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Phytoextraction of metals from contaminated soils – the basic principles

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Metal hyperaccumulation includes the following traits: 1) highly efficient root uptake, 2) enhanced root to shoot transport, 3) hypertolerance of metal(s), involving internal complexation and compartmentation (McGrath and Zhao, 2003). Model calculations demonstrate that both good biomass yields and, particularly, metal hyperaccumulation are required in order to make phytoextraction efficient over relatively short time periods. With rare exceptions, most plants have a bioconcentration factor (metal concentration in above ground parts/metal concentration in the topsoil) for heavy metals and metalloids of much smaller than 1. For these plants, phytoextraction is not feasible regardless how large their biomass production is, because the number of crops required to reduce the concentration of a metal in the top soil by half is much in excess of 100.

Therefore, it is emphasised that the ability to hyperaccumulate metals should be demonstrated on real field contaminated soils. Bioconcentration factors obtained from studies using hydroponic culture, sand culture, or even soils spiked with soluble metals, do not give a realistic measure of how the plants will perform on field contaminated soils, where metals are usually much less bioavailable. Hydroponic culture or metal spiking experiments are useful for investigating mechanisms of metal uptake and tolerance, but often the results cannot be extrapolated to the field. Metal tolerance is also important, because metal-sensitive plants are not likely to establish and produce large biomass on contaminated soils. Non-hyperaccumulators may achieve an apparently large bioconcentration factor under conditions of metal toxicity, when growth has been severely inhibited. For these reasons phytoextraction is impossible with non-hyperaccumulators.

Addition of chelators such as EDTA has been shown to greatly enhance metal sol-

ubility and induce Pb hyperaccumulation in a range of plant species that are otherwise non-hyperaccumulators (Blaylock et al., 1997; Huang et al., 1997). A similar approach has been applied to induce uranium hyperaccumulation by plants with the addition of citric acid to soil (Huang et al., 1998). However, applications of synthetic chelators such as EDTA can lead to a substantially increased risk of leaching of metals to groundwater. This environmental risk is likely to limit the usefulness of chelator-induced phytoextraction. One way to deal with this risk is to use hydrological barriers. However, due to the costs of construction of hydrological barriers, it would probably be simpler and quicker to flush metals out of the soils using chelators, without growing plants. Such operations require that the chelators to be used are cheap and easily degradable in soil; meeting both of these criteria is not easy.

These findings mean that it is necessary to understand the traits and the exact mechanisms responsible for hyperaccumulation, using natural hyperaccumulators as model plant species. Recent advances have been made in understanding the mechanisms responsible for hyperaccumulation of Zn, Cd, Ni and As by plants. We have investigated Cd hyperaccumulation by two contrasting ecotypes of the model species *Thlaspi caerulescens*. Our work on the root transporter suggests that a high-affinity Cd transporter may exist in the high Cd accumulating ecotype (Lombi et al, 2002), and this means that there is scope to screen and select more efficient genotypes of metal hyperaccumulators. We have also studied the rhizosphere processes associated with Zn/Cd hyperaccumulation in *T. caerulescens*, and found that root exudates and rhizosphere acidification were not involved. However, it has been shown that *T. caerulescens* was able to proliferate its roots in metal-rich zones. Recent research on the segregation of hyperaccumulation traits in reciprocal crosses of the two ecotypes shows that Cd accumulation is governed by multiple genes, and that Cd tolerance and accumulation are independent traits in *T. caerulescens* (Zha et al, 2004). Examples of attempts to engineer metal tolerance and accumulation in plants are limited to Hg, As and Cd at present and although there are a few promising demonstrations, they may be some way from practical application in phytoextraction.

In conclusion, more research is needed in order to give a fundamental understanding of the traits and mechanisms involved in hyperaccumulation before these can be transferred to high biomass plants so that phytoextraction can be optimised in future.

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