five different approaches. For all analyses, soil samples were first air dried, mixed and passed through a 2 mm sieve. Soil subsamples were ground and sieved through a 100 mesh (0.149 mm) sieve.

Method of Blair et al. (1995) (BI): Briefly, about 1 g of soil (<0.149 mm) was weighed into plastic screw top centrifuge tubes and 25 mL 333 mL⁻¹ KMnO₄ were added to each tube. All tubes were tightly sealed, tumbled for 1 h (60 rpm) and centrifuged for 5 min at 2000 rpm. The supernatant was subsequently diluted with deionized water (1:250), and the KMnO₄ consumed was determined by colorimetry (565 nm). The amount of LC was calculated from the change in the concentration of KMnO₄ when compared with the blank samples.

Method of Shang and Tiessen (1997) (Sg): same described above (Blair et al., 1995), with exception of the KMnO₄ concentration, which was 10 times lower, in this case 33 mL⁻¹.

Method of Chan et al. (2001) (Cn): About 0.5 g of soil (<0.149 mm) was weighed into an Erlenmeyer flask and 10 mL of 0.167 mol L⁻¹ K₂Cr₂O₇ was added, followed by 5 mL of concentrated sulfuric acid. After the reaction (30 min), the excess dichromate was determined by titrating against 0.5 mol L⁻¹ FeSO₄. The amount of dichromate consumed by the soil was used to calculate the amount of LC based on the theoretical value of 1.0 mL of 0.167 mol L⁻¹ K₂Cr₂O₇ oxidizing 3 mg of SOC.

Method Alternative (Al): We tested an alternative methodology using an adaptation of Chan et al. (2001), which we added only 2.5 mL of sulfuric acid instead of 5.0 mL.

Method of Diekow et al. (2005) (DK): Based on physical fractionation of SOM (Cambardella and Elliott, 1992; Christensen, 1992), Diekow et al. (2005) suggested the use of the particulate organic carbon (POC) as a measurement of LC. In our study, about 20 g of soil (<2 mm) were weighed into a 100 mL flask, adding 70 mL of deionized water. The sample was then treated with ultrasound for 15 min and transferred to a 200 mesh (0.074 mm) sieve, where it was washed with deionized water. The fraction retained on the 200 mesh was transferred to a crucible, where the organic and the mineral fractions were separated by flotation in deionized water (Christensen, 1992). The C content in the light coarse fraction of POC was determined by dry combustion method in an elemental analyzer and assumed to encompass the LC. Despite based on the suggestions of Diekow et al. (2005), our research employed a different approach to physical fractionation of SOM (Christensen, 1992).

2.4. Carbon management index and sensitivity index assessment

The C management index (CMI) originally proposed by (Blair et al., 1995) was calculated assuming LC values determined from each of the above methodologies. The non-labile organic carbon (NLC), equivalent to the residual SOC not quantified as LC, was estimated by difference (NLC = SOC – LC). SOC was assessed by dry combustion method in an elemental analyzer. The CMI was calculated using the follow Eq. (1):

$$\text{CMI} = \text{CPI} \times \text{LI} \times 100 \quad (1)$$

where, CPI (carbon pool index) = total soil organic C of a land use (pasture or sugarcane) (g kg⁻¹)/total soil organic C of native vegetation (g kg⁻¹); LI (lability index) = soil C lability of a land use (pasture or sugarcane)/soil C lability of native vegetation; lability = labile C (g kg⁻¹)/non-labile C (g kg⁻¹).

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