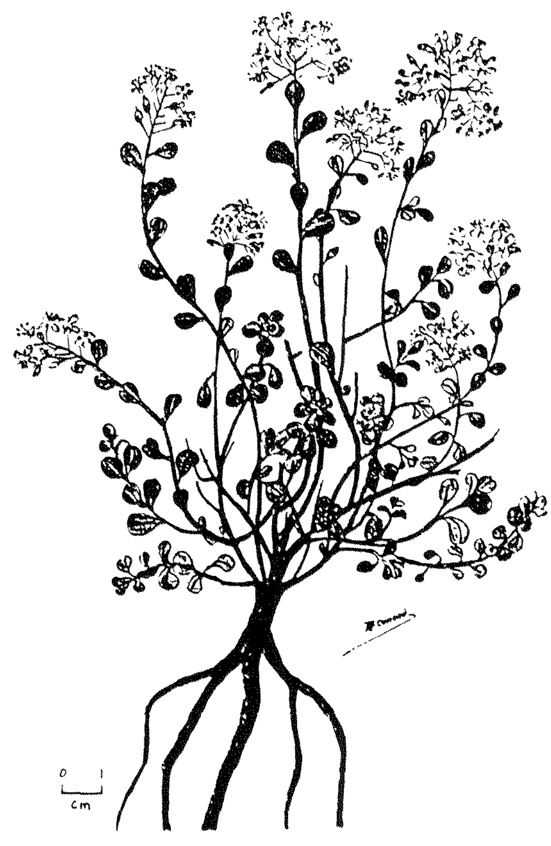
The phytoextraction of heavy metals from metalliferous soils



A thesis presented in partial fulfilment of
the requirements for the degree of Doctor of
Philosophy at Massey University

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1997

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Abstract

This study concerns the investigation of the potential use of plants to remove heavy metals, in particular nickel, zinc and cadmium, from soils. The study is divided into three sections, bioavailability, phytomining, and phytoremediation.

The effect of various extractants on the solubility of heavy metals in some soils was tested. It was found that the solubility of the metal invariably increased as the pH of the extractant decreased, and as the concentration of the extractant increased. These relationships could be predicted mathematically. It concluded that a more concentrated, neutral, non-chelating extractant such as 1M ammonium acetate, is the most suitable for estimating bioavailability.

An investigation into the addition of some compounds to soils to increase metal solubility showed that EDTA and citric acid should maximise solubility while keeping soil parameters (pH, osmotic potential, nutrient availability) within the growth range of the plant. These compounds are also relatively inexpensive. The effect of bioavailable elements on a New Zealand serpentine flora was investigated with regard to the soil's potential for phytoextraction. It was found that nickel was the only element that would be suitable for phytoextraction from these soils. The relative infertility of the serpentines was attributed primarily to the toxic effects of magnesium and/or nickel. Removing nickel from the soil by phytoextraction may enable the soil to be used as a magnesium-rich fertiliser.

The potential of the hyperaccumulator plants *Alyssum bertolonii* and *Berkheya coddii* for nickel phytoextraction was studied. With the addition of fertilisers, the plants could remove respectively in excess of 72 kg and 100 kg of nickel per hectare per annum. Were the metal to be sold, and energy from the plant's incineration utilised, the net profit per hectare would be greater than that of a crop of wheat. Both of these plants re-grew after harvesting without the need to re-sow. In the case of *B. coddii,* the nickel concentration in the regrowth was more than twice that of the original crop. Phytomining for nickel is a viable proposition provided the operation is carried out over a large area. The nickel concentration in the plants was logarithmically related to the nickel extracted by a 1M ammonium acetate extract. Theoretical nickel yields from various soils could be predicted by performing a 1M ammonium acetate extraction on the soils. About half of the soils tested from various locations around the world contained enough soluble nickel to be economically phytomined. *Alyssum bertolonii* and *B.*

coddii also have the potential to remove nickel from polluted soils. The addition of EDTA and citric acid to the soil in which the plants grew actually decreased the nickel concentration in the plants despite increasing the nickel solubility in the soil. The economics of phytomining are closely linked to the value of the metal. Cobalt and possibly even the noble metals could be economically phytomined at low concentrations in plants: a fertile area for future research.

Sequential extractions were used to model the effect of successive hyperaccumulator crops on the bioavailability of nickel in ultramafic soils from around the world. The nickel concentration in all of the soils tested, decreased in a regular manner and could be predicted mathematically. Assuming an initial nickel crop of 100 kg/ha, the number of nickel crops above 70 kg/ha that could be obtained was calculated for each soil. The number of economic nickel crops varied between 3 and 18 before the soil would have to have been modified to increase nickel bioavailability.

The possibility of removing zinc and cadmium using *Thlaspi caerulescens* showed that the plant has a potential use for removing cadmium from weakly polluted soils. The low bioaccumulation factor for zinc accumulation means that this element will never be removed in a reasonable time span. The concentration of both zinc and cadmium in the plant could be predicted by the extractable fraction in the soil as estimated by using 1M ammonium acetate as extractant.

It was concluded that phytomining and phytoremediation are feasible possibilities under certain conditions. (1) Metals necessarily have to be slightly soluble in the soil before they can be phytoextracted. Metal solubility may be improved by the addition of chemicals such as chelating agents. (2) Due to relatively low yields, phytomining will only be viable for more valuable elements where the concentrations in soils are too low for conventional mining. (3) Phytoremediation will be most effective on weakly polluted soils. (4) The economics of phytoextraction favour its use over large areas. The amount of metal able to be extracted from an area can be predicted by performing an extraction with 1M ammonium acetate.

ACKNOWLEDGEMENTS

I would like to express thanks to my supervisors, Prof. R.R. Brooks, Assoc. Prof. J.H. Kirkman, and Assoc. Prof. P.E. Gregg in New Zealand, and Prof. D. Petit in France, for their advice, assistance and encouragement throughout the period of this work. I also thank everyone in the department of soil science for making this work possible.

I am extremely grateful to Julie Hanna for assistance on field trips and in the lab for the duration of this work. Patrizia Gremigni helped collect and analyse samples from serpentines in the Nelson region. Hugo Varela Alvarez gave useful assistance in using the SAS programme for PCA. Joe Whitten carried out XRD work on some of the ultramafic soils.

Rorison Mineral Developments Ltd. of Piopio, gave us large amounts of serpentine mineral which was used in the outside plots here at Massey.

Thanks are also due to Alessandro Chiarucci, his family, and Ilaria Bonini for making the Italian work possible (and also making it very enjoyable). Carlo Celesti gave valuable assistance with the plasma emission analyses.

The Delmot family in Saint Laurent le Minier gave great assistance in sample retrieval and construction of *Thlaspi* plots. Dr. Marc Leblanc collected some of the vegetation samples from the same area.

I thank the staff and students at the Laboratoire de Génétique et Evolution, Université de Lille for making my stay there very enjoyable

My trip to Europe was possible thanks to a scholarship from the French government.

I am greatly indebted to Massey University for a doctoral scholarship. I acknowledge the receipt of a MURF and a Helen E. Akers scholarship for operational expenses.

Finally I would like to express my deepest thanks to all my family for their support and encouragement from the word go.

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