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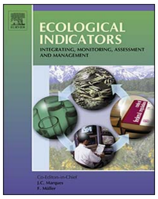

Original Articles

Soil carbon fractions and biological activity based indices can be used to study the impact of land management and ecological successions

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ABSTRACT

Soil organic carbon (SOC) is a strong indicator of soil health. Development of efficient soil quality indicators is crucial to better understand the impact of land management strategies on the recovery of degraded ecosystems. We hypothesized that SOC fractions and biological attributes can compose strong soil quality indicators to assess an ecosystem recovery following disturbance. Thus, the objective of this study was to evaluate the use of soil biological activity and SOC fractions to study the impact of different land use systems and ecological successions in ecosystem recovery. We selected six land use systems: tobacco (*Nicotiana tabacum*) cultivation; pastureland; reforested land with *Eucalyptus* sp.; and natural ecological successions with 10, 20 and 35 years of vegetation regeneration, respectively. We collected disturbed and undisturbed soil samples in triplicate at 0–5, 5–10, 10–20 and 20–40 cm depth intervals. Several fractionation approaches were used to determine SOC pools: hot water extractable organic carbon, permanganate oxidized organic carbon, particulate organic carbon, mineral associated organic carbon and total SOC. The activity of the enzyme arylsulfatase was used to represent soil biological attributes. We calculated three indices to represent the soil quality: carbon management index, soil resilience index and biological activity index. Our results suggest that the SOC fractions and the enzyme activity followed the increase of vegetation complexity of the ecological succession stages. The labile SOC pool, in addition to enzyme activity, was the most sensitive variable to assess land use changes. The biomass-C input was considered to be the main reason of SOC increase, and the gains of labile SOC fractions were directly related to the increase of SOC stocks. Both, biological and carbon management indices were efficient tools to characterize the impact of studied management systems. Also, we found that assessment of deeper soil layers (20–40 cm) was extremely important as incomplete inferences might be reached while evaluating only surface soil layers (0–20 cm). We conclude that the carbon management and biological indices captured the stage of soil degradation and the influence of vegetation diversity in the soil resilience restoration, providing an advance in monitoring strategies that can be reproducible in any environment.

Abbreviations: BAI, biological activity index; CC-TBC, conventional cultivation of tobacco; CDA, chest diameter amplitude; CMI, carbon management index; FR-1, forest level 1; FR-2, forest level 2; FR-3, forest level 3; HWEO-C, hot water extractable organic carbon; MAOC, mineral associated organic carbon; LOC, light organic carbon; PAST, pasture; PCA, principal component analysis; POC, particulate organic carbon; POX-C, permanganate oxidized carbon; R-EUC, eucalyptus reforestation; SOC, soil organic carbon; SRI, soil resilience index

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1. Introduction

The ecosystems and biodiversity regulate biogeochemical cycles and hydrological processes that are essential for ecological balance (Altieri, 1999). Conversion of native vegetation into agricultural fields through slash and burn, followed by plow tillage promotes soil structure disruption (Tivet et al., 2013) increasing soil erosion (Lal, 2004) and depleting soil organic carbon (SOC) stocks (Sá et al., 2009 and Lal, 2015). The SOC loss are much more intense under tropical and subtropical climates, and it ranges 5–10 times higher in comparison to lands managed in temperate environments (Lal and Logan, 1995). In tropical regions, many degraded fields are being abandoned due to high cost and labor demand of the restoration (Kramer and Gleixner, 2008; Meyer et al., 2013; Young, 2000).

Development of biogeochemical indicators which can effectively demonstrate the impact of disturbance and ecosystem recovery is an active area of research. The biodiversity (i.e. plants and animals) has been suggested as a major component of the quality indices (Albrecht, 2003; Perner and Malt, 2003; Pywell et al., 2003; Rousseau et al., 2013). Vegetation complexity level has been used as an important criteria in indicators, as it indicates the ecosystem recovery stages (Altieri, 1999; Grime, 1998; McGeoch, 1998). However, species diversity information is not enough to explain all vital cycles (i.e. carbon (C) and nitrogen (N) cycles, gas exchanges, water infiltration and conductivity) as well microbial activity within an ecosystem (Bastida et al., 2008). Therefore, SOC and N stocks, microbial biomass, basal respiration, enzyme activity and information about the meso and macro fauna are being considered as biological indicators largely adopted as indices to assess the ecosystem functioning (Kalinina et al., 2013; Knoepp et al., 2000; Saggar et al., 2001; Vasconcellos et al., 2013; Cenini et al., 2015; Chen et al., 2016; Inagaki et al., 2016). Although some of these have been demonstrated to be promising tools, there is still a lack of indicators that could represent a synergy of ecosystem changes. Among the mentioned indicators, SOC concentration and stock, and its association with microbial biomass C has been demonstrated to be an efficient, and easy to implement tool to measure environmental changes (Emmerling et al., 2001; Grigera et al., 2007; Mazzarino et al., 1993; Powlson et al., 1987). The soil enzyme assays has been good and sensitive indicators to study the impacts of land use changes (Bandick and Dick, 1999; Deng and Tabatabai, 1997; Jin et al., 2009; Wang et al., 2012; Cenini et al., 2015; Chen et al., 2016). Farrell et al. (1994) and Klose et al. (1999) demonstrated that the arylsulfatase activity was reduced up to 30% after five years of converting forest soil to agricultural land.

Balota et al. (2004) reported that under long-term experiment amylase, cellulase, acid phosphatase, alkaline phosphatase and arylsulfatase increased up to 68%, 90%, 46%, 61%, and 219% respectively in the surface layer of an Oxisol under NT cropping system in comparison to conventional tillage. Previous studies using enzymes such as dehidrogenase, cellulase and urease assays reported close relationship with soil physical and chemical properties (Vasconcelos et al., 2013), cellulase and ligninase with SOC dynamics (Cenini et al., 2015; Chen et al., 2016). Inagaki et al. (2016) reported that arylsulfatase and beta-glucosidase had a similar performance to indicate the SOC pool alterations (especially labile fractions) in a highly weathered Oxisol. Recently, Medeiros et al. (2017) reported that enzyme such as arylsulfatase, acid phosphatase and urease had a similar performance to identify the natural regenaration of the vegetation and the close relationship with C dynamic in a tropical region in northest Brazil.

In soils of the tropics, particle size fractionation techniques have been used to characterize relationship between SOC and aggregation at the macro and microaggregate scale (Feller et al., 1996). The concept is that soil organic fractions associated with different sized particles differ in structure and function, and therefore play different roles in SOC turnover (Christensen, 1992). In addition, labile SOC fractions obtained by oxidation stages can compose an efficient tool for evaluating the changes in soil quality as they reflect the influence of fresh crop residues added (Weil et al., 2003; Luan et al., 2010, 2014). Blair et al. (1995) proposed the use of carbon management index (CMI) to compute the lability of SOC as an indicator for environment changes. As the CMI captured the impact of crop rotations and soil management in SOC restoration (da Silva et al., 2014; Vieira et al., 2007), it may be used to study successional vegetation stages of the ecosystems. We hypothesized that the soil C changes is associated to vegetation complexity and biological activity, and C management indices can be used as the indicators to reveal these changes. Thus, the objectives of this study were: i) to quantify the biological activities through enzyme assays and SOC pools in different production systems and ecological successions; ii) to assess the use of SOC fractions as a recovery indicator of vegetation diversity; iii) to verify if the proposed indicators calculated based on the SOC pools and enzyme activity can be used to study the ecosystem recovery.

2. Material and methods

2.1. Study location and area description

This study was conducted in the Faxinal Taquari dos Ribeiros, in the State of Parana, southern Brazil. The region is located in the second Parana Plateau; the local altitude is approximately 856 m (Fig. 1). The climate of the region is classified as subtropical humid with moderate summers and frequent frost during the winter (Cfb) according to the Köppen classification (Maack, 1981). The maximum and minimum mean surface air temperatures are 21 and 13 °C, respectively and the mean annual precipitation is 1500 mm, with good distribution along the year and no excess rainy or dry seasons (IAPAR, 2016; http://www.iapar.br/modules/conteudo/conteúdo.php?conteudo = 1070).

The soil parent material of the study sites is composed of sedimentary rocks, argillites, siltites, and fine arenites. The main soil types are the Ferralsols (FAO, 2010; equivalent to Oxisols, Soil Survey 2014) in the elevated positions and an association of Cambisols (FAO, 2010; equivalent to Inceptisol, Soil Survey 2014) in the shoulder areas. The Arenosols (FAO, 2010; equivalent to Ultisol, Soil Survey, 2014) are found in the lower positions. All the soil management systems used in this study are located on Cambisols.

2.2. Faxinal system

The Faxinal are described as forest-crop-livestock systems characterized by the communitarian land use (Niedzielski et al., 2003). The land use in the Faxinal Taquari dos Ribeiros is described in detail by Struminski and Strachulski (2012). Briefly, the native vegetation is cut down manually or mechanically, the wood is removed for construction and the remaining vegetation is burned. After this, the soil is plowed to cultivate tobacco crop and livestock. After a period of approximately 10 years of cultivating tobacco using plow system and livestock, the degraded areas are abandoned and the recovery process occurs naturally.

Along the ecosystem regeneration, the abandoned areas are usually transformed to subsistence pasturelands. The animal traffic in these areas promote the ecosystem recovery through nutrient cycling by manure and urine deposition (Carvalho et al., 2011). On the other hand, they also inhibit the regeneration of several species due to pasturing.

2.3. Land use systems description

For this study, we selected six land use systems (detailed description in Table 1) as follows: i) conventional cultivation of Tobacco (*Nicotiana tabacum*) system adopted after the deforestation followed by intensive plow tillage between October and March, and between April and September, thereafter designated as **CC-TBC**; ii) pastureland system