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Carbon management index based on physical fractionation of soil organic matter in an Acrisol under long-term no-till cropping systems

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Abstract

The carbon management index (CMI) is derived from the total soil organic C pool and C lability and is useful to evaluate the capacity of management systems to promote soil quality. However, the CMI has not been commonly used for this purpose, possible due to some limitations of the 333 mM $KMnO_4$-chemical oxidation method conventionally employed to determine the labile C fraction. We hypothesized, however, that physical fractionation of organic matter is an alternative approach to determine the labile C. The objectives of this study were (i) to assess the physical fractionation with density (NaI 1.8 Mg m^{-3}) and particle-size separation (53 μm mesh) as alternative methods to the $KMnO_4$-chemical oxidation (60 and 333 mM) in determining the labile C and thus the CMI, and (ii) to evaluate the capacity of long-term (19 years) no-till cropping systems (oat/maize: O/M, oat + vetch/maize: O + V/M, oat + vetch/maize + cowpea: O + V/M + C, and pigeon pea + maize: P + M) and N fertilization (0 and 180 kg N ha^{-1}) to promote the soil quality of a Southern Brazilian Acrisol, using the CMI as the main assessment parameter. Soil samples were collected from 0 to 12.5 cm layer, and the soil of an adjacent native grassland was taken as reference. The mean annual C input of the cropping systems varied from 3.4 to 6.0 Mg ha^{-1} and the highest amounts occurred in legume-based cropping systems and N fertilized treatments. The C pool index was positively related to the annual C input ($r^2 = 0.93$, $P < 0.002$). The labile C determined by density (4.4–10.4% of C pool) and particle-size separation (9.5–17.7% of C pool) had a close relationship ($r = 0.60$ and 0.85, respectively) with the labile C determined using 60 mM $KMnO_4$ (7.3–10.5% of C pool). The labile C resulting from the three methods was related to the annual C input imparted by the cropping systems ($r^2 = 0.67$–0.88), reinforcing the possibility of using physical fractionation as an alternative approach to determine labile C. In contrast, the chemical method using 333 mM $KMnO_4$ was not sensitive to different cropping systems and resulted in too high percentage of labile C, varying from 16.8 to 35.2% of the C pool. The CMI based on physical fractionation was a sensitive tool for assessing the capacity of management systems to promote soil quality, as evidenced by its close correlation ($r = 0.88$, at average) with soil physical, chemical, and biological attributes. The introduction of winter (vetch) and, especially, summer legume cover crops (cowpea and pigeon pea), or application of fertilizer-N, improved the capacity of the management system into promote soil quality in this subtropical Acrisol.

Keywords: Soil C pool; Lability; C management index; No-tillage; Cropping systems

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1. Introduction

The soil organic C pool and the C lability directly influence soil physical, chemical and biological attributes as well as the self-organization capacity of soils (Addiscott, 1995; Blair and Crocker, 2000; Vezzani, 2001). Therefore, the integration of both soil organic C pool and C lability into the C management index (CMI), originally proposed by Blair et al. (1995), can provide a useful parameter to assess the capacity of management systems into promote soil quality (Blair et al., 1995, 2006a,b; Diekow et al., 2005a). In spite of the existence of a large number of long-term experiments that can provide a lot of relevant data pertaining to soil management, however, few are the studies that integrate the total soil organic C pool and the C lability into the CMI as a way to assess the capacity of management systems into promote soil quality.

The C lability is the ratio of labile C to non-labile C. Blair et al. (1995) proposed labile C as oxidizable in 333 mM $KMnO_4$ solution. This concentration, however, is often referred as too strong and not sensitive to detect changes in C lability among some tropical soils, and thus lower concentrations have been proposed (Shang and Tiessen, 1997; Weil et al., 2003). Besides the concentration, other methodological aspects, like reaction time, soil sample moisture (Shang and Tiessen, 1997; Weil et al., 2003) and potential of $KMnO_4$ decomposition due to its exposure to light or reaction with MnO_2 (Blair et al., 1995), are still to be better clarified when using $KMnO_4$ to determine the labile C. These may be the main reasons why the CMI, which depends on C lability, has not been commonly adopted in soil quality assessments.

Taking these constraints of the chemical oxidation method with $KMnO_4$ into account, we hypothesized that physical fractionation of soil organic matter can be an alternative method for determining the content of labile C and thus C lability and CMI. Although the principles of chemical oxidation and physical fractionation are completely different and the labile C determined through these two methods does not match exactly, the main idea is that both methods supply a relative index of soil C lability that allows the assessment of management systems comparatively.

Physical fractionation is based either on density or particle-size of organic matter, or both characteristics (Christensen, 1992). The light fraction obtained through density fractionation is composed mainly of plant residues, roots, and fungal hyphae at different decomposition stages (Gregorich and Janzen, 1996; Baldock and Skjemstad, 2000; Diekow et al., 2005a). Because of its higher turnover rate than the corresponding heavy fraction (Balesdent, 1996), the light fraction is considered to contain labile C. The coarse fraction obtained through particle-size fractionation has similar characteristics and is also considered to contain labile C (Cambardella and Elliott, 1992; Christensen, 1996; Feller and Beare, 1997).

An important argument supporting the physical fractionation is its ability to isolate the particulate organic matter (the fraction that still shows some structural characteristics of its precursor), which is partially decomposed (Baldock and Nelson, 2000) and is not mineral associated. On the other hand, the chemical oxidation may supposedly attack even some mineral-associated organic material that cannot be considered as available to biological activities. Besides, because the chemical oxidation is a surface attack, it is also possible that some labile compounds inside large fragments of particulate organic matter may not be oxidized.

The objectives of this study were (i) to assess the physical fractionation with density and particle-size separation as alternative methods to the $KMnO_4$-chemical oxidation in determining the labile C and thus the CMI, and (ii) to evaluate the capacity of long-term no-till cropping system and N fertilization to promote the soil quality of a Southern Brazilian Acrisol, using the CMI as the main assessment parameter.

2. Materials and methods

2.1. Field experiment, soil sampling and C analysis

This study was based on a long-term experiment (19 years) established at the Agronomic Experimental Station of the Federal University of Rio Grande do Sul, in Eldorado do Sul (RS), Southern Brazil (30°06′35″S and 51°40′37″W). The soil is classified as sandy clay loam Acrisol (FAO, 2002) or as Typic Paleudult (Soil Survey Staff, 2003) and, at the establishment of the experiment in 1983, showed visible signs of physical degradation caused by the conventional tillage management adopted in the previous 13 years of agricultural activities. The particle-size distribution is 540 g sand kg^{-1}, 240 g silt kg^{-1} and 220 g clay kg^{-1}. The clay fraction is composed mainly of kaolinite (720 g kg^{-1}) and iron oxides (109 g Fe_2O_3 kg^{-1}) (Bayer, 1996). The local climate is subtropical humid, Cfa, according to Köppen classification, with mean annual temperature of 19.4 °C and rainfall of 1440 mm.

The experiment comprises 10 no-till cropping systems, set in the main plots (8 m × 5 m), and two