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Soil microbial properties and temporal stability in degraded and restored lands of Northeast Brazil

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ABSTRACT

Human activities, such as land use change, cause severe land degradation in many ecosystems around the globe with potential impacts on soil processes. Restoration practices aim at reverting such impacts and reconstituting the biotic composition and functioning of an ecosystem to its initial condition. The aim of this study was to monitor soil microbial properties in degraded lands in Northeast Brazil and to compare those with land under restoration. Soil samplings were conducted in 2009, 2010 and 2011 in two different seasons (wet and dry season) at sites differing in degradation status: native vegetation (NAT), moderately degraded land (MDL), highly degraded land (HDL), and land under restoration for four years (RES). Soil microbial properties showed pronounced fluctuations between seasons with higher levels of functioning in the wet than in the dry season. Soil microbial biomass and enzymes had significantly higher values under native vegetation than in degraded land, while restored land mostly corresponded to native vegetation. Soil microbial biomass, respiratory quotient and enzyme activities were more strongly affected by land degradation than soil chemical properties. Soil microbial properties varied more between seasons and years in highly degraded land than under native vegetation suggesting a buffering effect of the native vegetation on soil microbial processes. However, land degradation effects on soil microbial properties were significant in both seasons. Moreover, our results indicate that the land restoration practice applied here shifted soil microbial community composition as indicated by soil microbial stoichiometry. Our results indicate that land degradation strongly deteriorates soil microbial properties and their stability in time, but that land restoration practices likely are successful in promoting the recovery of some soil microbial functions, even after only four years. However, shifts in soil microbial community composition in restored lands may have significant feedback effects on element cycles.

1. Introduction

The improper use of soil and water has promoted the emergence of large areas of degraded lands in various regions of the world, especially in Africa and Latin America (Abraham and Torres, 2007). Land degradation causes the reduction of biological productivity and affects the environmental, social and economic sustainability (Nunes et al., 2012). Especially, in the semi-arid region of Northeast Brazil, slash-and-burn practices combined with diamond-mining activities caused land degradation (Almeida-Filho and Carvalho, 2010). In addition, in this region, high temperatures and evapotranspiration associated with a short rainy period with high precipitation and fragile soils intensify the effects of anthropogenic land degradation.

The Brazilian Government has invested about one million dollars in this region for the purpose of recovery of degraded land. The main goal is to restore soil properties and increase the vegetation cover as important strategies for the recovery of soil productivity and sustainability (SEMAR, 2010). The restoration process involves the use of conservation practices, such as building terraces for water storage and the sowing of plant species, such as grasses and legumes. Previous studies found increasing vegetation cover to improve the chemical and physical properties of soils (Veloso et al., 2010) as well as soil microbial biomass and enzyme activity (Nunes et al., 2012). It remains however unexplored how land degradation as well as restoration influence soil microbial properties in different

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years and seasons. Given that severe precipitation events occur alongside long dry periods, it is likely that land degradation induces large variations in soil microbial functions and reduces their stability.

Soil microbial biomass is the living component of soil organic matter (SOM) (Jenkinson and Ladd, 1981) and can be seen as an ecological attribute to assess changes in soil properties caused by crops or forest devastation (Zimmermann and Frey, 2002; Lopes et al., 2011). Moreover, soil microorganisms produce a large array of enzymes which play essential roles in various ecosystem processes and are involved in the cellular metabolism, such as the decomposition of organic materials (Van der Heijden et al., 2008; Silva et al., 2012). Soil enzyme activity is one of the first soil properties that is altered when the soils get disturbed (Acosta-Martınez et al., 2007). Thus, soil enzyme activity has long been considered an indicator of soil quality because it controls both the supply of nutrients to plants and microbial growth (Burns, 1978; Burns et al., 2013).

The number of studies investigating the consequences of land degradation is increasing because of its importance on world food security and environmental quality. It is well known that land degradation decreases soil fertility as a result of loss of soil organic matter and nutrients (Lal, 1996) and reduces soil microbial biomass and activity (Nunes et al., 2012). Indeed, some previous studies in degraded lands from tropical regions showed decreased soil microbial biomass and activity in the short-term after slash-and-burn practices in the Eastern Amazonia (Denich et al., 2004) and Northeastern Semi Arid regions (Nunes et al., 2012) of Brazil. However, restoration practices, such as improving of soil properties and increasing of vegetation cover, may be a promising approach for the restoration of soil productivity and sustainability (Cooke and Johnson, 2002). Also, land restoration can shift the biological status once that microbial biomass changes being associated with alterations in ecosystem function (Potthoff et al., 2006) such as organic matter decomposition. However, there is limited knowledge of how soil microbial properties develop in time after starting agricultural and mechanical restoration practices like sowing of plant species and the building of terraces for water storage and avoiding soil erosion. In the USA, for instance, some restoration practices focus on the use of agricultural techniques, such as tillage and herbicide application to control exotic annuals before seeding with native perennials with strong effects on soil microbial communities (Potthoff et al., 2006). Thus, it is unclear how land degradation and restoration influence soil microbial properties and their variability in/among different seasons and years. Also, it is unknown if and how such treatments influence soil microbial element ratios. Specifically, we hypothesized that (1) land degradation decreases soil microbial properties (Nunes et al., 2012) and their stability, and (2) land restoration to recover soil microbial properties and their stability.

2. Materials and methods

The study was conducted at Gilbues (09° 49′ 55″ S and 45° 20′ 38″ W), Northeast Brazil. The climate is tropical dry with a mean precipitation of 1000 mm yr^{-1} (with rainfall from January through May) and an annual mean temperature of 35 °C, with minimum and maximum temperatures of 22 °C and 40 °C, respectively. According with Brazilian Soil Survey (Embrapa, 1986), the dominant soils are classified as Eutrophic Red-Yellow Podzolic soils with granite and gneiss as parental material.

The following four selected sites were studied: native vegetation (NAT), moderately degraded land (MDL), highly degraded land (HDL) and land under restoration (RES) (Table 1). The sites were very similar in soil type and climate (see above). At each site, we sampled four sub-sites (at each sub-site we randomly sampled 10 soil cores to cover some spatial heterogeneity), with each one covering an area of ~1000 m^2. The native vegetation is covered by trees, dominated by *Cenostigma macrophyllum*, *Tabebuia serratifolia*, *Hymenaea courbaril*, *Orbignya phalerata*, *Combretum leprosum*, *Guarea kunthiana and Lecythis pisonis*. These trees cover between 80 and 90% of the ground surface and contribute approximately with 1 kg m^{-2} of plant litter annually.

The MDL and HDL sites resulted from cutting of native vegetation for charcoal production in 2008 and 2004, respectively. Nowadays, the MDL site is dominated by herbaceous plant species (*Aristida sepfolia*, *Cyperus uncynulatus* and *Tragus berteronianus*) that cover approximately 24% of the soil surface, while that the HDE site has sparse vegetation cover (<5%). The land restoration at RES started in 2006 by shifting the degraded land by building terraces (approximately 500 m^2) for water storage and by applying fertilizer with 50, 200 and 100 kg ha^{-1} of N (urea), P_2O_5 (super single phosphate) and K_2O (potassium chloride), respectively. The fertilizers were applied annually spread on the soil surface. Afterward, the RES site was re-vegetated with the herbs *Crotalaria juncea* and *Panicum maximum* at densities of 2500 and 3000 plants ha^{-1}, respectively. The annual input of litter (air-dry) from green manure is approximately 1.5 kg m^{-2} on the soil surface.

Soil samples were collected at 0–10 cm depth in March (wet season) and September (dry season) of 2009, 2010 and 2011. At each site, the plant cover was carefully removed from the soil surface and soil cores (2.5 cm diameter) were taken randomly. All samples were immediately stored in sealed plastic bags in a cooler and transported to the laboratory. The field-moist samples were sieved (2-mm mesh) and stored in sealed plastic bags at 4 °C for microbial analyses.

Subsamples of the soils were ground and passed through a 0.21-mm sieve to evaluate chemical properties (Table 2). Soil pH was determined in a 1:2.5 soil/water extract. Exchangeable Ca was determined using extraction with 1 M KCl. Available P and exchangeable K were extracted using Mehlich-1 extraction method and determined by colorimetry and photometry, respectively (Tedesco et al., 1995). Total organic C (TOC) was determined by the wet combustion method using a mixture of potassium dichromate and sulfuric acid under heating (Yeomans and Bremner, 1998).

Table 1
Main characteristic of the evaluated sites: native vegetation (NAT), moderately degraded land (MDL), highly degraded land (HDL), and land under restoration for four years (RES).

Characteristic	NAT	RES	MDL	HDL
Longitude	45°20′42.7″W	45°20′32.2″W	45°20′41.1″W	45°20′29.2″W
Latitude	09°52′32.1″S	09°52′49.6″S	09°52′33.0″S	09°52′48.3″S
Altitude (m)	441	449	460	452
Slope (%)	2–5	5–9	5–9	5–9
Vegetation	Trees[a]	Herbs[b]	Herbs[c]	Herbs[d]
Clay (g kg^{-1})	510.2	510.8	500.4	520.1
Silt (g kg^{-1})	90.7	100.3	100.5	90.8
Sand (g kg^{-1})	390.1	370.9	390.1	380.1
SBD[e] (g cm^{-3})	1.15	1.23	1.38	1.40
SOM[f] (g kg^{-1})	22.6	10.4	5.8	2.1
Vegetation cover (%)	100	100	24	4

[a] Tree species: *Cenostigma macrophyllum* L., *Tabebuia serratifolia* L., *Hymenaea courbaril* L., *Orbignya phalerata* L., *Combretum leprosum* L., *Guarea kunthiana* L. and *Lecythis pisonis* L.).
[b] *Crotalaria juncea* L. and *Panicum maximum* L.
[c] *Aristida sepfolia* L., *Cyperus uncynulatus* L. and *Tragus berteronianus* L.
[d] Herbs (*Tragus berteronianus* L.).
[e] SBD, soil bulk density.
[f] SOM, soil organic matter.