PHYTOEXTRACTION OF METAL POLLUTED SOILS IN LATIN AMERICA

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Abstract

Phytoextraction is a cost-effective method that could be an alternative to remediate polluted sites in Latin America. In this communication, basic concepts relating to phytoextraction of metal-polluted soils are discussed as well as some limitations to and perspectives for applying this method in the region are considered.

Keywords: phytoremediation, phytoextraction, metals, contamination, Latin America.

Introduction

The long mining history in Latin America was not supported by adequate environmental laws and regulations until recent decades. Therefore, metal mining imposed severe and diverse environmental problems in the region, including wild environments, croplands, and human health (Ginocchio, 2003). Most of the mining sites are in the Andean countries (Table 1) and therefore high natural metal concentrations in soil and metal contamination problems can be expected. On the other hand, some soils in industrialized areas are contaminated either by heavy metals atmospheric deposition or through application of metal-rich sewage sludge, fertilizers, pesticides, etc. Unfortunately, there is no complete inventory showing polluted sites in Latin America, but there are several examples reported in the literature (Table 1). Likewise, site remediation is generally not a priority in these countries and current technologies for soil remediation are time consuming, too expensive, and in some cases create additional risks to the workers and produce secondary waste. Therefore, it is imperative to develop techniques that can treat and stabilize contaminants in situ in an efficient and cost effective manner.

Phytoremediation are technologies that use green or higher terrestrial plants for treating chemically- or radioactively- polluted soils (Wenzel et al., 1999). These technologies permit the decontamination in-situ, preserves the topsoil, reduces the amount of hazardous materials generated during clean-up and have public acceptance. Thereafter, the polluted plants have a proper control of the disposal and could be used to generate energy. Some of the disadvantages are related to the depth of the treatment and time required.

There are different fundamental processes by which plants can be used to remediate metal contaminated soils/ sediments (Wenzel et al., 1999):

- Containment processes: phytostabilisation and phytoimmobilisation; and
- Removal processes: phytoextraction, phytodegradation and phytovolatilization.

Among these technologies cleanup may be achieved with the removal processes to an extent depending on the type of contaminants and soil-chemical properties. The objective of this communication is to discuss basic concepts relating to phytoextraction of metal-polluted soils as well as some limitations to and perspectives for applying this method in Latin America.

Table 1 Mining ores and some polluted sites reported in Latin America.

Country	Mine ores Ginocchio (2003)	Metal contaminated sites	
Argentina	Zn, Pb, Cu, Au		
Bolivia	Au, Sn, Sb.	Muñoz, 2004	Hg
Brazil	Al, Au, Fe, Mn, Sn	Biller, 1994 Da Silva et al., 2003	Hg Cd, Zn
Chile	Cu	Ginnochio, 2000, 2003; Bech, 2002	Cu, As
Colombia	Ni, Au, and Fe-Ni		
Cuba, Puerto Rico Dominican Republic	Fe-Ni, Co		
Ecuador		Bech, 2002	As, Cu, Zn, Cd
		Requelme et al., 2003	Hg
Mexico	Ag, As, Cu, Pb, Mn, Mo, Zn	Bech et al., 1997; Razo et al., 2004	As
		Valdés & Cabrera, 1999	Pb
Peru	Cu, Au, Fe, Ag, Pb, Sn, Zn	Tolmos, 2000; Bech, 1997	Cu, As, Zn, Cd
Uruguay		Intendencia Municipal de Montevideo, 2003	Pb
Venezuela	Al, Au, Fe, Co, steel, bauxite, alumina, Fe-Ni		

Basically, a phytoremediation project consist of different phases, the application of which is mainly a function of the available time-costs:

- Sampling and analysis of native species and soils in polluted areas.
- Greenhouse experiments:
    - Hydroponic experiments (1-2 months): Rooted plants grown in pots containing a modified nutrient solution. After an acclimatization period, plants are exposed to different metal treatments. It is recommended in particular that the capacity of the plant for (hyper)accumulation and tolerance to metals be evaluated, phytotoxicity essays, or to carry out a fast screening among many species;
    - Pot experiments (1 vegetation period): the most promising species are planted in naturally polluted or spiked soils;
- Field experiments (minimum 1 vegetation period): the most promising species are planted in the polluted soil. The same species should be also evaluated in other soils and under other environmental conditions to verify the phytoremediation potential of the selected plants, and to confirm whether the property of accumulation, for example, is constitutive in the plant.

In parallel, experiments can be carried out to enhance the phytoremediation potential of the plants, e.g. improving the biomass production or increasing the metal bioavailability. The use of mycorrhiza has also been suggested to enhance the phytoextraction process or to help establishment of the plants in polluted soils (González-Chávez et al., 2002). Genomic approaches are increasingly being employed in phytoremediation-related research (Krämer, 2005) but there is a limitation related to public acceptance.

Phytoextraction

Phytoextraction processes extract both metallic and organic constituents from soil by direct uptake into plants and translocation to aboveground biomass using metal-(hyper)accumulating plants. The criteria described by Brooks (1998) to define hyperaccumulators are:

- Exceeding the hyperaccumulation threshold: Concentration 100 times higher than in normal plants for each metal of interest, i.e. (mg kg^{-1}): 100 Cd; 1000 As, Ni; 10000 Zn, Mn, etc.;
- Bioconcentration factor > 1 (concentration of the element in the plant > concentration in the soil); and
- Translocation factor > 1 (element concentration in the overground part of the plant > than in roots).

To date, the best studied hyperaccumulators (< 0.2% angiosperms) are: *Brassica juncea, Brassica oleracea, Berkeya coddii, Allysum bertolonii, Thlaspi caerulescens* and *Thlaspi goesingense*. Likewise, numerous plants with hyperaccumulation potential or tolerance to metals have been discovered in Brazil, Chile, Cuba, the Dominican Republic and Venezuela and include Ni (89%), Cu (5%) and As (3%) hyperaccumulators (Ginocchio & Backer, 2004).

Hyperaccumulators have been suggested for phytoextraction because of the large quantities of a specific metal that they are able to accumulate. However, most of these plants achieve low shoot biomass, which consequently considerable time period necessary for the remediation before an acceptable metal level in the soils is reached. Therefore, the use of trees in phytoextraction has been suggested and recently reviewed by Pulford & Dickinson (2005). *Alnus incana, Betula pendula, Fraxinius excelsior, Sorbus mongoeotii*, *Salix* and *Populus* species are some of the trees reported to grow on contaminated lands. Based on screenings, it has been found that *Salix* (willows) and *Populus* (poplars) are capable of accumulating metals, especially Cd and Zn in substantially large amounts in their leaves. Large metal concentrations (300 mg Cd kg^{-1}) were found in leaves of *Salix smithiana* BOKU 03 CZ-001*, S. purpurea* BOKU 05 CZ-001 and *S. caprea* BOKU 01 AT-004 clones growing on contaminated soils (Cd_{total} 30 mg kg^{-1}) (Dos Santos et al., submitted) and in shoots of *S.viminalis* (2695 mg Zn kg^{-1}) grown on an acidic soil (Zn_{total} 1158 $mgkg^{-1}$) (Hammer et al., 2003).

The phytoextraction process can be continuous (natural) using (hyper)accumulators or induced through the addition of chelates to increase the soil bioavailability. However, some authors have reported the persistence of metallic complexes in the water of the soil for several weeks in experiments using EDTA (ethylenediamine tetraacetic acid) to induce the phytoextraction (Lombi et al., 2001; Wenzel et al., 2003). For this reason, the chelates must be handled with care to avoid possible environmental risks due to the leachate enriched with metals.

Perspectives and limitations in Latin America

Currently, public institutions and private companies in Latin America are applying phytoremediation technologies to remediate soils polluted with organic compounds (Heidtmann, 2001, Fernandez et al., 2001; Olguin, 2001). However, there is a scarcity of studies aimed at cleaning up sites contaminated with heavy metals using phytoremediation technologies. Therefore this innovative and cost-effective alternative may present a potential market in Latin American countries, considering the numerous metallic ores in the region.

Potential species for phytoextraction purposes such as willows and poplars can be profitably used by the farmers i.e. for heat/ electricity production through the burning of harvested biomass. Also the comparative economics of the phytoremediation processes in general will also be a driving force for acceptance and include simple methods which can be applied by farmers.

Research on the following areas related to plant characterization and remediation of metal contaminated sites has been carried out in Latin America:

- Description of metal tolerant and hyperaccumulating plants (Brooks et al., 1992; Barreto and Casale, 2002; Flores-Tavizón et al., 2003; Reeves, 2003; Ginocchio, 2003, Ginocchio & Backer, 2004),
- Determination of soils, sediments and plants metal concentrations of species growing near the polluted sources, smelters, etc. (Jordao et al., 1999; Bech et al., 2002; Arribere et al., 2003; Carillo & González, 2005; Ginocchio, 2000),
- Studies related to metal accumulation and tolerance in seeds (Marques et al., 2000) and plants (Dos Santos et al., submitted);
- Revegetation (PUC-ECU, 1998),
- Use of microorganisms for phytoremediation purposes (Pérez et al., 2002) and
- Phytoremediation studies (Cusato et al., 2002, Pletsch et. al, 1999; Ortiz, 2002; Miretzki et al., 2004, Anderson et al., 2005).

Few metal-tolerant and metal-hyper accumulating plants have been reported for Latin America (172) in comparison with other areas of the world. Due to the scarcity of scientific studies of the native vegetation growing on natural mineralised or metal-contaminated sites (Ginocchio & Baker, 2004).

Plant selection criteria –prior to running a phytoremediation program in Latin America- should include the life cycle of the plant (dormancy period and harvest), plant cultivation, maintenance requirements and germination potential (Merkl et al., 2004), plant tolerance to the metals of interest, metal accumulation potential, easy propagation, availability of the plant material (commercially/ field), favourable root system and use of native (preferable) or introduced species.

Many studies related to soil and water characterization are unpublished, in the property of private companies or are not up to date. Only few sites near mining areas have been characterized due to the metal contamination and/ or recognized environmental and human risks. The scarcity of relevant publications in international journals does not help dissemination and effective transfer of information; this gives rise to unnecessary repetition and/ or loss of data of basic research.

It is very important not only to adapt the available study techniques to the climate, soil and vegetation conditions of the individual regions, but also consider the available technologies (maintenance/ monitoring) before phytoremediation technologies can be applied in the region. Special attention should be given to the metal-enriched biomass that requires a safe disposal. Recycling, incineration and/ or landfill solutions that should not be a problem in developed countries could be of limited availability in Latin America.

The social, economic and political situation in a given country also influences the strategies that governments choose to manage the problems of contamination (limit values), revegetation, etc. (Ginocchio, 2003). Local scientists have not been strongly involved in phytoremediation issues until recent years, maybe as result of the scarcity of resources (basic research, field experiments, analytical laboratories, etc.) and limited transfer of knowledge in this topic.

Conclusions

Phytoextraction in Latin America and in the developing countries in general, offers a feasible and economic alternative to achieve remediation of contaminated soils. It is hoped that governments will recognize the importance of the issues raised and support research on phytoremediation as a practical and effective technology for soil remediation. It is likely that governments could also draw on collateral funds from international agencies and other donors.

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