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Soil quality indicators for different restoration stages on Amazon rainforest

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ABSTRACT

Despite the global importance of Amazon rainforest, few studies have evaluated soil quality indicators (SQI) in this region. This study evaluated 13 SQIs according to their correlation and sensibility to differentiate four areas under different restoration stages in the Brazilian Amazon rainforest: degraded area (DEGR), two restoration areas (REST1 and REST2) and an undisturbed forest (FORE). The different restoration stages had influence on SQIs. Soil bulk density (ρ_s), total nitrogen (total N) and exchangeable potassium (K^+) on soil showed higher number of correlation ($P < 0.001$; $r_s > |0.70|$) with other SQIs and were sensitive ($P < 0.05$) to distinguish the different areas. Soil bulk density decreased in the following order: DEGR > REST1 > REST2 > FORE. Otherwise, soil total N decreased on a reverse order: FORE > REST2 > REST1 > DEGR. Increasing restoration status of Amazon rainforest is associated with lower ρ_s and higher N and K^+ concentration on soil.

1. Introduction

The global and regional environmental importance of Amazon has been recently highlighted (Aragão et al., 2012; Davidson et al., 2012). According to the last author, society should take urgent action to control tropical deforestation preventing future problems. Anthropic activities, such as deforestation, mining, hydroelectric power dam construction, logging decks, are responsible to degrade areas (DEGR) in the Amazon. Due to the public and environmental organizations pressure some of these DEGR are under restoration processes. On this scenario, soil quality indicators (SQIs) play an important role to evaluate the soil quality of areas under different restoration stages. Moreover, these SQIs are also necessary to environmental rules such as IBAMA (2011) for monitoring restoration projects of DEGRs.

A good SQI indicator should: (i) be sensitive to management-induced changes; (ii) discriminate between natural changes and those induced by management; (iii) be easily measured; (iv) be relevant across sites or over time; (v) be highly correlated to long-term response and; (vi) be responsive to corrective measures (Bone et al., 2010; Schoenholtz et al., 2000). Physical and chemical soil properties are commonly used as SQIs (Bone et al., 2010; Bautista-Cruz et al., 2012). However, it is difficult to clearly separate these properties because of their dynamic and interactivity (Schoenholtz et al., 2000), thus the values of one SQI are affected and associated with one or more of them (Arshad and Martin, 2002). Despite their critical role, few studies have considered the interaction/correlation among SQIs (Ghani et al., 2003; Paul et al., 2010a,b) and their sensitivity to differentiate ecosystems under different restoration stages on Amazon rainforest. Studies involving SQIs are preponderat on temperate forests (Vries et al., 2003; Shukla et al., 2006).

Promising results showed correlation between some SQIs. Positive correlation ($r = 0.60$, $P < 0.05$) was found between soil N-NO_3^- and carbon concentration on rainforest (Silver et al., 2005). Soil N had negative correlation ($r = -0.5$; $P < 0.001$) with ρ_s considering a rainforest, pasture and three reforestation pathways (Paul et al., 2010a). According to Shukla et al. (2006), soil ρ_s had negative correlation ($r = -0.49$) with soil carbon of different agroecosystems. Considering the SQIs sensitivity to differentiate areas, N-NO_3^- distinguished the remnant rainforest, pasture and ecological restoration (Paul et al., 2010b). Hot water extractable carbon was sensitive to differentiate various land uses (Ghani et al., 2003). Carbon and Total N increased with the age of tropical rainforest, and decreased ρ_s (Silver et al., 2005). Deforestation altered soil physical, chemical properties, biochemical cycles in rainforest, reducing nutrient stocks in soil as further growth of reforestations in Central Amazonia (Ferreira et al., 2009; Lopes, 2003). The reforestation restored N concentration on soil, which influenced the rainforest

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plants growth (Paul et al., 2010b). Despites these findings, medium term influences of other soil properties also remains an open question.

On this context, does different restoration stages affect SQIs? We hypothesize that different restoration stages affect SQIs and that there are correlation and distinct sensibility among SQIs to distinguish these areas, as well as, in pristine forest in the Central Amazon region.

2. Materials and methods

2.1. Study areas

The study was carried out at Presidente Figueiredo municipality, Amazonas, Brazil. The climate is Af, Köppen, with 2550 mm yr^{-1} of mean annual precipitation, and mean maximum and minimum annual temperature of 34 and 27 °C, respectively (Eletronorte, 1997). The rainy season occurs from December to April, and the warm season from August to October. Four areas were selected (Fig. 1) on a Xanthic Haplustox based on similarities regarding its topography, land use, and restoration status, tree inventory (Table 1) of 2012 and the historic of use:

(i) *Degraded area* (DEGR) – (01°55′51.9″ S; 59°29′46.8″ W, 56 m a.s.l.). This area was 4000 m^2 and was deforested and its soil surface removed during 1981 and 1989 for the construction of Balbina hydroelectric plant and shoreline. The area was abandoned in 1989.

(ii) *Restoration area 1* (REST1) – (01°56′03.7″ S; 59°29′26.4″ W, 50 m a.s.l.)–This area was 4000 m^2 and was also deforested to the hydroelectric plant construction and abandoned in 1987. In 2003 nursery trees of 16 different wild species of eight families were transplanted at 3 m × 3 m spaced, on REST1 area. Before the transplant, each planting hole received 0.5 kg of $CaCO_3$:$MgCO_3$, 0.5 kg of N:P:K, 10:10:10 and 2 kg of chicken manure. After the transplant, many plants died due to the soil erosion and competition with *Pueraria* sp.

(iii) *Restoration area 2* (REST2) – (01°56′31.6″ S; 59°29′26.9″ W, 40 m a.s.l.)–This was a 3000 m^2 area that suffered the same deforestation process described above, abandoned in 1987. In 2005, nursery trees of 28 wild species of eight families were transplanted. The same procedures of soil fertilization and nursery trees transplanting described for REST1 was used on REST2. Five years afterwards nursery trees transplanting, the following species were predominant on REST2 area: *Cedrela odorata* L.; *Carapa guianensis* Aubl.; *Piper aduncum* and creeping herbs.

(iv) *Forest* (FORE) – (01°55′54.0″ S; 59°29′46.7″ W, 58 m a.s.l.) – this was a 3000 m^2 polygon on an undisturbed forest close to DEGR, REST1 and REST2 was defined as FORE.

2.2. Soil sampling

Eight 10 m^2 (5 m × 2 m) quadrants were randomly distributed on each area in May 2011. Using an Edelman-type auger, on each quadrant, four soil cores were sampled on the vertices and one soil core in the center to make a composite sample. A total of 160 soil samples were collected (eight quadrants × five soil cores × four areas) at the depth of 0–20 cm. For physical analysis, soil samples were collected at the same points, however, using a hammer-driven core sampler.

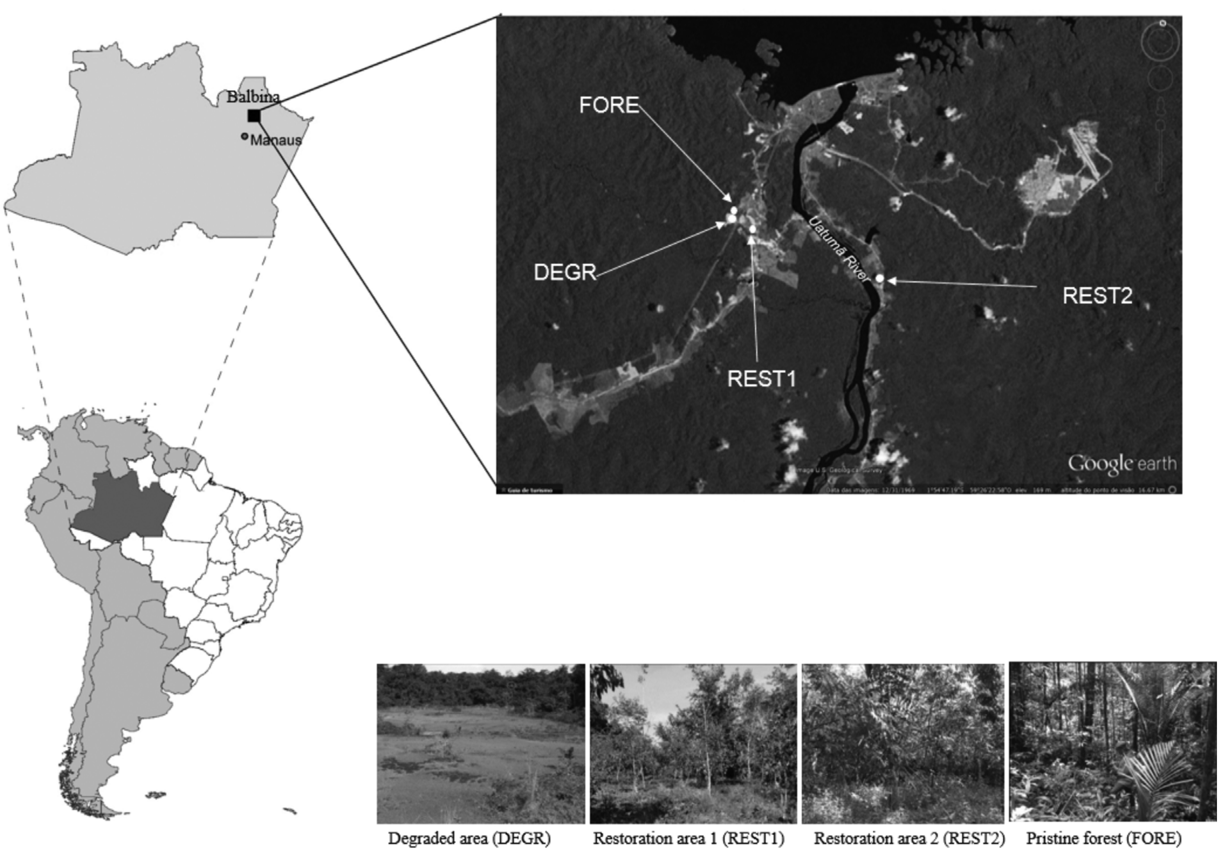

Fig. 1. Map of the location of four sites under different restoration stages on Brazilian Central Amazon region at Presidente Figueiredo, Amazonas, Brazil. Degraded area (DEGR), restoration area 1 (REST1), restoration area 2 (REST2) and undisturbed forest (FORE).