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Soil organic carbon, microbial biomass and enzyme activities responses to natural regeneration in a tropical dry region in Northeast Brazil

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ABSTRACT

Natural regeneration may be a cost-effective method for recovering areas previously used for intensive agricultural purposes. Plant diversity in the succession periods has been well documented; however, less attention has been paid to the changes in soil attributes, which may work as an instrument for the validation of regeneration methods. The present study is part of a broader interdisciplinary research project assessing the effects of natural regeneration on biodiversity and the quality of the soil. We investigated the effects of natural regeneration on the physicochemical attributes of the soil, as well as on soil organic carbon (SOC), microbial biomass carbon (MBC) and enzyme attributes. We assessed three stages and five areas of each natural regeneration stage (early-ER, intermediate-IR and late-LR) in two layers: 0–5 and 5–10 cm. The present study found a 20% SOC increase due to natural regeneration. In the first layer, SOC, urease, acid phosphatase and arylsulfatase absolute activities were significantly higher in the two older natural regeneration stages (IR and LR) than those found in the ER stage. We found a reduction in specific enzyme activities per SOC unit in the ER areas. Natural regeneration influenced SOC and MBC, the absolute enzyme activities, and the specific enzymes per SOC unit, mainly in the surface layer. The present study provided some of the first data concerning the beneficial effects of natural regeneration on the quality of soil as measured through enzyme activity, SOC and MBC in a tropical dry region in Northeastern Brazil.

1. Introduction

Significant changes in the processes and functions of ecosystems, such as carbon emissions and biodiversity losses, have happened as forests have been converted to intensive agricultural areas due to constant human interventions worldwide (Malhi et al., 2014). Tropical dry areas (TDA) constitute the most extensive terrestrial biome on Earth and cover approximately one-third of the planet's continental surface (Pointing and Belnap, 2012); these areas have suffered the most severity anthropic pressures (Quesada et al., 2009). México, for instance, had 73% of its tropical dry forest converted to other types of land use (Maass et al., 2005), and in Brazil, the conversion of tropical dry forest reached 46% (MMA, 2011). Deforestation and degradation have been responsible for 8 to 15% of the annual anthropogenic carbon emissions (Houghton et al., 2015).

However, little is known about the regeneration process in areas that have been intensively used for agricultural purposes. Accordingly, natural regeneration is an important strategy for reducing carbon emissions caused by deforestation and degradation (Chazdon et al., 2016).

Natural regeneration is the cheapest method available for providing habitat to improve the biodiversity of communities, sequester carbon (Gilroy et al., 2014) and increase carbon stocks (Moura et al., 2016). For instance, after 20 years of recovery, 3.05 Mg C ha^{-1} yr^{-1} of aboveground biomass uptake occurred (Poorter et al., 2016), whereas soil organic carbon (SOC) increased from 8.37 to 11.62 g C kg^{-1} soil after 57 years of natural regeneration in a Brazilian tropical dry forest (Moura et al., 2016).

Additionally, there are many studies about natural regeneration concern the composition of tree species (Van Rensen et al., 2015; Barna and Bosela, 2015) or fertilization (Campo and Vázquez-Yanes, 2004). Nevertheless, litterfall and root activities of different tree species have a direct

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impact on soil properties (Neumann et al., 2013), such as nutrient availability, soil microbial community (Scheibe et al., 2015) and enzyme activities (Boeddinghaus et al., 2015). On the other hand, there are several studies related to soil attributes in TDA in México (Campo and Vázquez-Yanes, 2004) and Argentina (Palma et al., 2000; Abril et al., 2013). There are just a few studies related to the biological and biochemical indicators of TDA. For example, Pajares et al. (2009) studied an Acrisol cultivated according to different management practices. Medeiros et al. (2015) compared tropical dry forests to intercroppings and monocroppings. Although, important questions remain unanswered in the literature, such as what is the range of microbial biomass and enzyme activities and how is it affected by natural regeneration stages? Understanding the microbial and biochemical soil activities in TDA is relevant for planning strategies of conservation, recovery of ecosystems and the generation of data for different areas.

It is important to assess the composition and activity of microorganisms in order to find the potential quality and nutrient cycling and C sequestration capabilities of the soil since these microorganisms are a relevant source of soil enzymes and are responsible for organic matter transformations in the soil (Smith et al., 2015). Soil enzyme activities are a sensitive indicator of soil quality and may respond to changes in the soil faster than other soil properties (Medeiros et al., 2015). Many recent studies have recommended using specific enzymes activities per unit of SOC and microbial biomass carbon (MBC) (Wang et al., 2012; Raiesi and Beheshti, 2014; Medeiros et al., 2015) because specific enzyme activities per unit of SOC can express the nutritional status of the organic matter from the perspective of the microorganism (Wang et al., 2012).

Studies about soil enzyme activities in TDA under regeneration are scarce. Future studies must aim to determine how natural regeneration influences the quality of the soil by using sensitive and rapid indicators. A recent study about the successional and seasonal variations in wet post-agricultural regeneration areas detected differences between young and old secondary and primary forests by assessing the microbial community composition and activity via phospholipid fatty acid analysis (PLFA) and extracellular enzyme activity (Smith et al., 2015). Different studies about plant diversity, phenotypic plasticity and ecophysiological plant strategies were conducted in TDA to assess how these areas recover through natural regeneration (Cabral et al., 2013; Falcão et al., 2015; Moura et al., 2016; Chazdon et al., 2016; Poorter et al., 2016). Studies on soil properties may explain some of the results described in many biodiversity studies (SISBIOTA Matas secas web- http://tropi-dry.eas.ualberta.ca). Therefore, determining soil attributes is crucial to understanding the efficiency of natural regeneration and to analyze whether these soils follow the same succession stage patterns in different plant species found in TDA. In this study, we have reported the effects of natural regeneration stages, based on different periods and plant species, on these areas have suffered the most severity anthropic pressures soil physicochemical properties, microbial biomass and enzyme activities in a reference Brazilian tropical dry area.

2. Materials and methods

2.1. Study area and soil samples

The study area is located in Paraíba State, Northeastern Brazil (06°59′13″ to 07°0′14″ S and 37°18′08″ to 37°20′38″ W), with an altitude of 250 to 350 m (Fig. 1). The climate in the region is tropical semiarid (Bsh) according to the Köppen classification system. The mean temperature and annual rainfall are 28 °C and 700 mm, respectively (Supplementary data). According to the classification system of the Food and Agriculture Organization (IUSS Working Group–FAO, 2006), the soil is a Cambisol. According to Lozano-García et al. (2016), these soils are characterized by low fertility, poor physical conditions, low organic matter (OM) contents due to climate conditions (semiarid climate) and sandy soil textures (Table 1).

Soil samples were collected in 2012 during the dry season (November) in areas presenting different natural regeneration stages, namely: early regeneration (ER), intermediate regeneration (IR) and late regeneration (LR). Five repetition plots of 1000 m^2 (50 × 20 m) in each natural regeneration stage were determined, totaling 15 areas. We collected samples of undisturbed soils using cylinders of 5 cm in diameter and 5 cm in height in two soil layers (0–5 and 5–10 cm).

The ER stage areas had been used for long fiber cotton (*Gossypium hirsutum*) cultivation and subjected to natural regeneration for over 15 years. Cabral et al. (2013) identified 6 species and 3 families of plants in these areas, namely: *Mimosa tenuiflora* (which represented 90.1% of all trees in the study area), *Poincianella pyramidalis*, *Croton blanchetianus, Cereus jamacaru, Caesalpinia ferrea* and *Bauhinia cheilantha*. The IR stage areas were also previously used for long fiber cotton cultivation and, thereafter, had been subjected to natural

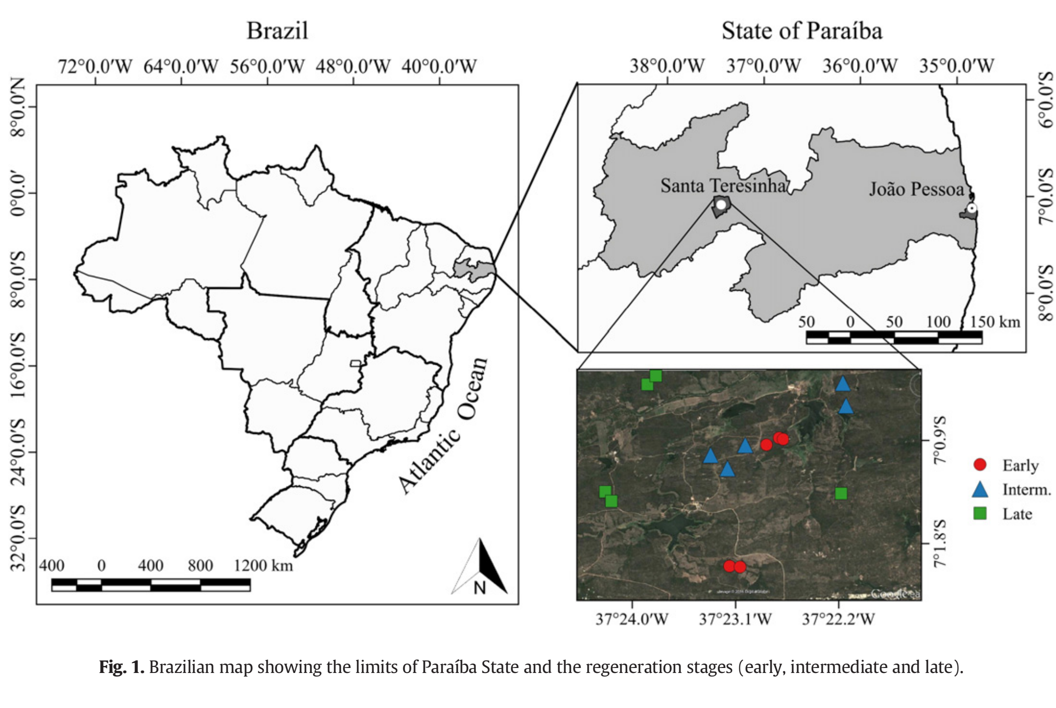

Fig. 1. Brazilian map showing the limits of Paraíba State and the regeneration stages (early, intermediate and late).