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Copper accumulation and changes in soil physical–chemical properties promoted by native plants in an abandoned mine site in northeastern Brazil: Implications for restoration of mine sites

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ABSTRACT

In this study, the copper-accumulating capacity of plants growing spontaneously in copper-contaminated soils in an abandoned mine site in northeastern Brazil was evaluated by calculating enrichment (EF) and translocation (TF) factors. The effects of physical and chemical changes in the rhizosphere soil on copper mobility were determined by using different compounds (Mehlich3/$MgCl_2$) to extract Cu from different types of soil samples (bulk/rhizosphere soil). Finally, the possible implications for the use of these plant species in restoring the area were assessed by calculating the balance between the Cu mobilized in the rhizosphere and the Cu absorbed by the plants. On the basis of the EF and TF values obtained (all <1), none of the species under study (*Ruellia paniculata*, *Bidens pilosa*, *Pityrogramma calomelanos* and *Combretum leprosum*) were classified as hyperaccumulators. However, consideration of readily bioavailable levels (extracted with $MgCl_2$) and the rhizosphere soils (rather than total levels and bulk soils) yielded higher correlations with the levels of metal in plant tissues. This approach therefore appears more appropriate for determining the capacity of the plants to accumulate copper. The different characteristics of the bulk and rhizosphere soils have direct effects on the concentrations of copper, which were much lower in the rhizosphere soil. In general, each species responded differently to the high concentration of Cu in soils (range 3604–9601 mg kg^{-1}). By calculating the balance between the amounts of Cu mobilized in the rhizosphere and uptake by plants, we found that the presence of such plants in the field may have antagonistic effects. Two of the species (*B. pilosa* and *P. calomelanos*) contained more Cu in their tissues than mobilized in the rhizosphere. This is a desirable characteristic for restoration purposes, as the plants can reduce the bioavailable Cu content in soils and thus act as facilitators for regeneration of the site. By contrast, the other two species (*R. paniculata* and *C. leprosum*) mobilized more Cu in the rhizosphere than they were able to take up, which may led to transfer of bioavailable Cu to the ecosystem, which is undesirable in terms of site restoration.

1. Introduction

The disposal of metallic mine waste in open pits represents a serious environmental problem worldwide as it is one of the main routes of release of toxic metals to the environment (Lottermoser, 2007). The practice may lead to unfavourable conditions for plant growth, affecting the diversity and abundance of many species and hindering the reestablishment and development of natural vegetation and, therefore, regeneration of the whole ecosystem (Bradshaw, 1997; Adriano, 2001; Bell, 2001; Hernández and Pastor,

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2008; Närhi et al., 2012). Depending on the geochemical composition of the mine waste, its disposal can have various different effects on soil quality: decreased nutrient contents (Schulz and Wiegleb, 2000; Nikolic et al., 2010); deteriorated physical quality (Shrestha and Lal, 2011); abrupt changes in pH (acidification or alkalinization) (Jurjovec et al., 2002; Aykol et al., 2003); and release of large amounts of toxic elements (Leblanc et al., 2000; Wu et al., 2011; Zornoza et al., 2012; Martínez-Sanchez et al., 2012; García-Lorenzo et al., 2012).

The vast majority of plant species do not tolerate high concentrations of metals in soil, and identification of species that spontaneously inhabit contaminated environments (autochthonous flora) is extremely valuable for restoration programs (Whiting et al., 2004; Pilon-Smits and Freeman, 2006), as well for helping scientists to understand the ecological mechanisms underlying adaptation to such environments (Boyd, 2004; Boojar and Goodarzi, 2007; Manara, 2012; Anawar et al., 2013). As primary resources for many other organisms, plants may also represent a large source of trace elements into the trophic chain. Thus, species that accumulate large amounts of trace elements in aboveground tissues (leaves, stems, fruits and flowers) are prone to release these elements throughout the environment (McLaughlin, 2001; Boyd, 2004; Peplow and Edmonds, 2005). However, species with such characteristics are suitable for use in phytoremediation programs (i.e. phytoextraction), as they can remove large amounts of contaminants by accumulating the elements in aboveground structures and then being removed from the site, and disposed at appropriate places (Reeves and Baker, 2000; Dzantor and Beauchamp, 2002; Pilon-Smits, 2005; Ernst, 2005). Contrastingly, plant species that accumulate metals in their roots, even at high levels, are not considered as metal accumulators according to the technical criteria used to classify hyperaccumulator plants (Baker and Brooks, 1989; Reeves, 2006). However, these plants are still of great interest for the remediation of contaminated areas, since they may be useful in the immobilization and/or revegetation programs. These species can immobilize contaminants in belowground tissues and/or favour metal complexation in their rhizospheres preventing metal release and limiting the bioavailability of the metal to other species. By doing so, these plants may facilitate the regeneration and phytostabilization processes (Whiting et al., 2004; Pilon-Smits, 2005; Mendez and Maier, 2008).

The specificity of the mechanisms that govern the forms of metals that plants absorb is still somewhat uncertain; however, in general, accumulation of an element in plant tissues is governed by the availability of the element in the soil solution, which is in turn determined by different variables, such as climatic, anthropogenic, biological and geochemical factors, and rhizosphere processes (Kabata-Pendias, 2004).

Different methods have been used to determine the bioavailability of metals in soils, with the aim of predicting the fraction of metal in the soil that is actually absorbed by plants. The pseudo-total concentration, which is extracted by strong acids, may comprise forms of metals that are scarcely accessible to plants, such as crystalline forms of primary minerals or very stable organometallic complexes (Fernandez-Calvino et al., 2009). The Mehlich3 extractant is widely used to extract the potentially bioavailable metal, as it extracts the readily bioavailable fraction plus the fractions that may be rendered readily available by small changes in soil conditions, such as those provided by the plant rhizosphere (Mehlich, 1984; Monterroso et al., 1999; Otero et al., 2012). The metal extracted by a salt solution such as $MgCl_2$ represents the fraction that is weakly adsorbed on soil surfaces and is therefore readily available to plants (Filgueiras et al., 2002). We propose that considering the different metal fractions extracted from bulk and rhizosphere soils, along with the metal levels absorbed and translocated by plants, may provide a more realistic approach to understand the response of plants to increase metal concentrations in soil. This has implications for phytoremediation and/or restoration programs, as well as for elucidating the mechanisms that enable these plants to survive in highly contaminated environments.

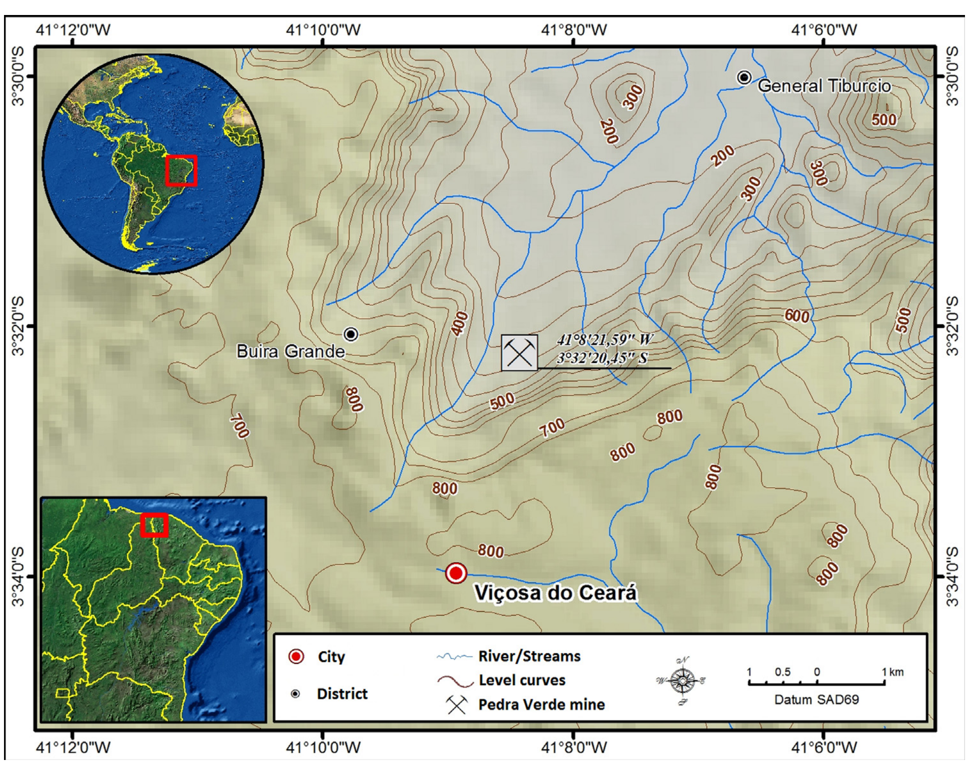

Fig. 1. Location of the Pedra Verde mine.