Zablotowicz, R. M., M. A. Locke and R. E. Hoagland (1997). Aromatic Nitroreduction of Acifluoren in Soils, Rhizospheres, and Pure Cultures of Rhizobacteria. Phytoremediation of Soil and Water Contaminants. E. L. Kruger, T. A. Anderson and J. R. Coats. Orlando, Fl, American Chemical Society: 38-53.

Zablotowicz, R.M., M.A. Locke, and R.E. Hoagland (1997). Aromatic nitroreduction of acifluorfen in soils, rhizospheres, and pure cultures of rhizobacteria. In E.L. Kruger, T.A. Anderson, and J.R. Coats (eds.), Phytoremediation of Soil and Water Contaminants, ACS Symposium Series No. 664. American Chemical Society, Washington, DC.

Zablotowicz, R.M., R.E. Hoagland, and M.A. Locke (1994). Glutathione S-transferase activity in rhizosphere bacteria and the potential for herbicide detoxification. Pp. 184-198. In T.A. Anderson and J.R. Coats (eds.), Bioremediation Through Rhizosphere Technology, ACS Symposium Series, Volume 563. American Chemical Society, Washington, DC.

Zaccheo, P., L. Crippa, et al. (2006). Ammonium nutrition as a strategy for cadmium mobilisation in the rhizosphere of sunflower. Plant and Soil 283(1-2): 43-56. Ammonium nutrition of higher plants results in rhizosphere acidification due to proton excretion by root cells. The acidification induced by ammonium-fed plants can be exploited to promote a localised metal mobilisation in neutral to alkaline polluted soils and therefore to improve phytoextraction. The effects of ammonium uptake by sunflower (*Helianthus annuus* L.) plants on the external medium pH, aerial and root growth and tolerance to soluble Cd were studied in hydroponic culture. The ammonium-fed sunflowers induced a strong acidification of the solution and, compared to the nitrate-fed sunflowers, a small modification in mineral nutrition and a different Cd partitioning between root and shoot. Moreover, ammonium nutrition was found to induce a great mobilisation of a sparingly soluble form of cadmium (CdCO3). A pot experiment studied the ability of different ammonium-based fertilisers (ammonium sulphate, ammonium thiosulphate, urea) to modify bulk and rhizo-soil pH, compared to the effect of calcium nitrate and to the unfertilised soil. Furthermore, in order to promote the persistence of ammonium in soil, a combined treatment of ammonium sulphate and DMPP, a nitrification inhibitor, was tested. Soil pH was strongly modified by chemical and biological processes involved in fertiliser transformations. In particular, due to nitrification, all ammonium-based treatments showed a bulk soil acidification of over 1.5 pH units and a relative increase in rhizo-soil pH as a consequence of nitrate uptake. The treatment with DMPP showed an opposite trend with a lower pH in rhizo-soil than in bulk soil. The ability of ammonium-fed plants to mobilise heavy metals from the non-labile pool was studied in another pot experiment using three soils with different properties and at different degree and type of heavy metal contamination. Whatever the soil, the metal concentrations in shoots were higher in plants fed with ammonium (ammonium sulphate plus DMPP treatment). Our results support the hypothesis that ammonium nutrition with nitrification inhibitors is a viable strategy to improve heavy metals phytoextraction while protecting bulk soil from acidification and presumably from metal leaching.

Zaidi, S., S. Usmani, et al. (2006). Significance of *Bacillus* subtilis strain SJ-101 as a bioinoculant for concurrent plant growth promotion and nickel accumulation in *Brassica juncea*. Chemosphere 64(6): 991-997. In this study, a nickel (Ni)-tolerant *Bacillus* subtilis strain SJ-101 was characterized based on the 16SrDNA homology and phylogenetic analysis. The role of this strain ascertained in facilitating Ni accumulation in the Indian mustard plant.(*Brassicajuncea* [L]. Czern and Coss) var. Pusa Bold (DIR-50), to elucidate the potential of Ni phytoremediation in combination with metal-tolerant rhizobacteria. The data revealed that the plants exposed to NiCl2 (1750 mg kg(-1)) in soil bioaugmented with strain SJ-101 have accumulated 0.147% Ni vis-A-vis 0.094% accumulation in dry biomass of the plants grown in uninoculated soil. The strain SJ-101 has also exhibited the capability of producing indole acetic acid (IAA) (55 mu g ml(-1)), and solubilizing inorganic phosphate (90 mu g ml(-1)) in specific culture media. The pot culture experiments clearly demonstrated the beneficial effects of bioinoculant strain SJ-101 with significant increase ($P < 0.05$) in the plant growth attributes in untreated control soil. Furthermore, the protective effect of the strain SJ-101 against Ni phytotoxicity was evident in plants grown in

soil treated with NiCl2 in concentration range of 250-1750 mg kg(-1). Thus, it is suggested that the strain SJ-101 owing to its intrinsic abilities of plant growth promotion, and attenuation of soil Ni by biosorption and bioaccumulation, could be exploited for bacteria-assisted phytoaccumulation of this toxic heavy metal from contaminated sites. (c) 2006 Elsevier Ltd.

Zak, D.R., K.S. Pregitzer, P.S. Curtis, J.A. Teeri, R. Fogel, and D.L. Randlett (1993). Elevated atmospheric CO2 and feedback between carbon and nitrogen cycles. Plant Soil. 151:105-118.

Zakharova, E., P. Kosterin, V. Brudnik, A. Shcherbakov, A. Ponomaryov, L. Shcherbakova, V. Mandich, E. Fedorov and V. Ignatov (2000). Soil Phytoremediation from the Breakdown Products of the Chemical Warfare Agent, Yperite. ENVIRON SCI POLLUT R 7(4): 191-194.

Zalesny, R. S., E. O. Bauer, et al. (2005). Clonal variation in survival and growth of hybrid poplar and willow in an in situ trial on soils heavily contaminated with petroleum hydrocarbons. International Journal of Phytoremediation 7(3): 177-197. Species and hybrids between species belonging to the genera *Populus* (poplar) and *Salix* (willow) have been used successfully for phytoremediation of contaminated soils. our objectives were to: 1) evaluate the potential for establishing genotypes of poplar and willow on soils heavily contaminated with petroleum hydrocarbons and 2) identify promising genotypes for potential use in future systems. We evaluated height, diameter, and volume after first year budset by testing 20 poplar clones and two willow clones. Unrooted cuttings, 20 cm long, were planted in randomized complete blocks at 0.91- x 0.91-m spacing at Gary, IN, USA (41.5 degrees N, 87.3 degrees W). Four commercial poplar clones (NM6, DN5, DN34, and DN182) were planted as 20- and 60-cm cuttings. Sixty-cm cuttings exhibited greater height and diameter than 20-cm cuttings; however, we recommend continued use and testing of different combinations of genotype and cutting length. We identified promising genotypes for potential use in future systems and we recommend allocating the majority of resources into commercial poplar clones, given their generalist growth performance. However, further utilization and selection of experimental clones is needed. Specific clones rather than genomic groups should be selected based on the geographic location and soil conditions of the site.

Zalesny, R. S., Jr., A. H. Wiese, et al. (2006). Sapflow of hybrid poplar (*Populus nigra* L. x P. maximowiczii A. Henry 'NM6') during phytoremediation of landfill leachate. Biomass and Bioenergy. R. S. Zalesny, Jr. 30: 784. Poplars are ideal for phytoremediation because of their high water usage, fast growth, and deep root systems. We measured in 2002 and 2003 the sapflow of hybrid poplars (*Populus nigra* L. x P. maximowiczii A. Henry 'NM6') planted in 1999 for phytoremediation of a landfill in Rhinelander, WI, USA (45.6degreesN, 89.4degreesW). Mean sap velocity per tree was 100 +- 10 and 120 +- 10 microm s-1 for 2002 and 2003, respectively. Mean sapflow per tree was 1.4000 +- 0.1698 and 5.6760 +- 0.2997 kg h-1 for 2002 and 2003, respectively. Sapflow was negatively correlated with temperature, wind speed, precipitation, and vapor pressure deficit for both years (0.002 < r2 < 0.61). Sapflow increased as mean sapwood area increased from 43.8 +- 2.6 to 122.3 +- 7.6 cm2 for 2002 and 2003, respectively (r2=0.88). Individual-tree extrapolations using the mean tree approach were: 34 and 136 kg tree-1 d-1 for 2002 and 2003, respectively, and 612 and 2 448 kg tree-1 18-d-1 for 2002 and 2003, respectively. Extrapolations to the stand were 2.8 and 11.3 mm d-1 (28.3 and 113.3 Mg ha-1 d-1) for 2002 and 2003, respectively (assuming 833 trees ha-1), and 354 and 1 416 mm yr-1 (3.54 and 14.16 Gg ha-1 yr-1) for 2002 and 2003, respectively (assuming a 125-d growing season). Thus, we believe NM6 and other superior-performing poplar genotypes exhibit great potential for phytoremediation applications where elevated water usage is critical.

Zambrzuski, S., G.S. Banuelos, F. Piyasil (1993). Abstract: Effects of boron, salt, and selenium on the germination of different kenaf varieties.

Zaranyika, M.F., and T. Ndapwadza (1995). Uptake on Ni, Zn, Fe, Co, Cr, Pb, Cu, and Cd by water hyacinth (*Echhornia craissipes*) in Mukuvisi and Manyame Rivers, Zimbabwe. J. Environ. Sci. Health. A30(1):157-170.

Zaurov, D., P. Perdomo and I. Raskin (1999). Optimizing Soil Fertility and Ph to Maximize Cadmium Removed by Indian Mustard from Contaminated Soils. J. Plant Nutr. 22(6): 977-986.

Zavala-Cruz, J., F. Gavi-Reyes, et al. (2005). Oil spills on soils and adaptation of tropical grass in Activo Cinco Presidentes, Tabasco, Mexico. Derrames de petroleo en suelos y adaptacion de pastos tropicales en el Activo Cinco Presidentes, Tabasco, Mexico. Terra. J. Zavala-Cruz. 23: 293. Activo Cinco Presidentes has the highest number of oil spills on soil, causing damage to grassland and natural vegetation, in the state of Tabasco, Mexico. A study was conducted to evaluate the effect of oil spills on the properties of five soil units, and dry biomass production of three tropical grasses in soils contaminated by these spills, as well as to identify alternative technologies for the recovery of areas affected by the spills. From the spills, detected in different soil units, unaltered soil samples (USS) were collected with PVC tubes (20 cm diameter and 30 cm length), in each one of the four zones visually detected in function of their colour centre, edge, spotted, and without spots. Under a shade awning, stems of the species *Brachiaria* humidicola were transplanted and grown in USS of Anthrosols and Acrisols, *Echinochloa* polystachya in USS of Gleysols, *Brachiaria* mutica in USS of Gleysols and Histosols. The HTP increased organic matter content in Anthrosols, Acrisols and Gleysols, Na in Gleysols, and acidity in Acrisols and Gleysols. Oil negatively affected the grasses in the establishing phase and positively once the plant was better developed. All the grasses, properly nurtured with P and Ca, could contribute to the phytoremediation of the contaminated soils, B. humidicola grass being the most promising in Anthrosols.

Zavoda, J., T. Cutright, J. Szpak and E. Fallon (2001). Uptake, Selectivity, and Inhibition of Hydroponic Treatment of Contaminants. J. Environ. Eng. 127(6): 502-508.

Zayed, A. M. and N. Terry (2003). Chromium in the environment: Factors affecting biological remediation. Plant and Soil 249(1): 139-156. Chromium, in the trivalent form (Cr(III)), is an important component of a balanced human and animal diet and its deficiency causes disturbance to the glucose and lipids metabolism in humans and animals. In contrast, hexavalent Cr (Cr(VI)) is highly toxic carcinogen and may cause death to animals and humans if ingested in large doses. Recently, concern about Cr as an environmental pollutant has been escalating due to its build up to toxic levels in the environment as a result of various industrial and agricultural activities. In this review, we present the state of knowledge about chromium mobility and distribution in the environment and the physiological responses of plants to Cr with the desire to understand how these processes influence our ability to use low cost, environmentally friendly biological remediation technologies to clean up Cr-contaminated soils, sediments, and waters. The use of biological remediation technologies such as bioremediation and phytoremediation for the cleanup of Cr-contaminated areas has received increasing interest from researchers worldwide. Several methods have been suggested and experimentally tested with varying degrees of success.

Zayed, A., C. Lytle and N. Terry (1998). Accumlation and Volatilization of Different Chemical Species of Selenium by Plants. Planta 206(2): 284-292.

Zayed, A., L. Pilon-Smits, D. Hansen, and N. Terry (1995). Poster Abstract: Phytoremediation of selenium pollution by biological volatilization. P. 100. 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.

Zayed, A., S. Gowthaman and N. Terry (1998). Phytoaccumulation of Trace Elements by Wetland Plants: I. Duckweed. J. Environ. Qual. 27: 715-721.

Zayed, A.M., and N. Terry (1992). Influence of sulfate level on Se volatilization in broccoli. Plant Physiol. 140:646-652.

Zayed, A.M., and N. Terry (1994). Selenium volatilization in roots and shoots: Effects of shoot removal and sulfate level. Plant Physiol. 143(1):8-14.

Zeeb, B. A., J. S. Amphlett, et al. (2006). Potential for phytoremediation of polychlorinated biphenyl-(PCB-)contaminated soil. International Journal of Phytoremediation 8(3): 199-221. Weathered soils contaminated with commercial-grade Aroclor 1260 from three sites in Canada were used to investigate the polychlorinated biphenyl (PCB) phytoextraction potential of nine plant species (*Festuca arundinacea*, Glycine max, *Medicago sativa*, *Phalaris arundinacea*, *Lolium multiflorum*, *Carex* normalis, and three varieties of *Cucurbita pepo* ssp. *pepo)* under controlled greenhouse conditions. The soils used varied in PCB concentration (90-4200 mu g/g) and total organic content (0.06-2.02%). Greenhouse experiments controlled for PCB volatilization through the use of a vented enclosure and by isolating the contaminated soils with parafilm. After 8 wks, PCB concentrations of 47-6700 mu g/g were observed in root tissues. Although PCB concentrations in shoot tissues were lower (< 1-470 mu g/g), the absolute amounts of PCBs observed in shoot tissue were significant (1.7-290 mu g) once shoot biomass was accounted for. Congener signatures indicated that tetra- to hexa-chlorobiphenyls contributed the largest proportions to shoot tissues, but heptato nona-chorobiphenyls were also present in measurable amounts. Overall, the results indicate that varieties of C. *pepo* were more effective at extracting PCBs from soil than other plants screened. The evidence suggests that this was mainly due to root uptake of PCBs and tranlocation to the shoots, rather than volatilization of PCBs from soil. All plants screened showed signs of stress in the most highly contaminated soil (4200 mu g/g), but not in the two lower PCB contaminated soils (250 and 99 mu g/g, respectively). No detectable decreases in soil PCB concentrations were observed in these short-term greenhouse experiments, but the results suggest that this may be achievable through multiple plantings.

Zehnalek, J., J. Vacek, et al. (2004). Use of plants in technologies of phytoremediation of heavy metals. Vyuziti rostlin ve fytoremediacni technologii tezkych kovu. Listy Cukrovarnicke a Reparske. J. Zehnalek. 120: 220. The possibility of using higher plants for decontamination of soil and water environments polluted by heavy metals is discussed. Information is considered on methods of bioremediation using white mustard (*Sinapis* alba), *Thlaspi arvense*, sunflowers and sugarbeet plants as hyperaccumulators of heavy metals. Processes of phytoremediation are outlined, i.e. phytoextraction, rhizofiltration, volatilisation and phytodegradation.

Zeleznick, J.D., and J.G. Skousen (1996). Survival of three tree species on old reclaimed surface mines in Ohio. J. Environ. Qual. 25:1429-1435.

Zellmer, S. D., J. F. Schneider, N. A. Tomczyk, W. L. Banwart and D. Chen (1995). Plant Uptake of Explosives from Contaminated Soil at the Joliet Army Ammunition Plant. U.S. Army Environmental Center: 56.

Zeng, Q., C. Mo, et al. (2006). Accumulation of di-n-butyl phthalate in different genotypes of *Brassica* campestris-soil systems. China Environmental Science. Q. Zeng. 26: 333. Different *Brassica* campestris genotypes (Teqing-60, Youqingsijiu, Yashuquannianyoulu, Youqing-60 and Xinxunsiwu) were pot-cultured in paddy soil polluted by di-n-butyl phthalate (DBP), and the distribution of DBP in B. campestris-soil system was studied by GC/MS. DBP accumulation of the leaves and roots of different genotypes of B. campestris varied obviously. The leaf and root DBP contents of Teqing-60 and Youqingsijiu were low, while Yashuquannianyoulu and Youqing-60 were high. The DBP content in the leaves showed definite positive correlation with leaf area. The

distribution of DBP in the different B. campestris genotype-soil systems was different obviously. The leaf and root DBP content of Xinxunsiwu and pot-cultured soil were low. The leaves and roots of Teqing-60 and Xinxunsijiu showed low DBP content but pot-cultured soil showed high content. The leaf and root DBP contents of Youqing-60 and pot-cultured soil were high.

Zhang, D.-q., G.-w. Chu, et al. (2003). Decontamination ability of garden plants to absorb sulfur dioxide and fluoride. Journal of Tropical and Subtropical Botany 11(4): 336-340. Seventy-five species of garden plant seedlings were potted under contaminated environment at Dongcun (DC) and Wuxing (WX) near ceramic industry sites in Foshan City, Guangdong, and at botanical garden (control). The contents of sulphur and fluorine in the leaves of the thirty-two surviving species were measured after 128 days, among which 14 species including *Ficus* religiosa, F. microcarpa var. fuyuensis, Lysidice rhodostegia, Carallia brachiata, Ilex rotunda, etc. had great ability to absorb air pollutants SO2 and fluoride. Average sulphur and fluorine contents in leaves of these species pot-grown at contaminated sites were 17 442 mg kg-1 DW and 3725.9 mg kg-1 DW, respectively, which were 1.9 times and 20 times higher than those at control site, respectively, showing that these species were more tolerant to SO2 and fluoride pollutants.

Zhang, H. Y., W. Z. Xu, et al. (2006). Functional characterization of cadmium-responsive garlic gene AsMT2b: A new member of metallothionein family. Chinese Science Bulletin 51(4): 409-416. A new gene of metallothionein (MT) family was cloned from garlic (*Allium sativum*) seedlings using RACE method and designated AsMT2b. The full length of AsMT2b cDNA was 520 bp encoding 80 amino acids. The deduced amino acids of AsMT2b showed that AsMT2b contained the characteristic structure of type 2 MT proteins, but the number and arrangement of the cysteine residues in the N- and C-terminal domains was different from other type 2 MT proteins. Semi-quantitative reverse transcriptase-PCR showed that transcript levels of AsMT2b were enhanced only in response to higher concentrations or longer incubation time of Cd. Such an expression pattern of AsMT2b greatly differed from that of other type 2 MT genes. Yeast cells transformed with this gene had improved resistance to Cd. AsMT2b overexpressing *Arabidopsis* showed stronger Cd tolerance and higher Cd accumulation compared with wild-type plants. These results suggest that AsMT2b should be useful in phytoremediation of Cd-polluted soil in the future.

Zhang, J. and Q. Sun (2005). Causes of wetland degradation and ecological restoration in the Yellow River delta region. Forestry Studies in China. J. Zhang. 7: 15. Yellow River delta (YRD) is one of the biggest deltas (1200 km2) in China, with a national wetland reserve of 1530 km. Thanks to soil (sands) sediment carried by the Yellow River, there was on average 21.3 km2 of newly formed land in the YRD per year. During the development of the petroleum industry and urban expansion, wetlands were degraded due to population growth and irrational land use, in addition to an adverse natural eco-environment such as lower precipitation, higher soil evaporation and soil salinization. The major ecological measures to restore degraded wetland were concerned with ensuring water supply, especially establishing perfect irrigation works; protecting virgin plant communities and assisting them to regenerate by the way of site preparationand improving living surroundings; introducing salt-tolerant plants to increase vegetation species and plant coverage, thereby enhancing the capability of wetland to combat contamination and pollution through plant remediation, uptake, absorption, etc. Finally making a comprehensive land use plan, accordingly removing deleterious facilities.

Zhang, L., J. S. Angle, et al. (2005). Degradation of *Alyssum murale* biomass in soil. International Journal of Phytoremediation. L. Zhang. 7: 169. The Ni-hyperaccumulating plant *Alyssum murale* accumulates exceptionally high concentrations of nickel in its aboveground biomass. The reasons for hyperaccumulation remain unproven; however, it has been proposed that elemental allelopathy might be important. High-Ni leaves shed by the plant may create a toxic zone around the plant where germination or growth of competing plants is inhibited. The efficacy of this argument will partially depend upon the rate at which leaves degrade in soil and free metals are released, and the subsequent rate at which metals are bound to soil constituents. To test the

degradation of biomass of hyperaccumulators, A. *murale* was grown on both high- and low-Ni soils to achieve high- (12.0 g Ni/kg) and low- (0.445 g Ni/kg) Ni biomass. Shredded leaf and stem biomass were added to a serpentine soil (Brockman variant very gravelly loam; fine, magnesic, mesic Typic Xerochrepts) from Oregon, USA, that was originally used to grow high-Ni biomass and a low-Ni control soil (Christiana fine sandy loam; clayey, kaolinitic, mesic Typic Paleudults) from Maryland. Biomass Ni was readily soluble and extractable, suggesting near immediate release as biomass was added to soil. Extractable nickel in soil amended with biomass declined rapidly over time due to Ni binding in soil. These results suggest that Ni released from biomass of Ni hyperaccumulators may significantly affect their immediate niche only for short periods of time soon after leaf fall, but repeated application may create high Ni levels under and around hyperaccumulators.

Zhang, L., J.-L. Qian, and D. Planas (1995). Mercury concentrations in tree rings of Black Spruce (Picea mariana Mill. B.S.P.) in boreal Quebec, Canada. Water Air Soil Pollut. 81:163-174.

Zhang, Q., L. C. Davis and L. E. Erickson (2000). An Experimental Study of Phytoremediation of Methyl-Tert-Butyl Ether (Mtbe) in Groundwater. J. Hazardous Substance Research 2.

Zhang, Q., L. C. Davis and L. E. Erickson (2000). Plant Uptake of Methyl Tert-Butyl Ether (Mtbe) from Groundwater. ASCE National Conf on Environmental and pipeline engineering, Kansas City, MO, ASCE.

Zhang, Q., L.E. Erickson, and L.C. Davis (1997). Poster 47. Abstract: Effect of air sparging on fate and transport of trichloroethylene in chambers with alfalfa plants. In 12th Annual Conference on Hazardous Waste Research, May 19-22, 1997, Kansas City, MO. To study the effect of air sparging in soil with trichloroethylene present as a dense nonaqueous phase, air was supplied through pipes installed at the bottoms of two chambers planted with alfalfa. Air input rate was 2.14 L/m2/day. The fate of trichloroethylene (TCE) was investigated by monitoring concentration in both outflow ground water phase and above soil gas phase. Experimental results are presented. Comparison of these results with those of our previous study without air introduction indicates that air sparging appreciably increases the ground water concentration. The above soil gas phase shows even greater concentration difference. The flux rate from soil is increased significantly. Accordingly, we can conclude that air sparging improved mass transfer of TCE from nonaqueous phase to ground water phase. Air sparging appeared to negatively impact the health of the alfalfa because of the elevated TCE present in the vadose zone of the chamber.

Zhang, W. H., Y. Cai, et al. (2002). Arsenic speciation and distribution in an arsenic hyperaccumulating plant. Science of the Total Environment 300(1-3): 167-177. Arsenic-contaminated soil is one of the major arsenic sources for drinking water. Phytoremediation, an emerging, plant-based technology for the removal of toxic contaminants from soil and water, has been receiving renewed attention. Although a number of plants have been identified as hyperaccumulators for the phytoextraction of a variety of metals, and some have been used in field applications, no hyperaccumulator for arsenic had been previously reported until the recent discovery of Brake fern (*Pteris vittata*), which can hyperaccumulate arsenic from soils. This finding may open a door for phytoremediation of arsenic-contaminated soils. Speciation and distribution of arsenic in the plant can provide important information helpful to understanding the mechanisms for arsenic accumulation, translocation, and transformation. In this study, plant samples after 20 weeks of growth in an arsenic-contaminated soil were used for arsenic speciation and distribution study. A mixture of methanol/water (1:1) was used to extract arsenic compounds from the plant tissue. Recoveries of 85 to 100% were obtained for most parts of the plant (rhizomes, fiddle heads, young fronds and old fronds) except for roots, for which extraction efficiency was approximately 60%. The results of this study demonstrate the ability of Brake fern as an arsenic hyperaccumulator. It transfers arsenic rapidly from soil to aboveground biomass with only minimal arsenic concentration in the roots. The arsenic is found to be predominantly as inorganic species; and it was hypothesized that the plant uptakes arsenic as arsenate [As(V)] and

arsenate was converted to arsenite [As(III)] within the plant. The mechanisms of arsenic uptake, translocation, and transformation by this plant are not known and are the objectives of our on-going research. (C) 2002 Elsevier Science B.V.

Zhang, W. H., Y. Cai, et al. (2004). Arsenic complexes in the arsenic hyperaccumulator *Pteris vittata* (Chinese brake fern). Journal of Chromatography A 1043(2): 249-254. *Pteris vittata* (Chinese brake fern), the first reported arsenic (As) hyperaccumulating plant, can be potentially applied in the phytoremediation of As-contaminated sites. Understanding the mechanisms of As tolerance and detoxification in this plant is critical to further enhance its capability of As hyperaccumulation. In this study, an unknown As species, other than arsenite (As-III) or arsenate (As-V) was found in leaflets by using anion-exchange chromatography-hydride generation-atomic fluorescence spectroscopy and size-exclusion chromatography-atomic fluorescence spectrometry. The chromatographic behavior of this unknown As species and its stability suggest that it is likely an As complex. Although phytochelatin with two subunits (PC2) was the only major thiol in P. *vittata* under As exposure, this unknown As complex was unlikely to be an As-III-PC2 complex by comparison of their chromatographic behaviors, stability at different pHs and charge states. The complex is sensitive to temperature and metal ions, but relatively insensitive to pH. In buffer solution of pH 5.9, it is present in a neutral form. (C) 2004 Elsevier B.V.

Zhang, W. H., Y. Cai, et al. (2004). Thiol synthesis and arsenic hyperaccumulation in *Pteris vittata* (Chinese brake fern). Environmental Pollution 131(3): 337-345. *Pteris vittata* (Chinese brake fern) has potential for phytoremediation of As-contaminated sites. In this study, the synthesis of total thiols and acid-soluble thiols in P. *vittata* was investigated under arsenic exposure. The strong and positive correlation between As concentration and acid-soluble thiols in plant leaflets suggests that acid-soluble thiols may play a role in As detoxification. A major As-induced thiol was purified and characterized. A molecular ion (M + 1) of 540 m/z suggests that the thiol was a phytochelatin (PC) with two base units (PC2). However, the ratios of acid-soluble thiols to As in leaflets exposed to As ranged from 0.012 to 0.026, suggesting that only a very small part of As is complexed by PC2. PCs could play a minor detoxification role in this hyperaccumulator. A PC-independent mechanism appears to be mainly involved in As tolerance, while PC-dependent detoxification seems to be a supplement. (C) 2004 Elsevier Ltd.

Zhang, W., Y. Cai, et al. (2002). Arsenic speciation and distribution in an arsenic hyperaccumulating plant. Science of the Total Environment 300(1-3): 167-177. Arsenic-contaminated soil is one of the major arsenic sources for drinking water. Phytoremediation, an emerging, plant-based technology for the removal of toxic contaminants from soil and water, has been receiving renewed attention. Although a number of plants have been identified as hyperaccumulators for the phytoextraction of a variety of metals, and some have been used in field applications, no hyperaccumulator for arsenic had been previously reported until the recent discovery of Brake fern (*Pteris vittata*), which can hyperaccumulate arsenic from soils. This finding may open a door for phytoremediation of arsenic-contaminated soils. Speciation and distribution of arsenic in the plant can provide important information helpful to understanding the mechanisms for arsenic accumulation, translocation, and transformation. In this study, plant samples after 20 weeks of growth in an arsenic-contaminated soil were used for arsenic speciation and distribution study. A mixture of methanol/water (1:1) was used to extract arsenic compounds from the plant tissue. Recoveries of '85 to 100% were obtained for most parts of the plant (rhizomes, fiddle heads, young fronds and old fronds) except for roots, for which extraction efficiency was approximately 60%. The results of this study demonstrate the ability of Brake fern as an arsenic hyperaccumulator. It transfers arsenic rapidly from soil to aboveground biomass with only minimal arsenic concentration in the roots. The arsenic is found to be predominantly as inorganic species; and it was hypothesized that the plant uptakes arsenic as arsenate (As(V)) and arsenate was converted to arsenite (As(III)) within the plant. The mechanisms of arsenic uptake, translocation, and transformation by this plant are not known and are the objectives of our on-going research.

Zhang, W., Y. Cai, et al. (2004). Arsenic complexes in the arsenic hyperaccumulator *Pteris vittata* (Chinese brake fern). Journal of Chromatography A 1043(2): 249-254. *Pteris vittata* (Chinese brake fern), the first reported arsenic (As) hyperaccumulating plant, can be potentially applied in the phytoremediation of As-contaminated sites. Understanding the mechanisms of As tolerance and detoxification in this plant is critical to further enhance its capability of As hyperaccumulation. In this study, an unknown As species, other than arsenite (AsIII) or arsenate (AsV) was found in leaflets by using anion-exchange chromatography-hydride generation-atomic fluorescence spectroscopy and size-exclusion chromatography-atomic fluorescence spectrometry. The chromatographic behavior of this unknown As species and its stability suggest that it is likely an As complex. Although phytochelatin with two subunits (PC2) was the only major thiol in P. *vittata* under As exposure, this unknown As complex was unlikely to be an AsIII-PC2 complex by comparison of their chromatographic behaviors, stability at different pHs and charge states. The complex is sensitive to temperature and metal ions, but relatively insensitive to pH. In buffer solution of pH 5.9, it is present in a neutral form. Copyright 2004 Elsevier B.V.

Zhang, W., Y. Cai, et al. (2004). Thiol synthesis and arsenic hyperaccumulation in *Pteris vittata* (Chinese brake fern). Environmental Pollution 131(3): 337-345. *Pteris vittata* (Chinese brake fern) has potential for phytoremediation of As-contaminated sites. In this study, the synthesis of total thiols and acid-soluble thiols in P. *vittata* was investigated under arsenic exposure. The strong and positive correlation between As concentration and acid-soluble thiols in plant leaflets suggests that acid-soluble thiols may play a role in As detoxification. A major As-induced thiol was purified and characterized. A molecular ion (M + 1) of 540 m/z suggests that the thiol was a phytochelatin (PC) with two base units (PC2). However, the ratios of acid-soluble thiols to As in leaflets exposed to As ranged from 0.012 to 0.026, suggesting that only a very small part of As is complexed by PC2. PCs could play a minor detoxification role in this hyperaccumulator. A PC-independent mechanism appears to be mainly involved in As tolerance, while PC-dependent detoxification seems to be a supplement. Copyright 2004 Elsevier Ltd.

Zhao, F. J. and R. E. Hamon (2001). Root Exudates of the Hyperaccumulator *Thlaspi caerulescens* Do Not Enahnce Metal Mobilization. New Phytologist 151: 613-620.

Zhao, F. J., E. Lombi, et al. (2003). Assessing the potential for zinc and cadmium phytoremediation with the hyperaccumulator *Thlaspi caerulescens*. Plant and Soil 249(1): 37-43. *Thlaspi caerulescens* is a Zn and Cd hyperaccumulator, and has been tested for its phytoremediation potential. In this paper we examine the relationships between the concentrations of Zn and Cd in soil and in *T. caerulescens* shoots, and calculate the rates of Zn and Cd extraction from soil. Using published data from field surveys, field and pot experiments, we show that the concentrations of Zn and Cd in the shoots correlate with the concentrations of Zn and Cd in soils in a log-linear fashion over three orders of magnitude. There is little systematic difference between different populations of *T. caerulescens* in the relationship between soil and plant Zn concentrations. In contrast, populations from southern France are far superior to those from other regions in Cd accumulation. Bioaccumulation factors (plant to soil concentration ratio) for Zn and Cd decrease log-linearly with soil metal concentration. Model calculations show that phytoremediation using *T. caerulescens* is feasible when soil is only moderately contaminated with Zn and Cd, and the phytoremediation potential is better for Cd than for Zn if the populations from southern France are used. Recent progress in the understanding of the mechanisms of Zn and Cd uptake by *T. caerulescens* is also reviewed.

Zhao, F. J., J. R. Wang, et al. (2003). The role of phytochelatins in arsenic tolerance in the hyperaccumulator *Pteris vittata*. New Phytologist. F. J. Zhao. 159: 403. *Pteris vittata* was the first identified arsenic (As) hyperaccumulator. Here we investigated whether phytochelatins (PCs) are involved in the hypertolerance of arsenic by P. *vittata*. P. *vittata* was exposed to 0-500 microM arsenate for 5 d, or to 50 microM arsenate for 0-7 d. In addition, L-buthionine-sulphoximine (BSO), an inhibitor of gamma-glutamylcysteine synthetase, was used in combination with different arsenate exposures. The relationships between As accumulation and the concentrations

of PCs and glutathione (GSH) were examined. PC synthesis was induced upon exposure to arsenate in P. *vittata*, with only PC2 detected in the plant. The As concentration correlated significantly with PC2 concentration in both roots and shoots, but not with GSH. The molar ratio of PC-SH to As was c. 0.09 and 0.03 for shoots and roots, respectively, suggesting that only a small proportion (1-3%) of the As in P. *vittata* can be complexed with PCs. In the presence of arsenate, addition of BSO decreased PC2 concentrations in roots and shoots by 89-96% and 30-33%, respectively. BSO alone was found to inhibit root growth of P. *vittata* markedly. The results suggest that PCs play a limited role in the hypertolerance of As in P. *vittata*.

Zhao, K., H. Fan, et al. (2005). Two Na+ and Cl- hyperaccumulators of the Chenopodiaceae. Journal of Integrative Plant Biology. K. Zhao. 47: 311. During 2000 and 2001, five sodium- (Na+) and chloride- (Cl-) hyperaccumulating halophytes were found in the temperate desert of Xinjiang, China, and two of them (Suaeda salsa and Kalidium foliatum) were studied. K. foliatum and S. salsa had an NaCl content of 32.1 and 29.8%, respectively, on a dry weight basis. X-ray microanalysis of the Na+ in the vacuole, apoplasts and cytoplasm of the two plants indicated a ratio of 7.3:5.6:1.0 in K. foliatum and 7.3:6.6:1.0 in S. salsa. These data show that K. foliatum and S. salsa both have a high Na+- and Cl--accumulating capacity, which is related to the high activity of tonoplast H+-ATPase and H+-PPase.

Zhao, S. H., E. L. Arthur, et al. (2003). The use of native prairie grasses to degrade atrazine and metolachlor in soil. Environmental Fate and Effects of Pesticides. 853: 157-166. The ability of native prairie grasses, big bluestem (Andropogon gerardii Vitman), Yellow indiangrass (Sorghastrum nutans L.), and switchgrass (*Panicum virgatum* L.), to degrade atrazine and metolachlor was evaluated in two soils denoted as Alpha and Bravo soils. Vegetation significantly decreased the amount of remaining atrazine in Alpha soil when the concentration of atrazine before vegetation was 93 mug g(-1), but had no effect on the degradation of atrazine when it was 4.9 mug g(-1). The significant effect of the plants on atrazine degradation in Alpha soil occurred at 57 days after the transplanting of vegetation, but not at 28 days after the transplanting of vegetation. The grasses did not enhance the degradation of atrazine in Bravo soil due to the population of atrazine-degrading microorganisms in that soil. The native prairie grasses had a significant positive effect on the enhanced degradation of metolachlor in both soils, and the significant effect was observed at 28 and 57 days after the transplanting of vegetation in Alpha and Bravo soil, respectively. NH4NO3 had no effect on the degradation of atrazine and metolachlor in either soil. Our results indicate that it is feasible to use the native prairie grasses to help remediate the soils contaminated with high concentrations of atrazine and metolachlor, especially in the absence of the indigenous atrazine or metolachlor degraders.

Zheljazkov, V. D., L. E. Craker, et al. (2006). Effects of Cd, Pb, and Cu on growth and essential oil contents in dill, peppermint, and basil. Environmental and Experimental Botany 58(1-3): 9-16. The hypothesis tested in this study was that some essential oil crops could be to grown as alternatives to edible crops in heavy metal enriched soils. Experiments were conducted to evaluate the effect of Cd, Pb, and Cu on yields and essential oils of peppermint, basil, and dill. The accumulation of Cd, Pb, and Cu in plant parts, in plant material and water after distillation, and in the essential oils, was also determined. Metal treatments of peppermint and basil consisted of Cd, Pb, Cu, Cd + Pb, Cd + Cu, Pb + Cu, Cd + Pb + Cu, and unamended control. Metal treatments of dill consisted of (in mg L-1): Cd at 2, 6, and 10; Pb at 50, 100, and 500; Cu at 20, 60, and 150 and an unamended control. Peppermint and basil yields were not affected by the treatments. Copper at 60 and Cu 150 mg L-1 reduced both yields and height of dill, Cu 150 mg L-1 resulted in Cu phytotoxicity symptoms and retarded growth. High Pb and Cu reduced Cd uptake by peppermint and basil. At elevated Cd concentrations in the growth medium, Cd transport from roots to shoots of the three species was impaired. The tested treatments slightly altered chemical composition of the essential oils of basil and dill, and reduced the menthol content in the peppermint oil. Oil content in basil from the CdPbCu treatment was lower that in the control. Copper application at 150 mg L-1 reduced oil content in dill relative to the control. No detectable amount of Cd, Cu, or Pb in the oils of any of the three species was found. Peppermint, basil, and

dill can be grown in soils enriched with Cd, Pb, and Cu medium without risk for metal transfer into the oils, and without significant alteration of essential oil composition that may impair marketability. Our results support the use of aromatic plants as alternative crops for Cd, Pb, and Cu enriched soils. (c) 2005 Elsevier B.V.

Zheljazkov, V.D., and N.E. Nielsen (1996). Studies on the effect of heavy metals (Cd, Pb, Cu, Mn, An, and Fe) upon the growth, productivity and quality of lavender (Lavandula augustifolia Mill.) production. J. Essent. Oil Res. 8(3):259-274.

Zheng, J., L.-i. Lou, et al. (2006). Petridium revolutum, a promising plant for phytoremediation of Cu-polluted soil. Yingyong Shengtai Xuebao 17(3): 507-511. A field survey on the Petridium revolutum growing on the Cu mining spoils in Yunnan Province and related greenhouse hydroponic sand culture experiment showed that when growing on the soil with an average Cu concentration of 2 432 mg(.)kg(-1) DW and the maximum Cu concentration of 7 554 mg(.)kg(-1) DW, P. revolutum had a large amount of aboveground biomass, with the maximum dry weight of 40.05 g(.)plant(-1) DW and the average dry weight of 18.33 g(.)plant(-1) DW. The average and maximum Cu contents were 201 and 567 mg(.)kg(-1) DW in aboveground biomass, and 346 and 1723 kg(-1) DW in underground biomass, respectively. The transfer factor of Cu reached a maximum of 3.88, with an average of 0.81. Under quartz sand culture condition, P. revolutum could grow well when the Cu concentration in nutrient solution was 7 mg(.)L(-1). The accumulation of Cu by P. revolutum plant increased significantly with increasing Cu concentration, with the most of absorbed Cu concentrated in underground biomass. It was suggested that P. revolutum had a remarkable tolerance to Cu and a potential capacity of Cu accumulation, and could be used in the phytoremediation of Cu-polluted soils.

Zheng, Z. and K. Shetty (2000). Azo Dye-Mediated Regulation of Total Phenolics and Peroxidase Activity in Thyme (Thymus *Vulgaris* L.) and Rosemary (Rosmarinus Officinalis L.) Clonal Lines. J. Agric. Food Chem. 48(3): 932-937.

Zhou, W. and B. Qiu (2004). Mechanisms for heavy metal detoxification and tolerance in algae. Hupo Kexue 16(3): 265-272. With the development of industry and agriculture, more and more heavy metals are released into water bodies. Today, many heavy metals constitute a global environmental hazard. Heavy metals such as copper, zinc, and nickel are essential for many physiological processes yet can be toxic at higher levels. Other metals such as cadmium, mercury and lead are nonessential and potentially highly toxic. Algae possess a range of potential cellular mechanisms that may be involved in the detoxification of heavy metals and thus tolerance to metal stress. These include roles for the following: for sequesteration of metals on extracellular components that reduce metal bioavailability; for chelation of metals in the cytosol by peptides and proteins; for sequestration of metals in polyphosphate bodies; for the compartmentation of metals away from metabolic process by transporting them into the vacuole; for increasing the efflux or exclusion of metals; for producing stress proteins such as heat shock proteins that repair the stress-damaged proteins; in addition, some heavy metals cause oxidative stress in algae, with the result that metal toxicity can be altered by synthesis of appropriate enzymes or metabolites counteracting metal-induced oxidative stress. In recent years, some attempts to engineer the production of metallothioneins (MTs) and phytochelatins (PCs) in algae to increase metal tolerance and/or accumulation have been reported. To date, however, it is mainly the model plant species that have been genetically engineered. Phytoremediation strategies have been proposed as an attractive alternative owing to their low cost and high efficiency. The concept of phytoremediation of heavy metal contaminated water has been increasingly supported by research. And, algae have been widely used as pollution indicators in water quality determination. Thus, studies on tolerance and detoxification mechanism of heavy metal in algae have numerous ecological and public health implications.

Zhou, W. and B. Qiu (2005). Effects of cadmium hyperaccumulation on physiological characteristics of *Sedum alfredii* Hance (Crassulaceae). Plant Science (Oxford) 169(4): 737-745.

Sedum alfredii is a newly found cadmium (Cd)-hyperaccumulator, but there have been no detailed studies on its physiological responses when Cd is hyperaccumulated. Leaf expansion and root growth were inhibited significantly at high Cd concentrations, and Cd was suggested to suppress cell expansion and induce senescence. Chlorophyll fluorescence analysis indicated that its photosynthesis appeared to be unaffected. Decreased F-v/F-m correlated well with decreased water content of leaves. Cd treatments were demonstrated to result in an increase of chlorophyll content. The chlorophyll a/b ratio showed a reduction with increasing Cd concentrations. The Cd content peaked and reached a maximum of 11,000 mg kg(-1) in leaves at 600 mu M Cd. It was almost saturated at 600 mu M Cd in stems and roots, and then was, respectively, up to a maximum of 5300 and 3100 mg kg(-1) at 800 mu M Cd. Fe concentrations in leaves, stems and roots increased significantly in the presence of Cd. Increasing Cd concentration might induce the expression of Fe transporter. This could have important implications both for human nutrition and for phytoremediation of metal contamination. Other elements (K, Ca, Zn and P) were distributed differently. Taking together, these results suggested that S. *alfredii* could be a good new model to investigate the mechanism of metal hyperaccumulation. (c) 2005 Elsevier Ireland Ltd.

Zhu, D., A.P. Schwab, and M.K. Banks (1997). Abstract: Impact of vegetation on heavy metal movement. Presentation 8. In 12th Annual Conference on Hazardous Waste Research - Abstracts Book, May 19-22, 1997, Kansas City, MO. Establishment of vegetation in mining areas is a primary method to minimize heavy metal contamination through wind erosion, runoff, and filtration. However, the influence of the plants on heavy metal downward movement to the ground water is not clear. This study was conducted to determine if plants will increase heavy metal leaching from mine tailings and heavy metal contaminated soil, and to evaluate the effect of two different grasses on heavy metal transport. A small column experiment was conducted in the greenhouse beginning summer 1995. Six-inch-diameter PVC pipe was cut into desired lengths and filled with heavy metal-contaminated soil, mine tailings, and uncontaminated topsoil to mimic field conditions. Two grasses, tall fescue (*Festuca arundinacea*) and big bluestem (Andropogon gerardii) were established in the columns. The multilayered soil columns were leached with 0.00lM CaCl2 solution with a proportioning pump under unsaturated conditions. The leachate was collected every 3 days. Cadmium(Cd) and zinc(Zn) in the leachate were analyzed using ICP (Inductively Coupled Plasma). Lead (Pb) was measured using graphite-tube AA. After one year, the plants were harvested, the columns were sacrificed, and heavy metal in the columns was investigated. Both tall fescue and big bluestem increased Zn and Cd concentrations in the leachate, especially at about 2 months after the plants were established, possibly due to the active roots. However, plants did not increase Pb concentration compared to unvegetated control columns. Even though plants reduced the total amount of water leached, total Zn and Cd leached increased in the presence of the plants, while total Pb leached was positively correlated to total water solution collected from each column (r=0.8). This study suggested that tall fescue and big bluestem may be used for Pb treatment, but it might be improper for Zn and Cd contamination treatment. Mine tailing remediation using the technology simulated in this study (covered with topsoil, with or without vegetation) may reduce Pb contamination, but it may enhance Cd and Zn contamination.

Zhu, L. and M. B. Kirkham (2003). Initial crop growth in soil collected from a closed animal waste lagoon. Bioresource Technology. L. Zhu. 87: 7. In the 21st century, remediation of the soil beneath animal waste lagoons will become an important issue, as they are closed due to environmental regulations or to abandonment. The possibility of growing crops in the soil, which has high concentrations of ammonium-N, has not been studied. The objective of this experiment was to determine if crop species would germinate and grow in lagoon soil. Soil was gathered from a lagoon that had received wastes from swine (Sus scrofa) and beef (Bos taurus) since 1968. Eight crops were grown in greenhouse pots containing the lagoon soil: winter barley (*Hordeum vulgare* L. 'Weskan'); field corn (*Zea mays* L., Cargill's hybrid 7997); 'Plainsman' winter rapeseed [*Brassica napus* L. spp. *oleifera* (Metzg.) Sinsk. f. biennis]; soybean [Glycine max (L.) Merr. 'KS 4694']; forage *Sorghum* [*Sorghum bicolor* (L.) Moench 'Norkan']; sunflower (*Helianthus annuus* L. 'Hysun 354'); and winter wheat (*Triticum aestivum* L.) -- two cultivars: '2137' and 'Turkey.' Plants

were grown for 35 days in lagoon soil or an agricultural soil (Haynie very fine sandy loam; coarse-silty, mixed, superactive, calcareous, mesic Mollic Udifluvent) obtained from a field near the closed lagoon. Ammonium-N (average value of 692 mg/kg) was about 70-85 times greater than the average value of 8-10 mg/kg NH4-N in Kansan soils. The lagoon soil was nonsodic and had a salinity ranking of medium with an electrical conductivity averaging 2.29 dS/m. The high ammonium-N concentration in the lagoon soil was not inhibitory to emergence and growth. The eight crops grew taller in the lagoon soil than in the agricultural soil. Except for '2137' wheat, dry weight was higher in the lagoon soil than in the agricultural soil. The results showed that the lagoon soil is not detrimental to early growth of eight crops.

Zhu, M. and W. E. Fahl (2000). Development of a Green Fluorescent Microplate Assay Forthe Screening of Chemopreventive Agents. Analytical Biochemistry 287: 210-217.

Zhu, Y. and G. Shaw (2000). Soil Contamination with Radionuclides and Potential Remediation. Chemosphere 41(1-2): 121-128.

Zhu, Y. G., S. B. Chen, et al. (2004). Effects of soil amendments on lead uptake by two vegetable crops from a lead-contaminated soil from Anhui, China. Environment International 30(3): 351-356. Previous studies have documented that phosphate compounds of lead (Pb) [e.g., pyromorphite Pb-5(PO4)(3)-(X), where X = OH, F or Cl] are comparatively insoluble, and their formation in Pb-contammated soil may be a means of reducing the bioavailability and chemical lability of Pb in soil. In this study, the effect of phosphate compound amendments on the bioavailability of Pb in a polluted alkaline soil was examined. A Pb-contaminated soil was treated with hydroxyapatite (HA), phosphate rock (PR), water-soluble P fertilizer (single superphosphate, SSP) and the combination of HA with SSP. The bioavailability of Pb was determined in plant uptake studies with vegetables (*Brassica* campetris L. var. *communis*, BC) and *Brassica oleracea* L. var. *acephala*, BO and sequential extraction. The results indicated that the Pb concentrations in both shoots and roots of two vegetable plants decreased with increasing quantities of added P compound, and the HA treatment had the best effect at the level of 5000 mg of P kg(-1) as compared with other treatments in which the Pb concentrations in shoots of 130 and BC decreased 51.9% and 65.5%, respectively, and the Pb concentrations in roots of 130 and BC decreased 67.3% and 57.2%, respectively, as compared with the control treatment. The SSP treatment had little effect on the Pb concentrations in plant tissues. Sequential extraction results indicated that the addition of soil amendments transform soil Pb from nonresidual fractions to residual fraction substantially. The effect of treatments followed this order at the equivalent P addition: HA>PR>HA+SSP>SSP. The results suggested that HA amendments can lower the bioavailability and increase the geochemical stability of soil Pb, so it has the potential for in situ remediation in Pb-contaminated soils. (C) 2003 Elsevier Ltd.

Zhu, Y. L., A. M. Zayed, J. H. Qian, M. P. de Souza and N. Terry (1999). Phytoaccumulation of Trace Elements by Wetland Plants: Ii. Water Hyacinth. Journal of Environmental Quality 28(1): 339-344.

Zhu, Y. L., E. Pilon-Smits, L. Jouanin and N. Terry (1999). Overexpression of Glutathione Synthetase in Indian Mustard Enhances Cadmium Accumulation and Tolerance. Plant Physiology (Rockville) 119(1): 73-79.

Zhu, Y. S., E. (2000). Plant Uptake of Radiocaesium: A Review of Mechanisms, Regulation and Application. Journal of Experimental Botany 51(351): 1635-1645.

Zhu, Y., E. Pilon-Smits, A. Tarun, S. Weber, L. Jouanin and N. Terry (1999). Cadmium Tolerance and Accumulation in Indian Mustard Is Enhanced by Overexpressing Gamma-Glutamylcysteine Synthetase. Plant Physiol. 121(4): 1169-1177.

Zhuang, P., Z. H. Ye, et al. (2005). Chemically assisted phytoextraction of heavy metal contaminated soils using three plant species. Plant and Soil 276(1-2): 153-162. Phytoextraction is a potential, innovative and cost-effective technology for non-destructive remediation of heavy metal-contaminated soils. A field trial was conducted to evaluate the phytoextraction efficiencies of three plants and the effects of EDTA or ammonium addition [(NH4)(2)SO4 and NH4NO3] for assisting heavy metal (Pb, Zn, and Cd) removal from contaminated soil. The tested plants include Viola baoshanensis, Vertiveria *zizanioides*, and *Rumex* K-1 (*Rumex patientia* X *R. timschmicus*). The application of EDTA soil was the most efficient to enhance the phytoavailability of Pb and Zn, but did not have significant effect on Cd. Lead phytoextraction rates of V. baoshanensis, V. *zizanioides* and *Rumex* K-1 were improved by 19-, 2-, and 13-folds compared with the control treatment, respectively. The application of ammonium did not have obvious effects on phytoextraction of the three metals, except that the accumulations of Zn and Cd in shoot of V. baoshanensis. Among the three tested plants, V. baoshanensis always accumulated the highest concentrations of Pb, Zn, and Cd. The concentrations of Pb, Zn, and Cd in the shoots of V. baoshanensis treated with EDTA were 624, 795, and 25 mg kg(-1)supercript stop, respectively, and the phytoextraction efficiencies of this species for Pb, Zn, and Cd were also the highest among the three species. Results presented here indicated that V. baoshanensis had great potential in phytoremediation of soils contaminated by multiple heavy metals, although the dry weight yield was the lowest among the three plants.

Zieve, R., and P.J. Peterson (1984). Volatilization of selenium from plants and soils. Sci. Total Environ. 32:197-202.

Zimmels, Y., F. Kirzhner, et al. (2004). Use of naturally growing aquatic plants for wastewater purification. Water Environment Research. Y. Zimmels. 76: 220. This paper examines potential uses of naturally growing aquatic plants (e.g. *Azolla* californiana [?A. *caroliniana*], *Echhornia craissipes*, Elodea canadensis, Hydrocotyle umbellata, *Lemna*, *Pistia stratioties* and *Salvinia natans*) for waste water purification. These plants enhance the removal of pollutants by consuming part of them in the form of plant nutrients. This applies to urban and agricultural waste water, in particular, where treatment units of different sizes can be applied at the pollution source. The effectiveness of waste water purification by different plants was tested on laboratory and pilot scales. The growth rate of the plants was related to the waste water content in the water. Batch and semicontinuous experiments verified that the plants are capable of decreasing all tested indicators for water quality to levels that permit the use of the purified water for irrigation. This applies to biochemical oxygen demand (BOD), chemical oxygen demand, total suspended solids, pH, and turbidity. In specific cases, the turbidity reached the level of drinking water. Comparison of BOD concentrations with typical levels in water treatment facilities across the country indicates the effectiveness of water purification with plants. A major effect of treatment with plants was elimination of the disturbing smell from the waste water. It is shown that mixtures of waste water and polluted water from the Kishon River in Israel are amenable in varying degrees to treatment by the plants. The higher the waste water content in the mixture, the more effective the treatment by the plants. In this context, a scheme for rehabilitation and restoration of the Kishon River is presented and technical and economical aspects of the purification technology are considered.

Zimmermann, P., G. Zardi, et al. (2003). Engineering the root-soil interface via targeted expression of a synthetic phytase gene in trichoblasts. Plant Biotechnology Journal 1(5): 353-360. For biochemical modification of the root-soil interface, the engineered secretion of stable enzymes from trichoblasts (= root hair bearing rhizodermal cells) is proposed. As a reporter activity, we chose to express a synthetic gene encoding a secretory phytase (PHY) directed by a trichoblast-specific promoter in root hair cells of the crop plant potato. Transgenic plants produced and secreted phytase in sufficient amounts to release phosphate from phytate in liquid medium. When grown in an unsterile substrate containing phytate, transgenic plants accumulated 40% more P in leaves than wild-type plants. The improved P nutrition driven by trichoblast-targeted expression and subsequent secretion of PHY illustrates the potential of using trichoblast-targeted

expression of suitable enzymes for future applications in plant nutrition, phytoremediation and molecular farming.

Zu, Y. Q., L. Yuang, et al. (2004). Accumulation of Pb, Cd, Cu and Zn in plants and hyperaccumulator choice in Lanping lead-zinc mine area, China. Environment International 30(4): 567-576. A field survey of higher terrestrial plants growing on Lanping lead-zinc mine, China were conducted to identify species accumulating exceptionally large concentrations of Pb, Cd, Cu and Zn of 20 samples of 17 plant species. Concentrations of Pb and Zn in soil and in plant were higher than that of Cu and Cd. Significant difference was observed among the average concentrations of four heavy metals in plants (except Cd and Cu) and in soil (except Pb and Zn) ($P < 0.05$). For the enrichment coefficient of the four heavy metals in plant, the order of average was Ph < Cu < Cd < Zn. Between four heavy metals, only significant difference was observed between the enrichment coefficient average of Cd and Cu ($P < 0.05$). The enrichment coefficients were higher than 1 in Llex plyneura and Rhododendron annae in Paomaping for Pb, *Salix* cathayana, L. plyneura and R. annae in Paomaping for Cd, and R. annae in Paomaping for Zn, respectively. Concentrations and enrichment coefficient of Ph, Cd and Zn of Rhododendron were higher than that of Gramimeae. Enrichment coefficient of Ph, Cd and Zn were bush > tree > herbaceous, and herbaceous grew in soil with the highest concentrations of four heavy metals. In different areas, the concentrations of Pb, Cd, Cu and Zn in plants and soils and enrichment coefficient were different. Plants in Paomaping had more accumulating ability to Pb, Cd and Zn, and plants in Jinfeng River had more accumulating ability to Cu. Six plant species, i.e. S. cathayana, Lithocarpus dealbatus, L. plyneura, Fargesia dura, Arundinella yunnanensis and R. annae in Paomaping. had high accumulation capacity. R. annae in Paomaping had hyperaccumulating capacity to Pb, Cd and Zn, L. plyneura to Ph and Cd, and S. cathayana to Cd, respectively. (C) 2003 Elsevier Ltd.

Zu, Y. Q., Y. Li, et al. (2005). Hyperaccumulation of Pb, Zn and Cd in herbaceous grown on lead-zinc mining area in Yunnan, China. Environment International 31(5): 755-762. A field survey of herbaceous growing on lead-zinc mining area in Yunnan, China were conducted to identify species accumulating exceptionally large concentrations of Pb, Zn and Cd in shoots. In total, 220 plant samples of 129 species of 50 families and 220 soil samples in which the plants were growing were collected. According to accumulation concentration in plant shoots and the concentration time levels compared to plants from non-polluted environments, 21 plant samples of 16 species were chosen as best-performing specimens, 11 plant samples of 10 species for Pb, 5 plant samples of 4 species for Zn and 5 plant samples of 5 species for Cd. Sonchus asper (L) Hill in Qilinkeng had hyperaccumulation capacity to Pb and Zn. Corydalis pterygopetala Franch in Paomaping had hyperaccumulation capacity to Zn and Cd. All 5 Cd hyperaccumulators came from Lanping lead-zinc mining area. Out of 11 Pb hyperaccumulators, 7 came from Minbingying of Huice lead-zinc mining area. The average of the concentration time levels compared to plants from non-polluted environments were higher than 10 times in all plant samples, the concentration time levels changed from 203 times to 620 times for Pb, from 50 times to 70 times for Zn and from 145 times to 330 times for Cd. Out of 21 plant samples, translocation factor changed from 0.35 to 1.90, only translocation factor of 7 plant samples were higher than 1. Enrichment coefficients of all samples were lower than 1. These plant species were primarily heavy metal hyperaccumulator, and will be used in phytoremediation of the metallic pollutants in soils after further research in accumulation mechanism. (c) 2005 Elsevier Ltd.

Zupancic, J.W. (1997). Industrial use of phytoremediation for management of wastewater. IBC's Second Annual Conference on Phytoremediation, June 18 - 19, 1997, Seattle, WA. International Business Communications, Southborough, MA.

Zurayk, R., B. Sukkariyah, et al. (2002). Ni phytoaccumulation in *Mentha aquatica* L. and *Mentha sylvestris* L. Water Air and Soil Pollution 139(1-4): 355-364. Ni phytoaccumulation in *Mentha aquatica* L. and *Mentha sylvestris* L., two hydrophytes that had shown high Ni accumulation potential in previous screenings, was evaluated for possible inclusion in aquatic phytoremediation

systems. The plants were grown for 14 days in full-strength (FS) and half-strength (HS) Hoagland's solutions spiked with 1, 2, 4, and 8 mg L-1 Ni. Roots and shoots were harvested and analysed for Ni. Ni accumulation and bioconcentration factor (BCF) generally increased with increasing external Ni levels, except for shoot Ni in HS solution at 8 mg L-1, which was lower than at 4 mg L-1. We suggest that a mechanism may exist to control Ni entry to the shoot at high external Ni levels in order to reduce injury. Ni phytoaccumulation and BCF were consistently larger in the HS solution, probably resulting from interaction between Ni and other nutrients, and indicating that manipulation of the nutrient concentration is a possible avenue for improving the efficiency of aquatic phytoremediation. Due to their large growth rates and biomass, both species accumulated Ni in the roots to levels equal or superior to those of known phytoremediator plants (8327 for *M*. *aquatica* and 6762 mg kg-1 for *M. sylvestris*), indicating their adequacy for use in phytoremediation systems.

Zurek, D.M., and B.A. McClure (1995). Poster Abstract: Self vs. Nonself recognition by stylar s-Rnases in the self-incompatibility reaction in Nicotiana. P. 114. 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.