

Eapen, S. and S. F. D'Souza (2005). Prospects of genetic engineering of plants for phytoremediation of toxic metals. *Biotechnology Advances*. S. Eapen. 23: 97. Bioremediation is gaining a lot of importance in recent times as an alternate technology for removal of elemental pollutants in soil and water, which require effective methods of decontamination. Phytoremediation -- the use of green plants to remove, contain or render harmless environmental pollutants -- may offer an effective, environmentally nondestructive and cheap remediation method. The use of genetic engineering to modify plants for metal uptake, transport and sequestration may open up new avenues for enhancing efficiency of phytoremediation. Metal chelator, metal transporter, metallothionein (MT), and phytochelatin (PC) genes have been transferred to plants for improved metal uptake and sequestration. Transgenic plants, which detoxify/accumulate cadmium, lead, mercury, arsenic and selenium have been developed. A better understanding of the mechanisms of rhizosphere interaction, uptake, transport and sequestration of metals in hyperaccumulator plants will lead to designing novel transgenic plants with improved remediation traits. As more genes related to metal metabolism are discovered, facilitated by the genome sequencing projects, new vistas will be opened up for development of efficient transgenic plants for phytoremediation.

Eastham, J. and T. Morald (2006). Effective nutrient sources for plant growth on bauxite residue: II. Evaluating the response to inorganic fertilizers. *Water, Air, and Soil Pollution*. J. Eastham. 171: 315. An integral part of managing dust emissions from bauxite residue storage areas in Western Australia is the establishment of native vegetation and dust control crops. Recent changes to local health department regulations preclude the routine use of poultry manure, the previous standard fertilizer for growing dust control crops on bauxite residue sand. This paper reports on a field evaluation of different forms of inorganic fertilizer, to assess their effectiveness as alternatives to poultry manure for supplying nutrients to dust control crops. We compared plant growth and nutrient uptake under different forms of nitrogen (N) and phosphorus (P) fertilizers with additional potassium (K) and trace elements. A diammonium phosphate (DAP) based fertilizer blend which supplied 270 kg N ha<sup>-1</sup> of N and 307.5 kg P ha<sup>-1</sup> was found to be more effective than a superphosphate based blend containing the same amounts of these nutrients. The DAP treatment did not respond to topdressing with different N fertilizers, but plant growth in the superphosphate treatment was responsive to topdressing with N. Of the three different nitrogenous fertilizers evaluated for topdressing the superphosphate treatment (ammonium sulphate, diammonium phosphate, and urea), the ammonium based fertilizers were most effective. The DAP blend was the most cost effective of all the fertilizers studied, costing only A\$1070 ha<sup>-1</sup> compared with A\$2473 ha<sup>-1</sup> for the superphosphate blend and A\$1600 ha<sup>-1</sup> for poultry manure. We concluded that the DAP fertilizer blend could be used as an effective replacement for poultry manure for growing dust control crops on bauxite residue sand.

Ebbs, S. (2004). Biological degradation of cyanide compounds. *Current Opinion in Biotechnology*. S. Ebbs. 15: 231. Cyanide compounds are produced as waste products of a number of industrial processes and several routes for their removal from the environment are under investigation, including the use of biodegradation. The most recent developments in this area have come from studies of the hydrolytic and oxidative pathways for biodegradation and the conditions that affect their activity. The biodegradation of cyanide under anaerobic conditions has also recently demonstrated the feasibility for concomitant biogas generation, a possible economic benefit of the process. Significant advances have been reported in the use of plants for the phytoremediation of cyanide compounds and evidence for the biodegradation of thiocyanate and metal-cyanide complexes has become available. Despite these advances, however, physical and economic factors still limit the application of cyanide biodegradation, as do competing technologies.

Ebbs, S. and L. Kochian (1998). Phytoextraction of Zinc by Oat (*Avena Sativa*), Barley (*Hordeum Vulgare*), and Indian Mustard (*Brassica Juncea*). *Environ. Sci. Technol.* 32(6): 802-806.

Ebbs, S., D. Brady and L. Kochian. (1998). Role of Uranium Speciation in the Uptake and Translocation of Uranium by Plants. *J. Exp. Biol.* 49(324): 1183-1190.

Ebbs, S., D. Brady, W. Norvell and L. Kochian (2000). Uranium Speciation, Plant Uptakes, and Phytoremediation. ASCE national Conf on Environmental and pipeline engineering, Kansas City, MO, ASCE.

Ebbs, S., J. Bushey, et al. (2003). Transport and metabolism of free cyanide and iron cyanide complexes by willow. *Plant Cell and Environment* 26(9): 1467-1478. Cyanide compounds are contaminants of growing importance that could be remediated biologically via phytoremediation, provided the plants possess suitable mechanisms for managing these pollutants without toxicity. The transport and metabolism of two cyanide compounds, potassium cyanide and potassium ferrocyanide, by willow (*Salix eriocephala* L. var. Michaux) were compared using a hydroponic system that preserved cyanide speciation and solubility. The cyanide compounds were labelled with <sup>15</sup>N to quantify transport while a novel tissue extraction procedure was used to relate tissue <sup>15</sup>N to cyanide content and speciation. These analyses revealed that although little free cyanide was detected in the aerial tissues of plants exposed to either of these two cyanide compounds, significant enrichments in <sup>15</sup>N were observed, suggesting transport and subsequent metabolism of free cyanide as well as ferrocyanide. The results for ferrocyanide are of interest because this molecule is resistant to microbial degradation and if oxidized to ferricyanide is purportedly membrane impermeable. Nevertheless, these results and mass balance calculations for tissue <sup>15</sup>N and solution cyanide confirming 100% recovery for the added ferrocyanide are suggestive of ferrocyanide uptake and metabolism. This study provides new information describing the biological transport and metabolism of these two cyanide compounds in plants. Moreover, the data also suggest that phytoremediation of cyanide may be possible and ecologically safe due to the lack of cyanide bioaccumulation in aerial tissues.

Ebbs, S.D. and L.V. Kochian (1998). Phytoextraction of zinc by oat (*Avena sativa*), barley (*Hordeum vulgare*), and Indian mustard (*Brassica juncea*). *Environ. Sci. Technol.* 32(6):802-806.

Ebbs, S.D. (1995). Poster Abstract: The effect of arsenic on the uptake, translocation, and volatilization of selenium by barley (*Hordeum vulgare* L.). P. 89. In Proceedings/Abstracts of the Fourteenth Annual Symposium, Current Topics in Plant Biochemistry, Physiology, and Molecular Biology - Will Plants Have a Role in Bioremediation?, April 19-22, 1995, Columbia, MO. Interdisciplinary Plant Group, University of Missouri, Columbia, MO.

Ebbs, S.D., and L.V. Kochian (1997). Toxicity of zinc and copper to *Brassica* species: Implications for phytoremediation. *J. Environ. Qual.* 26:776-781. Heavy metal (Pb, Zn, Cd, Cu, Cr and Ni) contamination of some soils poses serious problems to both human health and agriculture in the superfund sites in the US as well as abroad. Current engineering-based technologies used to remediate soils (e.g., removal of top soil for storage at landfills) are quite costly, and often dramatically disturb the landscape. Recently, there has been considerable interest focused on the use of terrestrial plants to absorb heavy metals from the soil and concentrate them in the easily harvestable shoot tissues as an alternative remediation technology. As over 70% of the metal contaminated sites in the U.S. involve 2 or more metals, the possibility of synergistic effects of multiple metal toxicities may be important for the remediation of these sites. Thus, in this study, we investigated the individual and combined toxicities of zinc and copper to *Brassica* species that might be used to remediate heavy metal contaminated sites. We found that copper was more toxic than zinc, and exposure to both heavy metals induced micronutrient (iron) deficiency in the plants, as well as causing a significant inhibition of root growth and a decrease in the accumulation of each metal in the shoots. These findings indicate that when remediating sites contaminated with these two metals, it may be necessary to use leaf applications of iron to promote better plant health and shoot biomass production, as well as apply organic materials to the soil to tie up the copper and minimize its toxic effects.

Ebbs, S.D., D.J. Brady, and L.V. Kochian (1996). Abstract: Heavy metal and uranium accumulation by grass and dicot species: Are hyperaccumulators required for phytoremediation? International Phytoremediation Conference, May 8-10, 1996, Arlington, VA. International Business Communications, Southborough, MA.

Ebbs, S.D., M.M. Lasat, D.J. Brady, J. Cornish, R. Gordon, and L.V. Kochian (1997). Phytoextraction of cadmium and zinc from a contaminated soil. *J. Environ. Qual.* 26:5, 1424-1430.

Ebbs, S.D., M.M. Lasat, D.J. Brandy, J. Cornish, R. Gordon, and L.V. Kochian (1997). Heavy metals in the environment - Phytoextraction of cadmium and zinc from a contaminated soil. *J. Environ. Qual.* 26:1424-1430.

Eberts, S. M., G. J. Harvey, et al. (2003). Multiple-process assessment for a chlorinated-solvent plume. *Phytoremediation: transformation and control of contaminants.* S. M. Eberts. Hoboken, Wiley-Interscience: 589. A field project (Texas, USA) establishes that eastern cottonwood (*Populus deltoides*) trees partially attenuate low levels of trichloroethene (TCE) in groundwater. A multiple-process assessment, based on the first 5 years of performance data from a site developed using short rotation-woody-crop-planting techniques, provides much of the science desired by the regulatory community. Trees planted where depth to water is 3.5 meters or less are estimated to reduce peak-growing-season outflow of contaminated groundwater by as much as 30 percent at full performance. Trees planted where depth to water is 3 meters or less delivered enough dissolved organic carbon to the aquifer to initiate microbial reductive dechlorination of the dissolved TCE. Hydraulic control was the primary in situ process for TCE-plume attenuation during the first 5 years of study. Enzyme transformation within the leaves may be the dominant attenuation process within the trees.

Eberts, S. M., S. A. Jones, et al. (2005). Long-term changes in ground water chemistry at a phytoremediation demonstration site. *Ground Water.* S. M. Eberts. 43: 178. A field-scale demonstration project was conducted to evaluate the capability of eastern cottonwood trees (*Populus deltoides*) to attenuate trichloroethene (TCE) contamination of ground water. By the middle of the sixth growing season, trees planted where depth to water was < 3 m delivered enough dissolved organic carbon to the underlying aquifer to lower dissolved oxygen concentrations, to create iron-reducing conditions along the plume centerline and sulfate-reducing or methanogenic conditions in localized areas, and to initiate in situ reductive dechlorination of TCE. Apparent biodegradation rate constants for TCE along the centerline of the plume beneath the phytoremediation system increased from 0.0002/d to 0.02/d during the first six growing seasons. The corresponding increase in natural attenuation capacity of the aquifer along the plume centerline, from 0.0004/m to 0.024/m, is associated with a potential decrease in plume-stabilization distance from 9680 to 160 m. Demonstration results provide insight into the amount of vegetation and time that may be needed to achieve cleanup objectives at the field scale.

Eberts, S.M., G.J. Harvey, and S. Rock (1997). Abstract: Phytoremediation of trichloroethylene in a shallow alluvial aquifer - a field demonstration. Presentation 54. In 12th Annual Conference on Hazardous Waste Research - Abstracts Book, May 19-22, 1997, Kansas City, MO.

A field demonstration designed to evaluate the use of phytoremediation to help clean up shallow trichloroethylene-contaminated ground water has been initiated at the Naval Air Station Fort Worth, Texas. The demonstration entails the planting and cultivation of eastern cottonwood trees above a dissolved trichloroethylene (TCE) plume in a shallow (6 - 11 feet below grade) alluvial aquifer. On the basis of published laboratory investigations, the trees are expected to serve as a natural-pump-and-treat system. Initial site characterization and final site selection were completed in January 1996. Site development, which included planting trees and installing an irrigation system, was completed in April 1996. Monitoring wells and equipment were installed during summer 1996. Baseline sampling also began during summer 1996; demonstration sampling will continue until the year 2000. A mature cottonwood tree adjacent to the site was selected for additional sampling to provide early feedback on the potential fate of the TCE. Ground water levels and TCE concentrations in the aquifer will be monitored to establish baseline conditions and to map changes within the aquifer throughout the life of the demonstration. Contaminant concentrations will also be monitored in the rhizosphere and in the tree tissues. Microbial activity in the rhizosphere will be monitored and tree transpiration rates will be modeled. These data will be used to determine the fate, and processes that affect the fate, of TCE at the site. A stand of whips (cuttings) and a stand of 1 -to 2-year-old trees are included in the study. These stands were planted and will be monitored in a similar fashion. Costs associated with the planting and cultivation of each tree stand will be compared to help assess the practicability of phytoremediation as a cleanup technology.

Echevarria, G., P.C. Vong, C. Valentin-Ranc, and J.L. Morel (1995). Poster Abstract: Factors affecting accumulation of technetium-99 by forage crops. P. 77. In Proceedings/Abstracts of the Fourteenth Annual Symposium, Current Topics in Plant Biochemistry, Physiology, and Molecular Biology - Will Plants Have a Role in Bioremediation?, April 19-22, 1995, Columbia, MO. Interdisciplinary Plant Group, University of Missouri, Columbia, MO.

Echevarria, G., P.C. Vong, E. LeClerc-Cessac and J.L. Morel (1997). Bioavailability of technetium-99 as affected by plant species and growth, application form, and soil incubation. *J. Environ. Qual.* 26(4):947-956.

Echevarria, G., S. T. Massoura, et al. (2006). Assessment and control of the bioavailability of nickel in soils. *Environmental Toxicology and Chemistry*. G. Echevarria. 25: 643. Nickel, a potentially toxic metal, is present in all soils with an average concentration of 20 to 30 mg/kg, sometimes exceeding 10000 mg/kg (e.g., ultramafic soils). The ecotoxicological risk of Ni in soils to organisms is controlled by its availability. It is therefore essential to identify an efficient and reliable method for the evaluation of this risk. This paper presents a complete study of the effect of Ni origin, localization, and soil properties on its availability as assessed with the isotopic exchange kinetics (IEK) method and compares plant response to isotopically exchangeable properties of Ni in soils. We performed IEK on 100 soil samples representing a worldwide range of Ni fate, and concentrations showed that pH was the main influencing parameter and that labile Ni (i.e., isotopically exchangeable Ni, Et) could be reasonably well assessed by a single diethylene triamine pentaacetic acid extraction. The identification of the soil mineral phases that bear Ni (bearing phases) in 16 Ni-rich samples selected among the 100 soils showed a strong effect of the mineralogy of the bearing phases on Ni availability (IEK). Plants with different Ni accumulation strategies all took up Ni from the same labile pool of Ni in four contrasting soils, and the amount taken up by hyperaccumulator plants could be anticipated with the IEK parameters, thus confirming the usefulness of isotopic dilution methods for risk assessment.

Ederli, L., L. Reale, et al. (2004). Responses induced by high concentration of cadmium in *Phragmites australis* roots. *Physiologia Plantarum* 121(1): 66-74. Cadmium is an important environmental pollutant with high toxicity to plants. We report the effects of high-dose Cd (100 µM for 21 days) on the root apparatus of *Phragmites australis* plants, which are characterized by elevated water detoxification capacity and widely used in phytoremediation programmes. The examination of root sections by light and electron microscopy failed to reveal any significant cadmium-induced structural or ultra-structural modifications. However, histochemical localization of Cd disclosed accumulation of the metal in the parenchyma cells below the exodermis. Phytochelatins (PC) are thiol-rich peptides whose synthesis is induced by a range of metals. Our results indicate that total PC production increases after exposure to Cd, which suggests a pivotal role for phytochelatins in the sequestration of metal. Cd treatment also induced lignin deposition and marked stimulation of root antioxidant systems, suggesting that, because of its ability to adopt different strategies against the harmful effects of cadmium, *Phragmites australis* is a plant with high detoxification potential.

Edwards, N.T. (1986). Uptake, translocation and metabolism of anthracene in bush bean (*Phaseolus vulgaris* L). *Environ. Toxicol. Chem.* 5:659-665.

Edwards, R., D. Del Buono, et al. (2005). Differential induction of glutathione transferases and glucosyltransferases in wheat, maize and *Arabidopsis thaliana* by herbicide safeners. *Zeitschrift Fur Naturforschung C-a Journal of Biosciences* 60(3-4): 307-316. By learning lessons from weed science we have adopted three approaches to make plants more effective in phytoremediation: 1. The application of functional genomics to identify key components involved in the detoxification of, or tolerance to, xenobiotics for use in subsequent genetic engineering/breeding programmes. 2. The rational metabolic engineering of plants through the use of forced evolution of protective enzymes, or alternatively transgenesis of detoxification pathways. 3. The use of chemical treatments which protect plants from herbicide injury. In this paper we examine the regulation of the xenome by herbicide safeners, which are chemicals widely used in crop protection due to their ability to enhance herbicide selectivity in cereals. We demonstrate that these chemicals act to enhance two major groups of phase 2 detoxification enzymes,

notably the glutathione transferases and glucosyltransferases, in both cereals and the model plant *Arabidopsis thaliana*, with the safeners acting in a chemical- and species-specific manner. Our results demonstrate that by choosing the right combination of safener and plant it should be possible to enhance the tolerance of diverse plants to a wide range of xenobiotics including pollutants.

Edwin-Wosu, N. L. and P. D. S. Kinako (2005). Phytoremediation innovative technology (Series 2): A short-term comparative analysis of enhanced biodegradation of crude oil in the soil by macrophytic nodulation. *Global Journal of Environmental Sciences*. N. L. Edwin-Wosu. 4: 11. A short term comparative ecological study of the use of two agro-forestry species, *Leucaenaleucocephala*, Lam De. Wit and *Bauhinia monandra*, Kurz, in bioremediation of oil polluted environment was carried out, focusing on the evaluation and enhancing potential of the macrophytic species for degradation of hydrocarbon (crude oil) in the soil relative to their nodulation efficacy. Results show that *L. leucocephala* had nodules with levels ranging between 1.40 +/- 1.40 to 11.60 +/- 2.20 plant<sup>-1</sup> and relative to various pollution levels and 15.10 +/- 6.10 plant<sup>-1</sup> in the control condition. Though *L. leucocephala* experienced pollution depression upon time lag in nodulation, the depression was directly proportional to the intensities of pollution. *Bauhinia monandra* had none at the end of the experiment both in the polluted and controlled conditions. Total hydrocarbon level following treatment of the soil by *L. leucocephala* and *B. monandra* has been deduced in relation to post-pollution concentration, disappearance and net % loss on such treated soil environment. A comparatively high value of 60% total loss of crude oil was indicated in *L. leucocephala* treated soil. This shows that natural biodegradation could be a major and ultimate mechanism for elimination of oil in terrestrial environment. The highest total % loss of crude oil was recorded in *Leucaenaleucocephala* than *Bauhinia monandra* treated soil. *Leucaenaleucocephala* showed an enhanced performance than *Bauhinia monandra* at the end of the study. *Leucaenaleucocephala* was thus considered more ideal and more promising for remediation work than *B. monandra*.

Egashira, K., K. Kurosawa, et al. (2005). Towards establishment of management practices for sustainable agricultural development. Proceedings of the joint symposium between Hanoi Agricultural University, Vietnam and Kyushu University, Japan, 8-9 December 2005, Hanoi, Vietnam. *Bulletin of the Institute of Tropical Agriculture, Kyushu University*. K. Egashira. 28: 1. This special issue contains 15 papers classified under two major topics: agronomy and bioresources (7 papers); and land/water and environment (8 papers). Topics covered in the first part include: resistance of Vietnamese rice varieties to insect pests (e.g., brown planthopper (*Nilaparvata lugens*), leaf miners) and plant pathogens; effects of light intensity and diurnal change in rice; and importance of multidisciplinary research for insect pest management. Land/water and environment section covers issues on: sustainable agriculture in the Red River basin; biochemical characteristics and crop yield of infertile soil in Hiep Hoa district; urbanization in Vietnam; accumulation of heavy metals and nutrient balance in agricultural soil; flood inundation analysis; inorganic nitrogen concentrations of groundwater; and removal of nitrate-nitrogen from irrigation water using wetland crops.

Egirani, D. (2004). Comments on: Removal of copper ions from aqueous solution by tree ferns. *Water Research (Oxford)*. D. Egirani. 38: 4535.

Eguchi, M., S. Yoshida, et al. (2005). An examination of trichloroethylene degradation in *Populus* cells of suspension culture. *Journal of Agricultural Meteorology* 60(6): 1141-1143. For an examination of application to trichloroethylene (TCE), phytoremediation in various plant species suitable for wide area in the world, we examined efficiency of a method of screening plant species for ability of TCE phytoremediation, by investigating possibility of TCE degradation in *Populus* cells of suspension culture. The callus derived from a leaf of *Populus nigra* var. *Italica* was grown in MS medium of suspension culture, and TCE was added into the medium. Viability of the *Populus* cells did not depressed even in the TCE-added medium. At a few days after the TCE treatment, n-hexane extracts of the treated cells and the medium were qualitatively analysed by a gas chromatograph-mass spectrometer, and trichloroethanol (TCOH; an intermediate of TCE in an aerobic bio-degradation) was detected. The intermediate was also detected even when the cells were crushed and then treated TCE, and the degradation ceased by boiling the, cell-crushed solution. This fact suggests that TCE in the medium in the *Populus* suspension culture is

degraded through a certain enzyme process of the living cells. Thus, this experimental procedure can be applicable to screening of the useful plant species for TCE phytoremediation.

Ejlertsson, J., E. Johansson, A. Karlsson, U. Meyerson, and B.H. Svensson (1996). Anaerobic degradation of xenobiotics by organisms from municipal solid waste under landfilling conditions. *Antonie van Leeuwenhoek* 69:67-74.

Eklund, M. (1995). Cadmium and lead deposition around a Swedish battery plant as recorded in Oak tree rings. *J. Environ. Qual.* 24:126-131.

Ekman, D. R., N. L. Wolfe, et al. (2005). Gene expression changes in *Arabidopsis thaliana* seedling roots exposed to the munition hexahydro-1,3,5-trinitro-1,3,5-triazine. *Environmental Science & Technology* 39(16): 6313-6320. *Arabidopsis thaliana* root transcriptome responses to the munition, hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), were assessed using serial analysis of gene expression (SAGE). Sequencing of SAGE libraries from control and RDX-exposed root tissues revealed induction of genes known to respond to a variety of general stresses. Among the highly induced genes were several encoding molecular chaperones and transcription factors as well as vacuolar proteins and peroxidases. Strongly repressed transcripts included ones encoding ribosomal proteins, a cyclophilin, a katanin, and a peroxidase. Comparison of the transcriptional profile for the RDX response to a profile previously described for *Arabidopsis* roots exposed to trinitrotoluene (TNT) revealed significant differences in the inferred gene expression patterns. This suggests that *Arabidopsis* employs drastically different mechanisms for coping with these two compounds. With respect to the goal of engineering plants to better tolerate and degrade explosives at contaminated sites, these results suggest that enhancement of different genes and metabolic pathways may be required to deal effectively with each type of explosive. This has ramifications for phytoremediation efforts since many contaminated sites harbor both compounds.

Ekman, D. R., W. W. Lorenz, et al. (2003). SAGE analysis of transcriptome responses in *Arabidopsis* roots exposed to 2,4,6-trinitrotoluene. *Plant Physiology (Rockville)* 133(3): 1397-1406. Serial analysis of gene expression was used to profile transcript levels in *Arabidopsis* roots and assess their responses to 2,4,6-trinitrotoluene (TNT) exposure. SAGE libraries representing control and TNT-exposed seedling root transcripts were constructed, and each was sequenced to a depth of roughly 32,000 tags. More than 19,000 unique tags were identified overall. The second most highly induced tag (27-fold increase) represented a glutathione S-transferase. Cytochrome P450 enzymes, as well as an ABC transporter and a probable nitroreductase, were highly induced by TNT exposure. Analyses also revealed an oxidative stress response upon TNT exposure. Although some increases were anticipated in light of current models for xenobiotic metabolism in plants, evidence for unsuspected conjugation pathways was also noted. Identifying transcriptome-level responses to TNT exposure will better define the metabolic pathways plants use to detoxify this xenobiotic compound, which should help improve phytoremediation strategies directed at TNT and other nitroaromatic compounds.

El Aziz, R., J.S. Angle, and R.L. Chaney. (1991). Metal tolerance of *Rhizobium meliloti* isolated from heavy-metal contaminated soils. *Soil Biol. Biochem.* 23(8):795-798.

El Kherbawy, M., J.S. Angle, A. Heggio, and R.L. Chaney (1989). Soil pH, rhizobia, and vesicular-arbuscular mycorrhizae inoculation effects on growth and heavy metal uptake of alfalfa (*Medicago sativa* L.). *Biol. Fertil. Soil.* 8(1):61-65.

El-Gendy, A. S., N. Biswas, et al. (2005). A floating aquatic system employing water hyacinth for municipal landfill leachate treatment: effect of leachate characteristics on the plant growth. *Journal of Environmental Engineering and Science.* A. S. El-Gendy. 4: 227. The current research demonstrates the effects of certain parameters, usually present in municipal landfill leachate, on the growth of water hyacinth (*Echhornia crassipes*), a floating aquatic plant, when used for treatment of leachate. Experiments were carried out to investigate the ability of water hyacinth to grow in leachate with different salinity ions

concentrations, nutrients, pH, and heavy metals concentrations. The ability of water hyacinth to remove some parameters such as nitrogen, potassium, phosphorus, total solids, and chloride were also investigated. All experiments were conducted in batch reactors in a greenhouse environment. The leachate samples were collected from Essex-Windsor Regional Landfill, Windsor, Ontario. It was found that this treatment system required the presence of sufficient amount of nutrients (N, P, and K) to ensure plant growth. Optimum growth took place when the initial chloride and sodium concentrations were 560 mg L<sup>-1</sup> and 330 mg L<sup>-1</sup>, respectively. The leachate pH for optimum water hyacinth growth was found to be in the range of 5.8 to 6.0. Total heavy metal concentrations below 0.10 mequiv L<sup>-1</sup> supported the plant growth; concentrations above 0.91 mequiv L<sup>-1</sup> inhibited the plant growth. Removal efficiencies of nitrogen, potassium, phosphorus, chloride, and total solids from leachate were found to be affected by the growth of water hyacinth. Higher removals were obtained with higher plant growth.

Eliot, J.L. (1998). Treating toxic PCBs with toxic plants. National Geographic. May 1998

Elkhatib, E. A., A. M. Mahdy, et al. (2005). Enhancement of cadmium phytoextraction from calcareous soils. Bioscience Research. E. A. Elkhatib. 2: 1. Cadmium phytoextraction, the use of plants to remove Cd from contaminated soil, is an emerging environmental clean up technology. Successful Cd phytoextraction must increase Cd mobilization into soil solution in order to maximize the transfer of Cd to plant shoots. In this study, the potential of adding, various organic complexing agents (malic acid, citric acid, cetyl trimethyl ammonium bromide, CTAB, and ethylene diamine tetra acetate, EDTA) to Cd-contaminated soils to increase Cd concentration in sunflower plants (*Helianthus annuus* cv. Avante) was investigated. Cadmium concentration in sunflower shoots was significantly enhanced as a result of organic complexing agents additions and rate of applications in the two soils studied. The order of effectiveness of organic complexing agents on increasing Cd concentration in plant shoots was the following EDTA > CTAB > citric acid > malic acid. The effectiveness of the organic complexing agents used on Cd desorption from soil to soil solution coincides with the Cd concentration in plant shoots. Results from this study suggest that organic complexing agents-assisted Cd phytoextraction may provide a promising soil decontamination strategy.

Elless, M. P. and M. J. Blaylock (2000). Amendment Optimization to Enhance Lead Extractability from Contaminated Soils for Phytoremediation. International Journal of Phytoremediation 2.

Elless, M., M. Blaylock, J. Huang and C. Gussman (2000). Plants as a Natural Source of Concentrated Mineral Nutritional Supplements. Food Chem. 71( 2): 181-188.

Elless, M.P. (1997). Phytoextraction of metals from contaminated soils - Enhancing phytoextraction by altering the target metals solubility behavior. IBC's Second Annual Conference on Phytoremediation, June 18 - 19, 1997, Seattle, WA. International Business Communications, Southborough, MA.

El-lil, A. H. A. (2006). Evaluation of the efficiency of some hydrophytes for trapping suspended matters from different aquatic ecosystems. Biotechnology. A. H. A. El-lil. 5: 90. The efficiency of different investigated hydrophytes for trapping suspended particles and epiphytes from different water sources (River Nile, canals and drains) during different seasons was studied. Species that form canopies e.g., *Potamogeton pectinatus* were found as poor trapping, *Myriophyllum spicatum* and *Ceratophyllum demersum* that form dense understories, were found to be highly efficient for suspended particles traps. The floating hydrophytes *Echhornia craissipes* fixed valuable amounts of sediments through its root system. Also, the present data indicated factors affecting the trapping efficiencies of investigated hydrophytes to avoid wrong weighing of fresh hydrophytes as a result to trapping suspended particles as follows ( $W_r = W_0 \times F$ ) whereas  $W_r$ =real wt.,  $W_0$ =fresh wt. and  $F$ =factor detected in each species. In conclusion, trapping of suspended silt and clay may lead to protection of the plant from harmful chemicals due to sprout it on its surface by colloidal affinities or opposite charges. Also, supplies the plant with essential minerals especially under unfavourable conditions. This may explain to some extent, the abilities of some hydrophytes like *E. craissipes* to overcome the nutrient and mineral deficiency in outer media via picking up its nutrient requirements from suspended particles trapped by its root which acts as minerals

store. Also we can study the using of these plants as tools to filtrates the water from impurities (organic and inorganic) for industrial and sanitaries purposes.

Elliott, L.F., R.I. Papendick, and D.F. Bezdicsek (1987). Cropping practices using legumes with conservation tillage and soil benefits. P. 81-90. Soil Conservation Society of America/et. al. Legumes in Conservation Tillage Symposium, April 27-29, 1987, Athens, GA.

Ellis, B., P. Harold, and H. Kronberg (1991). Bioremediation of cresosote contaminated site. Environmental Technology, 12, 447-459.

Ellis, D. R. and D. E. Salt (2003). Plants, selenium and human health. Current Opinion in Plant Biology. D. R. Ellis. 6: 273. Selenium is an essential nutrient for animals, microorganisms and some other eukaryotes. Although selenium has not been demonstrated to be essential in vascular plants, the ability of some plants to accumulate and transform selenium into bioactive compounds has important implications for human nutrition and health, and for the environment. Selenium-accumulating plants provide unique tools to help us understand selenium metabolism. They are also a source of genetic material that can be used to alter selenium metabolism and tolerance to help develop food crops that have enhanced levels of anticarcinogenic selenium compounds, as well as plants that are ideally suited for the phytoremediation of selenium-contaminated soils. In this review, we discuss plant selenium biochemistry, selenium hyperaccumulators and the potential to alter selenium metabolism in economically important plants.

Ellis, D. R., T. G. Sors, et al. (2004). Production of Se-methylselenocysteine in transgenic plants expressing selenocysteine methyltransferase. BMC Plant Biology. D. R. Ellis. 4: 28. Background: It has become increasingly evident that dietary Se plays a significant role in reducing the incidence of lung, colorectal and prostate cancer in humans. Different forms of Se vary in their chemopreventative efficacy, with Se-methylselenocysteine being one of the most potent. Interestingly, the Se accumulating plant *Astragalus bisulcatus* (Two-grooved poison vetch) contains up to 0.6% of its shoot dry weight as Se-methylselenocysteine. The ability of this Se accumulator to biosynthesize Se-methylselenocysteine provides a critical metabolic shunt that prevents selenocysteine and selenomethionine from entering the protein biosynthetic machinery. Such a metabolic shunt has been proposed to be vital for Se tolerance in *A. bisulcatus*. Utilization of this mechanism in other plants may provide a possible avenue for the genetic engineering of Se tolerance in plants ideally suited for the phytoremediation of Se contaminated land. Here, we describe the overexpression of a selenocysteine methyltransferase from *A. bisulcatus* to engineer Se-methylselenocysteine metabolism in the Se non-accumulator *Arabidopsis thaliana* (Thale cress). Results: By over producing the *A. bisulcatus* enzyme selenocysteine methyltransferase in *A. thaliana*, we have introduced a novel biosynthetic ability that allows the non-accumulator to accumulate Se-methylselenocysteine and gamma-glutamylmethylselenocysteine in shoots. The biosynthesis of Se-methylselenocysteine in *A. thaliana* also confers significantly increased selenite tolerance and foliar Se accumulation. Conclusion: These results demonstrate the feasibility of developing transgenic plant-based production of Se-methylselenocysteine, as well as bioengineering selenite resistance in plants. Selenite resistance is the first step in engineering plants that are resistant to selenate, the predominant form of Se in the environment.

Ellis, R.W. and L. Eslick (1997). Variation and range of mercury uptake into plants at a mercury-contaminated abandoned mine site. Bull. Environ. Contam. Toxicol. 59:763-769.

Elmaci, A., T. Yonar, et al. (2005). The investigation of biosorption characteristics of dried *Chara* sp., *Cladophora* sp. and *Chlorella* sp. for the removal of Zn (II), Cd (II), Co (II) and Remazol Turkish Blue-G in aqueous solutions / Zn(II), Cd(II), Co(II) ve Remazol Turkish Blue-G boyar maddesinin sulu cozeltelerinde kurut *Ulmus* *Chara* sp., *Cladophora* sp. ve *Chlorella* sp. turleri ile biyosorpsiyonun arastirilmasi. Ekoloji. A. Elmaci. 14: 24. Environmental pollution caused by toxic heavy metals and waste water treatment processes in removing dyes from textile effluents have become of increasing importance in recent years. In this study, three algae species (*Chara* sp., *Cladophora* sp. and *Chlorella* sp.) were used for biosorption of a synthetically prepared hydrolysable dye (Remazol Turkish Blue-G), Zn(II), Cd(II) and Co(II). The biosorption characteristics of algae species were investigated under different pH levels (2.0-8.0) and

under different azo dye and heavy metal concentrations (40-100 mg/L and 20-60 mg/L, respectively) in batch trials. The optimum pH values for the removal of Cd(II), Zn(II) and Co(II) were 6.0; 5.0 and 5.0, respectively for *Cladophora* sp., 6.0; 5.0 and 6.0 respectively for *Chara* sp., and 5.0; 6.0 and 5.0 respectively for *Chlorella* sp. The best heavy metal removal efficiency was obtained with *Cladophora* sp. The optimum pH for decolorization study was 2.0 for each algae species and the best azo dye removal efficiency was observed in *Chlorella* sp. Consequently, the investigated algae species were found to be effective in both azo dye and heavy metal removal.

Elmayan, T., F. Borne, C. Roton, L. Hys, and M. Tepfer (1997). Poster abstract: Cadmium in transgenic tobacco plants expressing a mammalian metallothionein gene. IBC's Second Annual Conference on Phytoremediation, June 18 - 19, 1997, Seattle, WA. International Business Communications, Southborough, MA.

Elmayan. T. and M. Tepfer (1995). Poster Abstract: Improved reduction of leaf cadmium levels in transgenic tobacco plants by over-expression of a mammalian metallothionein gene. P. 73. In Proceedings/Abstracts of the Fourteenth Annual Symposium, Current Topics in Plant Biochemistry, Physiology, and Molecular Biology - Will Plants Have a Role in Bioremediation?, April 19-22, 1995, Columbia, MO. Interdisciplinary Plant Group, University of Missouri, Columbia, MO.

El-Sawaf, N. (2005). Response of *Sorghum* spp. to sewage waste-water irrigation. International Journal of Agriculture and Biology. N. El-Sawaf. 7: 869. A study was carried out under natural conditions in Giza, Egypt, from June to August 2003 to investigate the effect of irrigation with 3 sewage waste-water samples (raw sewage water, 1ry-treated sewage water and 2ry-treated sewage water) on the growth and bio-availability of some macro- and microelements in two plant species, *Sorghum durra* and *S. dochna*. Plants irrigated with tap water served as the control. The results showed significant increases in shoot length, number of leaves per plant, total leaf area per plant and dry weights of shoot and root of *S. durra* irrigated with sewage waste-water, more so in plants irrigated with raw sewage waste-water. There were significant increases in total leaf area per plant and dry weights of shoot and root of *S. dochna* plants irrigated with sewage waste-water, the effect was more pronounced in plants irrigated with 1ry-treated sewage waste-water. In both species, there were higher contents of anions (Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and PO<sub>4</sub><sup>3-</sup>) and cations (Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup> and Mg<sup>2+</sup>) than in the control. The uptake of Zn<sup>2+</sup>, Mn<sup>2+</sup>, Cu<sup>2+</sup> and Ni<sup>2+</sup> by the two species was relatively high in all sewage water types, while the opposite trend was obtained with Fe<sup>3+</sup>. The accumulation of microelements in shoots and roots of *S. durra* and *S. dochna* plants irrigated with sewage waste-water showed great variation in spatial pattern. Growing fodder plants with sewage water paves way for effective disposal of sewage water and pollution control.

Elsenheimer, D. and L. Thomas (1998). Phytoremediation of Nitrogen Impacted Derailment Site. 14th Annual Conference on Contaminated Soils. October 1998. University of Massachusetts at Amherst, Amherst, MA.

El-Shafai, S. A., F. A. Nasr, et al. (2006). Toxicity of heavy metals to duckweed-based wastewater treatment ponds with different depth. Management of Environmental Quality. 17: 313. This study investigated the bioaccumulation pattern and fate of heavy metals in duckweed (*Lemna gibba*)-based waste water treatment ponds with different depth. Three replicates of four reactors used were randomly distributed on the bench and filled with 50% diluted sewage for the control reactors whereas diluted sewage mixed with 5 mg Pb/litre and 5 mg Zn/litre was used for the treatment reactors. The reactors were stocked with *L. gibba* at 1000 g fresh weight per each square metre. The culture tanks were exposed to temperature range of 21-25degreesC and light regime of 16 h light using halogen lamps and 8 h dark. The light intensity was maintained approximately 200 microEm-2 S-1. The experiment was extended for 30 days. Regular monitoring of the growth performance of duckweed was carried out with subsequent analysis of dry matter, heavy metals, phosphorus and nitrogen content. Composite samples from the water phase were subjected to the analysis of ammonia, nitrite, nitrate, orthophosphate and sulfate concentration. The analysis of sediment and biofilm were carried out at the end of the experiment. Interpretation of results was carried out using one-way analysis of variance. Statistical analysis showed a significant reduction in the growth rate of duckweed within the first five days exposure time. After five days

exposure, the growth rate in the treatments returned to the normal growth till day 15 after which the growth became significantly lower in the small and medium scale ponds. The results revealed that zinc is more bioavailable than lead and both metals are mostly precipitated in the sediment probably as sulfides. The results of the study confirm the positive effect of pond depth in reducing the heavy metal toxicity to the duckweed-based waste water treatment ponds.

Elsharawy, M. A. O., M. M. Elbordiny, et al. (2004). Phytoremediation of wastewater for irrigation purpose using *Azolla*. Egyptian Journal of Soil Science. M. A. O. Elsharawy. 44: 73. Remediation of contaminated water using plants, or phytoremediation, is one of the most promising new technologies for remediation. This work shows that aquatic plants, *Azolla pinnata* and *Azolla filiculoides*, are capable of causing a significant decline in nitrogen and certain heavy metals in mixed waste water (industrial, sewage and agricultural waste water) of the Shibin-Alqunatir drain, Qalubia Governorate, Egypt. Results revealed that total uptake of N, Fe, Zn, Cu and Mn by *Azolla* tissues increased with time up to three weeks. For *Azolla filiculoides*, such increases reached 4.15, 2.50, 3.27, 3.80 and 4.33 fold that of the Hoagland nutrient solution (control) for N, Fe, Zn, Cu and Mn, respectively. *Azolla pinnata* showed a similar trend for such elements reaching 4.39, 2.91, 3.15, 3.43 and 3.20 fold that of the control, respectively. The elements concentrations in waste water were significantly decreased after removing of *Azolla* at the end of the experiment. For *Azolla filiculoides* decreases were 56.4, 91.0, 41.5, 82.5, 37.7, 12.1, 46.7 and 67.2% of the initial concentration of N, Fe, Zn, Cu, Mn, Co, Cd and Ni, respectively, while for *Azolla pinnata* decreases were 53.7, 92.7, 83.0, 59.1, 65.1, 95.0, 90.0 and 73.1%, respectively. Depending on the biological accumulation factor, values of Fe, Cu, Co and Cd showed higher response for phytoremediation than Zn, Mn and Ni.

El-Zawahry, M. M. and M. M. Kamel (2004). Removal of azo and anthraquinone dyes from aqueous solutions by *Echhornia Crassipes*. Water Research (Oxford). M. M. El-Zawahry. 38: 2967. The rate of adsorption of two azo and four anthraquinone anionic dyes on *Echhornia crassipes* (E.C.) has been studied. Raw E.C. and three aminated derivatives of E.C. with different nitrogen percent were used as dye adsorbents. The parameters studied include the amount of substrate, shaking time, chemical structure, concentration of dyestuff and pH of dyeing bath. Simple kinetic adsorption models of dynamics and adsorption parameters for the Langmuir and Entry, J.A., N.C. Vance, M.A. Hamilton, D.Z. Zabowski, L.S. Watrud, and D.C. Adriano. (1996). Phytoremediation of soil contaminated with low concentrations of radionuclides. Water, Air, Soil, Pollut. 88:167-177. Ecosystems throughout the world have been contaminated with radionuclides by above ground nuclear testing, nuclear reactor accidents and nuclear power generation. Radioisotopes characteristic of nuclear fission, such as  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ , that are released into the environment can become more concentrated as they move up the food chain often becoming human health hazards. Natural environmental processes will redistribute long lived radionuclides that are released into the environment among soil, plants, and wildlife. Numerous studies have shown that  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  are not removed from the top 0.4 meters of soil even under high rainfall, and migration rate from the top few centimeters of soil is slow. The top 0.04 meters of soil is where plant roots actively accumulate elements. Since plants are known to take up and accumulate  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ , removal of these radionuclides from contaminated soils by plants could provide a reliable and economical method of remediation. One approach is to use fast growing plants inoculated with micorrhizal fungi combined with soil organic amendments to maximize the plant accumulation and removal of radionuclides from contaminated soils, followed by harvest of above-ground portion of the plants. High temperature combustion would be used to oxidize plant material concentrating  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in ash for disposal. When areas of land have been contaminated with radionuclides are large, using energy intensive solutions to remediate huge volumes of soil is not feasible of economical. Plants are proposed as a viable and cost effective method to remove radionuclides from the soils that have been contaminated by nuclear testing and nuclear reactor incidents.

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Ensley, B.D. (1996). Abstract: Opening Address: Phytoremediation Applications. International Phytoremediation Conference, May 8-10, 1996, Arlington, VA. International Business Communications, Southborough, MA.

Ensley, B.D. (1997). The use of plants for the remediation of environmental contamination. In P.T. Kostecki and E.J. Calabrese (eds.), 12th Annual Conference on Contaminated Soils - Analysis, Site Assessment, Fate, Environmental and Human Risk Assessment, Remediation and Regulation, October 20-23, 1997, Amherst, MA. Environmental Health Sciences Program, School of Public Health, University of Massachusetts, Amherst, MA.

Ensley, B.D. (1997). Why phytoremediation - Phytoremediation is the most cost-effective approach for many sites. IBC's Second Annual Conference on Phytoremediation, June 18 - 19, 1997, Seattle, WA. International Business Communications, Southborough, MA.

Ensley, B.D., V. Dushenkov, I. Raskin, and D.E. Salt (1994). Rhizofiltration: A new technology to remove metals from aqueous streams. Pp. 153-156. In B.J. Scheiner, T.D. Chatwin, H. El-Shall, S.K. Kawatra, and E.A. Torma (eds.), New Remediation Technology. The Changing Environmental Arena. Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO.

Ensley, H. E., J. T. Barber, M. A. Polito and A. I. Oliver (1994). Toxicity and Metabolism of 2,4-Dichlorophenol by the Aquatic Angiosperm *Lemna Gibba*. Environmental Toxicology and Chemistry 13(2): 325-331.

Entry, J. A., L. S. Watrud and M. Reeves (2001). Influence of Organic Amendments on the Accumulation of Cs-137 and Sr-90 from Contaminated Soil by Three Grass Species. Water Air & Soil Pollution 126(3-4): 385-398.

Entry, J. A., N.C. Vance, M.A. Hamilton, and D. Zabowski (1994). In-situ remediation of soil contaminated with low concentrations of radionuclides. Pp.1055-1067. In-Situ Remediation: Scientific Basis for Current and Future Technologies: 33rd Hanford Symposium on Health and the Environment, November 7-11, 1994, Pasco, WA.

Entry, J. and L. Watrud (1998). Potential Remediation of Cs-137 and Sr-90 Contaminated Soil by Accumulation in Alamo Switchgrass. Water, Air, Soil Pollut. 104(3-4): 339-352.

Entry, J., L. Watrud and M. Reeves (2001). Influence of Organic Amendments on the Accumulation of 137Cs and 90Sr from Contaminated Soil by Three Grass Species. Water, Air, & Soil Pollution 126(3-4): 385-398.

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Phytoremediation of Soil and Water Contaminants, ACS Symposium Series No. 664. American Chemical Society, Washington, DC.

Entry, J.A., N.C. Vance, and L.S. Watrud (1996). Selection of plants for phytoremediation of soils contaminated with radionuclides. Abstracts of Papers of the American Chemical Society. 212:108-AGRO.

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Erdei, L., G. Mezosi, et al. (2005). Phytoremediation as a program for decontamination of heavy-metal polluted environment. Acta Biologica Szegediensis 49(1-2): 75-76. The aim of the project is to develop a biotechnology which is able to detect and eliminate pollutant heavy metals from the environment. Elements of the system include introduction of heavy metal accumulating plants (endemic or foreign) in the target areas (polluted soil, refuse dumps, slurry); increasing the uptake of heavy metals with local stress resistant bacteria and fungi species in the plant rhizosphere; monitoring the actual metal load with transgenic cyanobacteria functioning as biosensors. The expected result is a technology ready for application, involving special combinations of soil- and heavy metal-specific plant and microbial species, and the technical details of application and related know-how including detoxification of the final product. Application of the technology decreases the rate of pollution under limiting values. The advantage of phytoremediation methods include reduced expenses and the natural restoration of nature.

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Ernst, W. (1998). Sulfur Metabolism in Higher Plants: Potential for Phytoremediation. Biodegradation 9(3-4): 311-318.

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Errampallie, D., J.T. Trevors., H. Lee, K. Leung, M. Cassidy, K. Knoke, T. Marwood, K. Shaw, M. Blears, and E. Chung (1997). Bioremediation: A Perspective. Journal of Soil Contamination. 6(3):207-218.

Escalante-Espinosa, E., M. E. Gallegos-Martinez, et al. (2005). Improvement of the hydrocarbon phytoremediation rate by *Cyperus laxus* Lam. inoculated with a microbial consortium in a model system. Chemosphere 59(3): 405-413. Hydrocarbon phytoremediation by *Cyperus laxus* Lam. growing on perlite and inoculated with hydrocarbon-degrading microorganisms was evaluated. Total petroleum hydrocarbons (TPH) were extracted from weathered soil (60.7 g of TPH kg<sup>-1</sup> of dry soil) and spiked on perlite at initial concentration of 5 g of TPH kg<sup>-1</sup> of dry perlite. Phenological characteristics, total microbial viable counts, hydrocarbon degraders and residual hydrocarbons were determined through 180 days of culture. Phenological characteristics of inoculated plants were improved as compared with non-inoculated plants: root biomass was 1.6 times greater, flowering time was reduced (13%), and the number of inflorescences was 1.5 times higher. The rhizospheric bacterial and fungi counts were higher for planted treatments (inoculated and not inoculated) than for unplanted pots. The maximum phytoremediation rate (0.51 mg of TPH g<sup>-1</sup> of dry plant d<sup>-1</sup>) for inoculated plants was reached at 60 days of culture, and was two times higher than for non-inoculated plants (55% TPH removal). Similar hydrocarbon phytoremediation extent values for inoculated (90%) and non-inoculated (85%) plants were obtained at 180 days of culture. The present study demonstrated that mutual benefits between *C. laxus* and inoculated hydrocarbon-degrading microorganisms are improved during phytoremediation. It is pertinent to note that this is the first report of hydrocarbon phytoremediation by *Cyperus laxus* Lam., a native plant growing in highly contaminated swamps. (c) 2004 Elsevier Ltd.

Escarre, J., C. Lefebvre, W. Gruber, M. Leblanc, J. Lepart, Y. Riviere and B. Delay (2000). Zinc and Cadmium Hyperaccumulation by *Thlaspi caerulescens* from Metalliferous and Nonmetalliferous Sites in the Mediterranean Area: Implications for Phytoremediation. New Phytol. 145(3): 429-437.

Esteban, E., R. O. Carpena, et al. (2003). High-affinity phosphate/arsenate transport in white lupin (*LuPinus albus*) is relatively insensitive to phosphate status. New Phytologist 158(1): 165-173. The development of proteoid roots under phosphorus deficiency by white lupin (*LuPinus albus*) may result in increased arsenate uptake, as arsenate is a phosphate analogue. This, together with its high biomass production, rapid growth and ability to survive in soils with low phosphate and nitrogen contents, low pH and high metal contents make them an interesting species to investigate with respect to revegetation, and possibly also for long-term phytoremediation, of arsenic contaminated soils. Kinetic parameters for arsenate uptake for P-deficient and P-sufficient plants, as well as for proteoid and nonproteoid roots were obtained. Down-regulation of arsenate uptake by phosphate, as well as phosphate/arsenate competition for P-deficient and P-sufficient plants was studied. Arsenate uptake was reduced by phosphate, but small differences were found between P-deficient and P-sufficient plants. Arsenate uptake by proteoid roots was higher than for nonproteoid roots of P-deficient plants, with higher V<sub>max</sub> and similar K<sub>m</sub> values. Down-regulation of the high affinity phosphate/arsenate uptake system by phosphate does take place but seems to be slower than in other plants. This study suggests that the low sensitivity of the phosphate/arsenate uptake system to regulation by phosphate may be related to the adaptations of white lupin to low P available environments. Such adaptation are absent in plants unable to develop proteoid roots.

Eun, S., H. Youn and Y. Lee (2000). Lead Disturbs Microtubule Organization in the Root Meristem of *Zea mays*. Physiol. Plant. 110(3): 357-365.

Evangelou, M. W. H., H. Daghan, et al. (2004). The influence of humic acids on the phytoextraction of cadmium from soil. *Chemosphere* 57(3): 207-213. Cadmium poses a major environmental and human health threat because of its constant release through anthropogenic activities. A need, therefore, exists for cost-effective remediation procedures. Phytoremediation, the use of plants to extract contaminants from soils and groundwater, has revealed great potential. However, it is limited by the fact that plants need time, nutrient supply and, moreover, have a limited metal uptake capacity. Synthetic chelators have shown positive effects in enhancing heavy metal extraction through phytoremediation, but they have also revealed a vast number of negative side-effects. The objective of this research was to investigate the use of humic acids as an alternative to synthetic chelators. Humic acids were applied to a cadmium-contaminated soil at various dosages, and the uptake of cadmium into *Nicotiana tabacum* SR-1 was determined in relation to the amounts of total and bioavailable cadmium in the soil. It was found that the theoretical bioavailability of cadmium, as determined by diethylenetriaminepentaacetic acid (DTPA) extraction, did not change, but its plant uptake was enhanced significantly, in some cases up to 65%. Humic acids added at a rate of 2 g kg<sup>-1</sup> soil increased the cadmium concentration in the shoots from 30.9 to 39.9 mg kg<sup>-1</sup>. A possible reason for this enhancement is the decrease in pH, resulting in higher cadmium availability. Another possibility taken into account is that plants may take up cadmium complexes with humic acid fragments, which result from microbiological degradation or, self-dissociation. (C) 2004 Elsevier Ltd.

Evangelou, M. W. H., M. Ebel, et al. (2006). Evaluation of the effect of small organic acids on phytoextraction of Cu and Pb from soil with tobacco *Nicotiana tabacum*. *Chemosphere* 63(6): 996-1004. Phytoremediation, the use of plants to extract contaminants from soils and groundwater, is a promising approach for cleaning up soils contaminated with heavy metals. However its use is limited by the time required for plant growth, the nutrient supply and, moreover, by the limited metal uptake capacity. Synthetic chelators have shown positive effects in enhancing heavy metal extraction, but they have also revealed several negative side-effects. The objective of this study was to investigate the use of three natural low molecular weight organic acids (NLMWOA) (citric, oxalic, and tartaric acid) as an alternative to synthetic chelators. Slurry-, column-, toxicity- and phytoextraction experiments were performed. For the phytoextraction experiment the three NLMWOA were applied to a copper- and a lead-contaminated soil respectively. A significant increase in copper uptake was visible only in the citric acid treatment (67 mg kg<sup>-1</sup>) in comparison to the EDTA treatment (42 mg kg<sup>-1</sup>). The NLMWOA application showed no enhanced effect concerning the lead phytoextraction. A possible explanation for this lack of significance could be the rate of the degradation of NLMWOA. This rate might well be too high for these heavy metals with low mobility and bioavailability such as lead. The amounts of NLMWOA applied to the soil were very high (62.5 mmol kg<sup>-1</sup> of soil) and the effect was too little. In this respect EDTA, which was applied in very small amounts (0.125 mmol kg<sup>-1</sup>) was more efficient. Thus making NLMWOA unsuitable to enhance phytoextraction of heavy metals from soil. (c) 2005 Elsevier Ltd.

Everhart, J. L., D. McNear, et al. (2006). Assessing nickel bioavailability in smelter-contaminated soils. *Science of the Total Environment* 367(2-3): 732-744. Metal contaminants in soil environments derived from industrial pollution have clearly established the need for research on bioavailability and potential health risks. Much research has been conducted on metal sorption in soils. However, there is still a need to better understand the availability of metal contaminants to plants and microbes. Such information will enhance both human health and decisions about remediation efforts. In this study, Welland Loam (Typic epiaquolo and Quarry Muck (Terric haplohemist) Ni contaminated soils from Port Colborne (Canada) which had been treated and untreated with limestone, were employed in greenhouse and bioavailability studies. These soils varied in pH from 5.1 to 7.5, in organic matter content from 6% to 72%, and in total Ni from 63 to 22,000mg/kg. Oat (*Avena sativa*), a nonhyperaccumulator, and *Alyssum murale*, a hyperaccumulating plant species, were grown on these soils in greenhouse studies for 45 and 120 days, respectively, to estimate Ni accumulation. A Ni specific bacteria] biosensor was also used to determine Ni bioavailability, and the results were compared to those from the greenhouse studies and more conventional, indirect chemical extraction techniques (employing MgCl<sub>2</sub> and a Sr(NO<sub>3</sub>)<sub>2</sub>). Results from the greenhouse, chemical extraction, and biosensor studies suggested that as the pH of the soil was increased with liming, Ni bioavailability decreased. However, the phytoextraction capability of *A. murale* increased as soil pH increased, which was not the case for *A. sativa*. Furthermore, the Ni specific bacterial

biosensor was successful in predicting Ni bioavailability in the soils and suggested that higher Ni bioavailabilities occur in the soils at pH values of 5.1 and 6. The combination of plant growth, chemical extraction, and bacterial biosensor approaches are recommended for assessing bioavailability of toxic metals