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Available contents of potentially toxic elements in soils from the Eastern Amazon

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ABSTRACT

Background Values of potentially toxic elements (PTEs) in soils are typically obtained from total or pseudo-total contents, but not represent the fraction of these elements available for plant uptake due to the predominance of the stable forms. Available contents to plants, in turn, tend to be positively correlated with the potential risk of contamination of PTEs. In this study, we determined the available contents, extracted with Mehlich-III solution, of Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in Oxisols and Ultisols in the state of Pará, Eastern Amazon, Brazil. Available contents ranged from low to very low when compared to soils from other Brazilian regions and from other countries. Contents of PTE were higher in Oxisols than in Ultisols, except for Cu and Ni. In the Oxisols, PTEs were positively correlated with clay content. However, PTEs were not correlated with soil pH, organic matter and cation exchange capacity. In the Ultisols, Ba, Cu, Pb, and Mn contents were significantly correlated with pH, while Ni contents were correlated with the contents of silt.

1. Introduction

The Brazilian State of Pará is located in the Eastern Amazon. In the last years, a significant growth has been observed in agriculture, ranching and industry, largely due to mining operations and the construction of large hydroelectric power plants. This development, however, has led to the deforestation of large areas and to changes in soil quality. Most changes in soils resulted from air pollutants, pesticides and fertilizers, industrial and urban solid wastes, and toxic and radioactive material (Moreira-Nodermann, 1987), in addition to gold mining, which is a very important activity in the state that has caused large-scale environmental pollution.

The main inorganic contaminants that either occur naturally or are deposited in the soils by anthropogenic activities are heavy metals and other trace elements, henceforth referred to as potentially toxic elements (PTEs). Since adding these elements to soils may increase their concentrations to levels that compromise ecosystem quality, potentially causing problems for animal and plant health, they are categorized as pollutants (Pierzynski et al., 2005).

The Brazilian Ministry of Agriculture requires the state environmental agencies to establish their own legislation to ensure the monitoring of these pollutants in ecosystems, in line with procedures established by Brazil's National Council for the Environment for defining soil background values (BVs) for naturally occurring inorganic substances (Conama, 2009). Monitoring the extent of soil pollution (i.e., soil quality) requires comparing the contents of trace elements of a soil to those occurring in natural (unpolluted) conditions or to background values. Determining natural occurring contents of PTEs is thus a condition for defining BVs, and can help minimize development practices that cause financial and social harm (Baize and Sterckeman, 2001), as well as harm to animal and plant health.

BVs are typically obtained based on the total or pseudo-total natural contents, but these are not good indicators for potential risks to the environment or human health, because only a fraction is available for plant uptake (Davies, 1992). On the other hand, solutions extracting the bioavailable contents of potentially toxic

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elements are more useful in assessing potential risk and toxicity of PTEs (McBride, 1994). For example, only 1–2% of the total Zn content is bioavailable in soils from the Brazilian Savanna ("Cerrado") (Marques et al., 2004).

Several studies on soil PTE contents have been carried out in various Brazilian regions and the world (Oliveira et al., 2000; Pereira et al., 2001; Cancela et al., 2002; Soumaré et al., 2003; Burt et al., 2003; Vázquez et al., 2005; Oliveira and Nascimento, 2006; Milagres et al., 2007; Bortolon and Gianello, 2009; Burak et al., 2010; Otero et al., 2012). Studies carried out with PTEs under eastern Amazon conditions are scarce and have not included areas without anthropogenic impacts. Determining the naturally occurring PTE contents available in the region's main soil classes will improve understanding of their capacity for providing plants with elements essential to grow and for passing on toxic compounds to animals and plants.

In this study, we determined the available contents of Ba, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in Oxisols and Ultisols, and explored their correlations with soil attributes. These elements were chosen because of their high potential of becoming toxic due to air pollutants, application of pesticides and fertilizers, industrial and urban wastes, radioactive materials and gold mining. Based on these data, we established BVs for environmental purposes.

2. Materials and methods

Oxisols and Ultisols were selected to reflect a representative and well distributed sample from across the state of Pará, eastern Amazonia. Samples were collected to span the range of variation in chemical, physical, and mineralogical attributes occurring in the state. To choose the soil classes, we used soil maps of the state of Pará. Some soil samples were also collected from the most populous townships in the state, because of the high likelihood of pollution there, and from townships either affected by mining or with large-scale agricultural or industrial activity (Fig. 1). Pará has 1,247,950.003 km^2, of which approximately 57% consists of indigenous territories and protected areas.

The Amazon is dominated by highly weathered Oxisols and Ultisols that are physically well suited to agriculture but have severe limitations with regard to nutrient availability (Vieira and Santos, 1987). Approximately 70% of soils in the Amazon are acidic (Sánchez, 1981). The clay fraction is mainly composed by 1:1 minerals sheet silicates (kaolinite) (Souza Braz et al., 2013) as a result of the high degree of weathering. Oxisols and Ultisols usually develop from sediments of the Barriers formation (Plio-Pleistocene) and the Alter do Chão formation (Cretaceous). Dematte et al. (1994) found Oxisols and Ultisols developed on the Barriers formation sediments in Pará. The differentiation of both soils was not a result of lithological variations, but of the pedogenic processes of destruction and/or removal of the fine fraction.

Soils were sampled from sites with native vegetation or vegetation more than 20 years old, in order to minimize the possibility of studying soils that had experienced anthropogenic impacts in the recent past (Singh and Steinnes, 1994). For each soil class, we selected areas smaller than 20 ha with homogeneous color, soil texture, topography, drainage and vegetation cover. Three composite samples were collected in each area from ten single samples at depths of 0–0.2 m and 0.8–1.0 m using stainless steel augers. Oxisols and Ultisols were the soil classes sampled, and sampling points were marked using a Garmin Etrex HC GPS, georeferenced with ArcGIS 9.3 software (Fig. 1). Soil samples were stored in marked plastic bags and sieved through 2.0 mm stainless steel mesh after drying.

Particle size was determined by the densimeter method described by Gee and Or (2002). Chemical analyses were performed according to Raij et al. (2001): pH in water at a 1:2.5 soil:water; exchangeable calcium, magnesium, and aluminum extracted with 1 M KCl; Ca and Mg quantified by atomic absorption spectrophotometry, and exchangeable Al by titration with 0.025 M NaOH; K was extracted with an

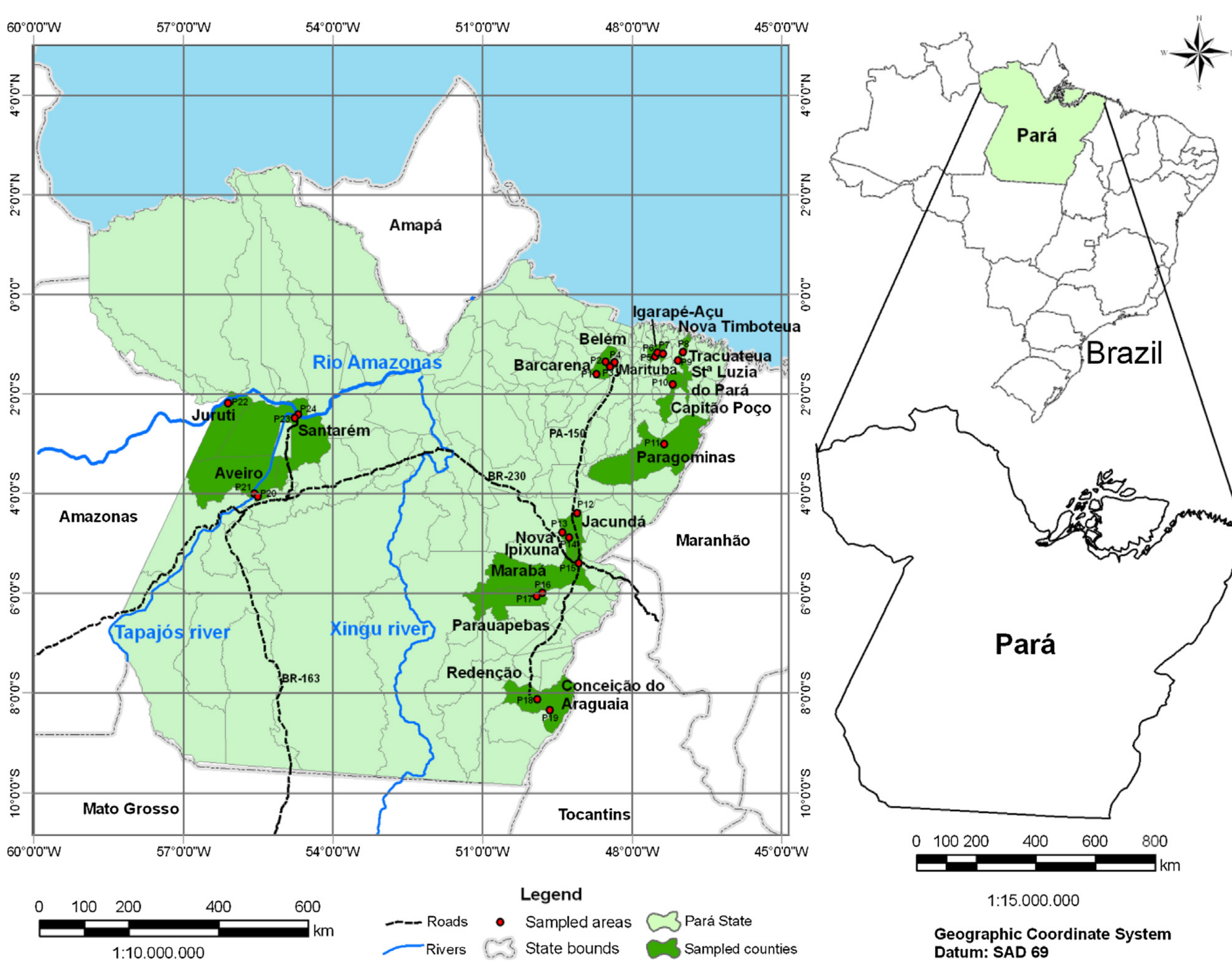

Fig. 1. Location of soil collection areas in the state of Pará, Brazilian Amazon.