Assessing phytoextraction: biogeochemical and economic viability.

Brett Robinson, Jose-Enrique Fernandez, Steve Green, Brent Clothier, Iris Vogeler, Thabo Thayalakumaran, Lindsay Fung, Markus Deurer, Carlo van den Dijssel and Sarah Hurst

HortResearch, Private Bag 11 030, Palmerston North, New Zealand.
e-mail: brobinson@hortresearch.co.nz

1. Introduction

Ever since the pioneering studies on plants that hyperaccumulate heavy-metals by R.R. Brooks, their potential use for the extraction of heavy-metals from soils has been investigated. Studies by McGrath et al. (1993) and Baker et al. (1994) demonstrated that the hyperaccumulator *Thlaspi caerulescens* had potential use for the *in situ* remediation of zinc contaminated soils. The technology of *phytoremediation*, defined as the use of plants and their associated microflora to remove, degrade or render harmless environmental contaminants, is now burgeoning.

Nicks and Chambers (1994) reported pioneering studies on a second use for hyperaccumulator plants: the use of plants for economic gain in the mining industry. This operation, termed *phytomining* includes the generation of profit by extracting saleable heavy-metals from sub-economic ore bodies

The technology of phytoextraction is inherently limited by the mass of metal a single crop of plants can remove. Hyperaccumulator plants have a high metal concentration, however, their biomass production is usually inferior to non-hyperaccumulator plants. Moreover for some common metals such as lead (Pb), there are no reliable reports of any hyperaccumulator species. A possible solution to these problems is the *induced hyperaccumulaton*. Non-hyperaccumulator plants can be made to take up metals such as lead or even gold by the addition of solubilising agents to the substrate (Anderson et al., 1998). Such additions mobilise the metal in the soil, allowing it to be taken up by the plant or leach down the soil profile, possibly into groundwater. Soil amendments may also be persistent in the environment propounding the problem.

The aim of this study was to collate knowledge on the phytoextraction of heavy-metals from metalliferous soils to create a framework that will allow the assessment of phytoextraction as a viable option for land-management.

2. Materials and methods

Studies conducted at HortResearch and Massey University, Palmerston North investigated relationships between plant metal uptake and various environmental parameters such as soil-metal concentrations, the soluble fraction in the soil and plant water-use. Both hyperaccumulator plants (*Berkheya coddii, Alyssum bertolonii, Thlaspi caerulescens, Iberis intermedia*) and non-hyperaccumulator plants (*Populus spp., Salix spp., Brassica juncea, Arrhenatherum elatius*) were studied.

A framework was created considering both the biogeochemical and economic aspects of phytoextraction using contaminated sites surrounding the Guadiamar river, Southern Spain as a case study.

3. Results and discussion.

Plant uptake of heavy-metals was found to be driven by transpiration. High water use aligns with high metal uptake. Important factors determining the amount of metal taken up in the transpiration stream are the solubility of the metal in the soil and the ease by which that metal can pass from the root apoplast to the symplast. Root permissivity is dependant on the plant species. The effectiveness of phytoremediation is therefore primarily dependant on the plant species used and the solubility of the contaminant in the soil. The operation is negatively affected by factors that reduce transpiration, such as drought and toxic soil factors. The change in contaminant concentration at a given depth may be calculated by:

$$\Delta[M]_z = \frac{1}{\rho_z}\int_0^{\tau} R_z T C \phi \; d\tau$$

where: $\Delta[M]_z$ = change in contaminant metal at depth z (mg kg^{-1}), ρ_z = bulk density of the soil at depth z (g cm^{-2}), τ = time (days), R_z = root density fraction at depth z = (root mass at depth z) / (total root mass), T = water use (L day^{-1}), C = concentration of metal in soil solution (mg L^{-1}), $\varnothing$= root permissivity for the metal =root symplast/apoplast metal concentration coefficient. It is clear from the above equation that the phytoextraction process can be enhanced by increasing the concentration of metal in the soil solution (C). This may be done by using soil amendments such as chelates. In such cases, a simple metal mass balance calculation is essential. Decreases in soil metal concentration may be due to 1) plant uptake, 2) a re-distribution of metal down the soil profile, or 3) leaching of the metal into groundwater. Soil processes such as preferential flow may exacerbate metal leaching (Bundt *et al.,* 2000)

4. When should phytoextraction be used?

The basic requirement for any phytoextraction operation is that the extracting crop will grow. This precludes the use of phytoextraction in extremely hot, cold or dry climates. Soil toxicity should not prohibit plant-growth and the plants should be able to out-compete weeds as well as survive pests and pathogens.

If these requirements are met, then the decision weather or not to use phytoextraction depends on solely on economic considerations. When assessing its viability, cost phytoextraction should be compared to the cost of doing nothing and the cost of the most effective alternative technology. In most cases, the productivity of the remediated land does not even cover the interest on an operation such as physical removal of the contaminated soil. Remediation is therefore driven by legal obligation and the 'goodwill' of he organisation responsible for the land.

If the phytoextraction operation generates a profit via the production of wood, fibre, fuel or metal, then the time taken to remediate the land is usually unimportant. The major barrier to the use of phytoextraction is public and legal perceptions of the technology.

5. References

Anderson, C.W.N., Brooks, R.R., Stewart, R.B. and Simcock, R. 1998. Induced hyperaccumulation of gold in plants. Nature. **395**, 553-554.

Baker, A.J.M., McGrath, S.P., Sidoli, C.M.D. and Reeves, R.D. 1994. The possibility of in situ metal decontamination of polluted soils using crops of metal-accumulating plants – a feasibility study. Resources, Conservation and Recycling. **11**. 41-49

Bundt, M., Albrecht, A., Froidevaux, P., Blaser, P. and Fluhler H. 2000. Impact of Preferential Flow on Radionuclide Distribution in Soil. Environ. Sci. Technol. **34**, 3895 – 3899.

McGrath S P, Sidoli C M D, Baker A J M and Reeves R D 1993 The potential for the use of metal-accumulating plants for the *in situ* decontamination of metal-polluted soils. *In* Integrated Soil and Sediment Research: A Basis for Proper Protection. Eds. H.J.P Eijsackers and T.Hamers. pp.673-676. Kluwer Academic Publishers, Dordrecht.

Nicks,L. and Chambers,M.F., 1994. Nickel farm. Discover, September: 19.