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Fact Sheet

Fact Sheet 768

PHYTOREMEDIATION–PLANT-BASED STRATEGIES FOR CLEANING UP CONTAMINATED SOILS
Metal Contaminants

The use of plant systems for cleaning up soils contaminated with organic compounds was discussed in Fact Sheet 764, "Phytoremediation–Plant-based strategies for cleaning up contaminated soils. Organic Contaminants." One of the most appealing attributes of plant-based cleanup approaches is that when the appropriate plants are used, the approaches can be used on sites that are contaminated with heavy metals as well as organic contaminants. The second part of this discussion on phytoremediation focuses on the use of plant systems for remediating heavy metal contamination.

Phytoremediation of metal contamination has received research attention for far longer than the use of the strategy for remediation of organics contamination; however, both strategies share at least one historical similarity. Like the effects of plants on organic compounds, knowledge of plant uptake of metals has existed for quite some time, but application of this knowledge to remediation is relatively new. For example, geologists in the mining industry have long used 'indicator' plants to locate sites with lucrative mining potential. Indeed, the disciplines called *geobotany*, *biogeochemistry*, and *phytochemistry* have long dealt with issues ranging from type and distribution of plants common to metal-rich soils to the levels, function, and mechanisms of tolerance of metals within plants. Now, these disciplines are being applied to remediation of metal contamination. Perhaps the major reason why full- and large-scale deployment of metal phytoremediation has not kept pace with the length or intensity of research exploration is the specialized nature of most of the plants that are effective in removing high levels of metals from their growth media. Because of the uniqueness of many of these plants their growth conditions are generally not well known. Furthermore, these specialized plants are not high biomass producers, a likely consequence of their unusual adaptation to harsh ecological niches. So, while the amounts of metal concentration per unit of plant biomass can be high, the total amounts of metal removed at a site during a given period can be quite low. Increasingly, there is better understanding of the cultural conditions of such plants, and management practices that further enhance these plants' metal uptake capabilities are integral parts of phytoremediation applications. Perhaps more importantly, research is progressing in efforts to address the issue of biomass production through genetic engineering.

The Phenomenon of Hyperaccumulation of Metal by Plants: What Is It? How and Why Does It Occur?

Hyperaccumulator is the term used to describe certain plants that can take up and accumulate metals in their shoots at concentrations toxic to normal plants. For most metals, this concentration is greater than 1,000 parts per million (ppm); for manganese and zinc, the threshold concentration for characterization as hyperaccumulator is 10,000 ppm because many plants tend to take up those elements almost in direct proportion to their availability in soil. Important as the hyperaccumulator terminology is, there are even more important and intriguing questions about how some plants take up metals against physiological gradients and accumulate them in their shoots; how they tolerate such high metal concentrations; and

whether high metal concentrations confer additional advantages on hyperaccumulators other than the ability to colonize environments with elevated metal levels. Understanding these issues is essential to effectively exploit the full potential of such plants for cleaning up metal contamination.

Metal hyperaccumulation is an evolutionary adaptation of some plants to soils formed from parent materials that are rich in specific minerals. This characteristic confers on such plants an ecological advantage over other plants to which elevated metals concentrations are detrimental to growth. Accordingly, metal hyperaccumulators appear to be restricted to localized geographical regions that have specific mineral enrichments. These locations range widely, from Central Europe to New Caledonia and Central Africa (Table 1). Plant families that possess this characteristic are just as diverse as the diversity of locations (Table 1); however, the most studied to date belong to the brassica family, which contains several members that hyperaccumulate nickel and zinc.

But how do hyperaccumulators tolerate extremely high levels of metals in their tissues? Tolerance of high concentrations of metals is genetically controlled, which enables the hyperaccumulator plants to produce specific molecules that bind metals into complexes that can then be stored (compartmentalized), thereby eliminating encroachment on sensitive tissues. These molecules are reported to be low molecular weight peptides called *phytochelatins* and their production has been shown to be triggered in certain plants by increasing the concentration of specific metals in their growth environment. Other reports suggest that, in some plants, metals are also complexed with organic acids such as citric, oxalic, and malic acids. The involvement of organic acids is interesting. Most of those reported to be involved also belong to reactions of the tricarboxylic acid cycle (TCA), which is a central pathway of energy generation for aerobic organisms. The significance of this coincidence has not been elucidated. One thing is significant, however. It is known that some plants can survive quite well under elevated metal conditions without the hyperaccumulation characteristic. These plants appear to tolerate metals in their environment by using a variety of mechanisms, including exudation of compounds that complex metals in the contaminated environment, thereby preventing their entry into the root in the first place.

In view of the fact that other tolerance mechanisms exist for surviving environments with elevated metal levels, the reason plants adopt hyperaccumulation (which appears to be a more costly strategy) is unclear. In addition to the obvious competitive advantage that it affords specific plants from a colonization standpoint, other functions have been ascribed to the phenomenon of hyperaccumulation. For example, it has been suggested that high levels of metals accumulated in cell walls can be helpful in preventing moisture loss under drying conditions. It has also been proposed that some hyperaccumulators under water stress conditions might use high metal concentrations in sap as a moisture management strategy. Finally, it has been suggested that high levels of metals in plants' foliage might act as protection from feeding animals or insects by making the foliage unpalatable or deadly to the feeding party. At this time, for each suggestion that has been advanced to explain the ecophysiological function of hyperaccumulation, several examples have been found that bring those contentions into question. For example, hyperaccumulators have been found at perennial swamp locations, which would cast doubt on the moisture management function of the characteristic. Also, animals have been found to feed quite well on some hyperaccumulators with no perceived problems.

Like phytoremediation of organics contamination, activity leading to the full-scale deployment of phytoremediation of metal contamination has continued at an intense pace. To date, plant species have been identified that can be used for removing copper, cadmium, cobalt, manganese, nickel, and zinc from soils containing contaminant levels of those elements. There is also a potential for use of phytoremediation on sites contaminated with radionuclides. In spite of the great promise, field implementation of the practice has continued to lag behind the tremendous research activity. As explained above, some of the difficulty in implementing the practice is related to limited knowledge of all the cultural requirements of specialized plants involved in the processes. It appears that these limitations are now crumbling at a fast pace. As evidence, a research team including Drs. Scott Angle, associate Agricultural Experiment Station director, University of Maryland; Rufus Chaney, Senior Scientist of the Beltsville Agricultural Research Center (USDA); and Alan Baker, botanist at the University of Sheffield, England, have patented a new technology for using phytoremediation for mining economic levels of nickel and cobalt in soil ("Plants are key to successful metal mining technology," *Outlook*, University of Maryland

Faculty and Staff Newspaper, March 2, 1999). It now seems only a matter of time until the full potential of metal phytoremediation is realized.

Future Phytoremediation Needs for Heavy Metals and Other Inorganics

Again, like the application of phytoremediation to organics contamination, a number of issues remain to be addressed before the full potential of phytoremediation of inorganic elements can be realized. Some of the more obvious include

- Search for plants with superior hyperaccumulation potential for metals and other inorganics, including P whose contribution to environmental degradation in Maryland is well-documented,
- Elucidate mechanisms of plant uptake and tolerance of excessively high levels of inorganic contaminants–which should lead to greater ability to manipulate plants for further enhanced remediation, and
- Study cultural requirements of the specialized hyperaccumulator plants.

Already, genetic engineering has been employed to develop plants that can enhance removal of metal toxicants such as mercury, utilizing bacterial genes inserted into a plant that is normally considered a weed (see Rugh in References). In contrast to the unquestioned use of naturally occurring plants for phytoremediation, the use of genetically manipulated plants will undoubtedly come under public scrutiny. The potential for phytoremediation of metal contaminants is enormous. However, technical as well as social issues relating to the full implementation of these strategies need to be satisfactorily addressed.

References

Additional technical and nontechnical information on phytoremediation can be obtained from these selected references:

Baker, A.J.M. and R.R. Brooks. 1990. "Terrestrial higher plants that hyperaccumulate metallic elements–A review of their distribution, ecology and phytochemistry." *Biorecovery*, 1:81.

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Rugh, C.L., H.D. Wilde, N.C. Stack, D.M. Thompson, A.O. Summers, and R.B. Meagher. 1996. "Mercuric ion reduction and resistance in transgenic *Arabidopsis thaliana* plants expressing a modified bacterial merA gene." Proceedings, National Academy of Sciences, 93:3182-3187.

Phytonet Links: http//www.dsa.unipr.it/phytonet/links.htm.

Table 1. Abbreviated List of Hyperaccumulator Families and Their Distribution.[1]

Predominant Metal Hyperaccumulation	Plant Family	Geographic Distribution
Co, Cu	Lamiaceae Scrophulariaceae Asteraceae Cyperaceae	Zambian copper belt; Shaban copper arc
Pb	Plumbaginaceae Brassicaceae Caryophyllaceae	Hartz Mts. (Central Germany); Australia
Mn	Apocynaceae Proteaceae Calastraceae	New Caledonia, Italy, Central Europe
Ni	Brassicaceae Violaceae Flacourtiaceae	Italy, New Caledonia, the Philippines, Western USA
Zn	Brassicaceae Violaceae Lamiaceae	Germany, U.K., Dem. Republic of Congo

1 Summarized from Baker and Brooks. 1989.

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Metal Contaminants

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