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Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils

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Abstract

This paper reviews the ecological aspects of mined soil restoration, with special emphasis on maintaining a long-term sustainable vegetation on toxic metal mine sites. The metal mined soils are man-made habitats which are very unstable and will become sources of air and water pollution. Establishment of a vegetation cover is essential to stabilize the bare area and to minimize the pollution problem. In addition to remediate the adverse physical and chemical properties of the sites, the choice of appropriate vegetation will be important. Phytostabilization and phytoextraction are two common phytoremediation techniques in treating metal-contaminated soils, for stabilizing toxic mine spoils, and the removal of toxic metals from the spoils respectively. Soil amendments should be added to aid stabilizing mine spoils, and to enhance metal uptake accordingly.

Keywords: Physical and chemical problems; Phytostabilization; Phytoextraction; Phytofiltration

1. Introduction

Mining activities generate a large amount of waste rocks and tailings which deposited at the surface. The land surface is damaged and the waste rocks and tailings are often very unstable and will become sources of pollution. The direct effects will be loss of cultivated land, forest or grazing land, and the overall loss of production. The indirect effects will include air and water pollution and siltation of rivers. These will eventually lead to the loss of biodiversity, amenity and economic wealth (Bradshaw, 1993). Restoration of a vegetation cover can fulfill the objectives of stabilization, pollution control, visual improvement and removal of threats to human beings. The constraints related to plant establishment, and amendment of the physical and chemical properties of the toxic metal-mined soils, and the choice of appropriate plant species will be discussed.

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2. Physical and chemical constraints of mined degraded soils

Mined degraded soils are man-made habitat which experience a wide range of problems for establishing and maintaining vegetation, depending on the types of mines such as metal mines, coal mines and quarries. The physico-chemical properties of the metal-contaminated soils tend to inhibit soil-forming processes and plant growth. In addition to elevated metal concentrations, other adverse factors included absence of topsoil; periodic sheet erosion; drought; surface mobility; compaction; wide temperature fluctuations; absence of soil-forming fine materials; and shortage of essential nutrients (Wong et al., 1999a,b).

The original soil of mine degraded lands is usually lost or damaged, with only skeletal materials. There is commonly a lack of organic matter and its associated nutrients such as nitrogen (N) in most degraded land materials. Organic matter provides a continuous source of nutrients, e.g., it provides most of the N reserve in

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Table 1
Factors that may affect the bioavailability of metals (from Adriano et al., 1997)

Soil capacity	Plant capacity	Environmental and other factors
pH	Plant species	Climatic conditions
Cation exchange capacity	Plant cultivars	Management practices
Organic matter	Plant part and age	Irrigation water/ salinity
Amount and type of clay	Ion interactions	
Oxides of Fe and Mn		
Redox potential		

soils and comprises typically 5% N which is mineralized at about 2% per year (Harris et al., 1996).

For soils contaminated by heavy metals such as copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn), metal toxicity would restrict the growth of all but the most tolerant plants. Toxic metals can also adversely affect the number, diversity and activity of soil organisms, inhibiting soil organic matter decomposition and N mineralization processes. However, toxicity is not a simple matter of particular concentrations of substances being toxic to a plant. The chemical form of the potential toxic metal, the presence of other chemicals which may aggravate or ameliorate metal toxicity, the prevailing pH and nutrient status of the contaminated soil will affect the way plants respond to the toxic metal. Substrate pH affects plant growth mainly through its effect on the solubility of chemicals, including toxic metals and nutrients. It is commonly recognized that at pH 6.5 nutrient availability to plants is at a maximum and toxicity at a minimum (Harris et al., 1996). Table 1 lists the factors that may affect the bioavailability of metals (Adriano et al., 1997).

The bioavailability of heavy metals to plants and soil ?tul=0>biota including fauna and microorganisms is controlled by their total concentration in the soil and their chemical forms. As to plants, the bioavailability is governed by the factors that control the activity of soluble metal species in the soil solution that is preferentially taken up (Thornton, 1999). Methods for determining the soluble and thus bioavailable fractions of metals in soils have been extensively studied for the past 20 years. For the soil-plant/microorganisms pathway, these included the use of (a) single chemical extractants of varying concentrations, such as EDTA, DTPA, acetic acid and 0.01 M $CaCl_2$ (Allen, 1989) and (b) operationally defined sequential extraction procedures (Tessier et al., 1979) in which increasing strong extractants are used to release metals associated with different soil fractions.

3. Treatment of physical and chemical problems

Techniques such as crushing, compacting, ripping, grading, and drainage are employed to improve physical conditions of mine degraded soils. Terracing planting, use of run-off channels and stabilization ponds, and mulches should be practiced. Erosion control could be achieved once an overall plant cover has been established.

Topsoil is used to cover poor substrates and to provide improved growing conditions for plants. To maintain a good topsoil quality is a must for any revegetation scheme. In addition to a suitable physical property, application of appropriate fertilizers, and inoculation of nitrogen-fixing bacteria and mycorrhiza would facilitate reconstruction of self-sustained ecosystems. The role of other soil organisms, e.g. earthworms in maintaining soil fertility should not be overlooked (Ma et al., in press).

Organic wastes such as sewage sludge and refuse or manure compost can be used as soil amendment and to certain extent as a slow release nutrient source. Table 2 shows the organic matter and nutrient content of some common organic materials which could be used to lower metal availability, in addition to remediating the physical and chemical properties of the spoils, and the provision of plant nutrients (Bradshaw and Chadwick, 1980). Plant residues (e.g. rice and barley straw) can be used as a mulch to insulate the surface from temperature extremes, permits the soil to absorb moisture and reduce water erosion. In addition to organic amendments, inorganic amendments are used to improve substrate characteristics. These included quarry waste, pulverized refuse, pulverized fuel ash, etc. Inert materials including colliery spoils and steel slag are very often necessary to serve as an insulation layer, to avoid upward migration of toxic elements to the topsoil. It is a common practice to apply liming materials to overcome some of the problems associated with acidic condition.

Table 2
Nutrient and organic matter contents of some organic soil amendments (from Bradshaw and Chadwick, 1980) (% dry solids)

Material	Nitrogen	Phosphorus	Potassium	Organic matter
Farmyard manure	0.6	0.1	0.5	26
Poultry manure	2.3	0.9	1.6	68
Sewage sludge	2.0	0.3	0.2	45
Domestic refuse	0.5	0.2	0.3	65
Straw	0.5	0.1	0.8	95