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Heavy metal contamination from mining sites in South Morocco: 2. Assessment of metal accumulation and toxicity in plants

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Abstract

Metalliferous soils cover a relatively large surface area in Morocco, and up to now no hyperaccumulating plants have been identified on these mining or these industrial sites. The aim of this work was to assess the extent of metal accumulation by plants found in three mining areas in southern Morocco with the ultimate goal of finding metal hyperaccumulating species by using the MetPAD™ biotest. The biotest helps to obtain information on the selective metal toxicity of aqueous extracts from the plants. A strong metal toxicity, as revealed by the biotest is an indication of a hyperaccumulating plant. Toxicity tests were run concurrently with chemicals analyses of metals in plants and their water extracts. The chemical analyses allow the determination of the hyperaccumulated metal(s). Specimens of the plant species mainly growing on and in the vicinity of the three mines were sampled with their corresponding soils. The results show that all plants analyzed had lower heavy metal content and toxicity despite the relatively very high soil concentrations. A comparison of our results with the criterion used to classify the hyperaccumulator plants indicates that plants we collected from mining sites were hypertolerant but not hyperaccumulators. This was confirmed by transfer factors generally lower than 1. Nevertheless, these tolerant plants species can be used as tools for revegetation for erosion control in metals-contaminated sites (phytostabilization).

Keywords: Heavy metal toxicity; Tolerant plants; Hyperaccumulating plants; Phytoremediation; MetPAD™

1. Introduction

Soils are reservoirs for heavy metals generated by industrial activities (e.g., metal finishing, paint pigment and battery manufacturing, leather tanning, mining

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activities, municipal waste water sludges, urban composts, pesticides, phosphate fertilizers, or from atmospheric depositions) (Adriano, 1986; Kabata-Pendias and Pendias, 1992). Metals are non-biodegradable and therefore persist for long periods in aquatic as well as terrestrial environments. They may be transported also through soils to reach groundwaters or may be taken up by plants, including agricultural crops.

Soils, especially those found in or near the metalliferous sites and metal smelters, are highly contaminated with heavy metals, including cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn). For example, soils sampled on a former Zn/Cd smelter site contained up to 99 500 mg kg^{-1} Zn in addition to 1005–17 220 mg kg Pb^{-1}, 2500–4500 mg kg^{-1} Cu, and 28–578 mg kg^{-1} Cd (Reeves et al., 2001).

Metalliferous or industrial soils, which are heavily enriched with toxic metals, can support the growth of specific plant species called metallophytes, which have long attracted the interest of botanists and are now considered as potential tools for phytoremediation (phytostabilization or phytoextraction). Some of these hypertolerant plants also have the ability to accumulate high concentrations of metals in their tissues. Approximately 450 plants species have been classified as hyperaccumulators of heavy metals, and most of them (about 300) hyperaccumulate Ni (Baker, 1981; Baker et al., 1994; Morel et al., 1997). To classify a given plant as a hyperaccumulator, the concentration criterion depends on the type of metal. For example, a plant is defined as a Ni hyperaccumulator if the Ni concentration in leaves exceed 1000 mg kg^{-1} dry weight (DW) whereas for a Zn hyperaccumulator, the leaf concentration should exceed 10 000 mg kg^{-1} DW (Baker, 1995).

Morocco has large areas covered by metalliferous sites (Chronicle of mineral research and exploration, 1998). The mining activity in the country dates back to antiquity. Presently, it is estimated that there are large reserves of Fe, Cu, Zn, Ag, and Pb. The metal contamination from mining sites of south Morocco was studied regarding their mobility and availability measured by selective chemical extraction and the MetPAD™ biotest (Boularbah et al., 2005). Water extractable metals in soils were highly toxic as shown by MetPAD™ test. The toxicity of soil water extracts was mainly due to high concentrations of Zn (785–1753 mg l^{-1}), Cu (1.8–82 mg l^{-1}), and Cd (2.0–2.7 mg l^{-1}). Therefore, the soils and tailing materials were sources of available heavy metals for potential uptake by plants. Until now, few studies were undertaken to acquire information about the plants in metalliferous sites in Morocco (Dunn et al., 1996; Ater et al., 2000).

The aim of this work was to assess the extent of metal accumulation by plants in mining areas in southern Morocco with the ultimate goal of finding metal-hyperaccumulating species. This information could be useful for the selection of adapted plant species that could be used for phytoremediation of these mining sites. Thus, the total metal concentration of the aerial parts of plants growing on these contaminated sites was determined. The metal concentration of plant biomass and water extracts as well as their toxicity using a biotest (Boularbah et al., 2000) were also measured. The biotest helps to obtain information on the general metal toxicity of the plants. A strong metal toxicity, as revealed by the biotest in comparison to the control (moderately hard water) is an indication of a hyperaccumulating plant. Concurrent chemical analyses allow the determination of the hyperaccumulated metal(s). Therefore, the use of chemical analyses of soils and plants in combination with biotests provide us with information on indication of whether the plants growing on mining or industrial sites are hyperaccumulators or merely tolerant to metals.

2. Materials and methods

2.1. Site description

The mining sites (mines A (Cu), B (polymetallic), and C (Cu)) were all located in southern Morocco (Boularbah et al., 2005). The climate on the sampling areas is semi-arid for mine A (rainfall ranging from 300 to 600 mm per year) and arid for mines B and C (precipitations ranging from 150 to 300 mm per year).

2.2. Plant sampling and identification

Specimens of the plant species mainly growing in the vicinity of the three mines were sampled with their corresponding soils. The total metal concentrations in soils were very high and were depending on the mine and the type of ore (Boularbah et al., 2005) (Table 1). For each plant species, five specimens were sampled on each selected site of the mine. Species identification was undertaken in the Plant Ecology Laboratory at the Faculty of Sciences Semlalia, Marrakech. Before homogenization of the biomass of the collected specimens, the leaves and stems of the specimens were washed with tap water

Table 1
Range of concentrations of metals in soils collected from three mining sites in south Morocco

Site	Concentration range (mg kg^{-1})			
	Cd	Cu	Pb	Zn
Mine A	0.6–2.4	84–154	51–170	173–651
Mine B	<dl*–31.5	290–570	383–5756	1738–8361
Mine C	0.2–1.0	42–1683	32–80	110–269

Adapted from Boularbah et al. (2005).
* <dl: Lower than detection limit.