Faisal, M. and S. Hasnain (2005). Beneficial role of hydrophytes in removing Cr(VI) from wastewater in association with chromate-reducing bacterial strains Ochrobactrum intermedium and Brevibacterium. International Journal of Phytoremediation 7(4): 271-277. This study deals with the use of three chromium-resistant bacterial strains (Ochrobactrum intermedium CrT-1, Brevibacterium CrT-13, and CrM-1) in conjunction with Eichornia *craissipes* for the removal of toxic chromium from wastewater. Bacterial strains resulted in reduced uptake of chromate into inoculated plants! as compared to noninoculated control plants. In the presence of different heavy metals, chromium uptake into the plants was 28.7 and 7.15% less at an initial K2CrO4 concentration of 100 and 500 ug ml(-1) in comparison to a metal free chromium solution. K2CrO4 uptake into the plant occurred at different pHs tested, but maximum uptake was observed at pH 5. Nevertheless, the bacterial strains caused some decrease in chromate uptake into the plants, but the combined effect of plants and bacterial strains conduce more removal of Cr(VI) from the solution.

Fan, T., A. Lane, J. Pedler, D. Crowley, and R. Higashi. (1997).Comprehensive analysis of organic ligands in whole root exudates using nuclear magnetic resonance and gas chromatography/mass spectroscopy. Anal. Biochem. 251(1):57.

Fan, T.W.-M., and R.M. Higashi. (1995). Environmental considerations of phytoremediation. pp. 57-58. 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.

Fang, W. X. and P. W. Wu (2004). Elevated selenium and other mineral element concentrations in soil and plant tissue in bone coal sites in Haoping area, Ziyang County, China. Plant and Soil 261(1-2): 135-146. The Shuang' an site is the most serious selenosis site in Ziyang County, Shaanxi Province, which was the second selenosis site in China. In order to investigate the relationships between Se and other mineral elements and selenosis, bone coals, V-Mo ores, rocks, soils and plants were sampled from each site. The higher mean concentrations of Se, Mo, V and F in bone coals and ores may be the main environmental geochemical sources for soils and plants in this local ecosystem. Inappropriate revegetation in the Shuang'an mining site have posed the greatest risk of pollution, resulting in elevated mean concentrations of Se (16.9 mug/g), Mo ( 99 mug/g), V (1134 mug/g), F (1041 mug/g) and As (111 mug/g) in the soil directly derived from bone coal and V-Mo ore dumps. Most plants, which grow in the revegetated soil, contain elevated Se, Mo, V and F concentrations. The revegetated soil derived from bone coal and V-Mo ore dumps with excess Se, Mo, V and F concentrations in this ecosystem might have been essentially responsible for selenosis incidence of Shuang'an site in Ziyang County, Shaanxi Province. It is proposed that this selenosis area coincides with Mo, F and V toxicity based on their higher concentrations in rocks, soils and plants.

Farago, M.E., A.J. Clark, and M.J. Pit. (1975). The chemistry of plants which accumulate metals. Chem. Rev. 16:1-8.

Farago, M.E., A.J. Clark, and M.J. Pitt. (1977). Plants which accumulate metals. I. The metal content of three Australian plants growing over mineralized sites. Inorg. Chem. Acta. 24:53-56.

Fargasova, A. Effect of Pb, Cd, Hg, As, and Cr on germination and root growth of *Sinapis alba* seeds. (1994), Bull. Environ. Contam. Toxicol. 52(3):452-457.

Fargo, Margaret E. Metal-Tolerant Plants. (1981), ChemTech. November 1981, 684-687.

Farrell, M. Purifying wastewater in greenhouses. (1996), BioCycle. 37:30-33. Small mouth bass, snails, and daffodils are just three components of an unconventional method for purifying sewage and septage that is gaining acceptance in both Canada and America. The technology - trademarked as Solar Aquatics - was developed by inventor John Todd at his nonprofit research facility, Ocean Arks International in Falmouth, Massachusetts. It utilizes a combination of ecological and microbiological processes to treat

wastewater in greenhouses. Rows of translucent tanks along with engineered streams and marshes host a variety of aquatic and nonaquatic plants, animals and organisms. Water is gravity fed by pipes through the various components in a specific sequence. In the process, contaminants and nutrients are metabolized or bound up as the wastewater flows through the tanks, ponds and marshes.

Fayiga, A. O. and L. Q. Ma (2005). Arsenic uptake by two hyperaccumulator ferns from four arsenic contaminated soils. Water Air and Soil Pollution 168(1-4): 71-89. A greenhouse study was conducted to evaluate and compare arsenic accumulation from four arsenic contaminated soils by two arsenic hyperaccumulators, *Pteris vittata* and *Pteris cretica.* After growing in soils for six weeks, the plants were harvested and separated into above- and below-ground biomass. Total As, P, Ca, K, glutathione and biomass were measured for the plants, and total As, Mehlich-3 P and As, exchangeable K and Ca, and arsenic fractionation were performed for the soils. *Pteris vittata* had significantly higher total biomass (14 g/plant) and As accumulation than P. *cretica.* Arsenic accumulation in both ferns followed the arsenic concentrations in the soil. The P/As molar ratio in the fronds, growing in arsenic contaminated soils, ranged from 80 to 939 in *P*. *vittata* and 130 to 421 in *P. cretica.* Plant arsenic concentrations were significantly positively correlated with Mehlich-3 arsenic in the soils. Soil pH was also significantly correlated with Mehlich-3 arsenic before and after plant uptake. Plant As uptake was significantly correlated with exchangeable potassium in the soil before plant uptake. Glutathione availability was not implicated as a major detoxification mechanism in these ferns. Though both plants were effective in taking up arsenic from various arsenic contaminated soils, P. *vittata* was overall a better candidate for phytoremediation of arsenic contaminated soils.

Fayiga, A. O. and L. Q. Ma (2006). Using phosphate rock to immobilize metals in soil and increase arsenic uptake by hyperaccumulator *Pteris vittata*. Science of the Total Environment 359(1-3): 17-25. This greenhouse experiment evaluated the effects of phosphate rock (PR) on arsenic and metal uptake by the arsenic hyperaccumulator *Pteris vittata* in a soil spiked with arsenic and heavy metals Cd, Pb and Zn. Five soil treatments were used, 1) control with no arsenic, 2) spiked with 50 mg kg(-1) As (As) as Na2H AsO4, 3) spiked with 50 mg kg(-1) As and P as PR (Asp), 4) spiked with 50 mg kg(-1) As, Ph, Cd, and Zn (AsM), and 5) spiked with 50 mg kg(-1) As, Pb, Cd, Zn and P (AsMP). The plants were harvested after growing in the soil for five weeks. Compared to the As treatment, the presence of heavy metals (AsM) reduced arsenic concentrations in the fronds from 1631 to 608 mg kg(-1). However, this effect was mitigated by PR (AsMP), with arsenic concentrations in the fronds increased from 608 to 1046 mg kg(-1). Phosphate rock also significantly reduced Pb (13.5 to 4.10 mg kg(-1)) and Cd (13.0 to 3.45 mg kg(-1)) concentrations in the fronds. Most of the arsenic in R *vittata* was accumulated in the fronds (89-93%). Compared to the control, P was more concentrated in the roots along with less P being translocated to the fronds in the treatments with arsenic. While in those same treatments higher Ca concentrations in both the fronds and roots were observed. This research shows that PR was effective in increasing arsenic uptake and decreasing metal uptake by P *vittata* and thus can be used as a cost-effective amendment for phytoremediation of arsenic and metal polluted soils. (C) 2005 Elsevier B.V.

Fayiga, A. O., L. Q. Ma, et al. (2004). Effects of heavy metals on growth and arsenic accumulation in the arsenic hyperaccumulator *Pteris vittata* L. Environmental Pollution 132(2): 289-296. The effects of Cd, Ni, Pb, and Zn on arsenic accumulation by the arsenic hyperaccumulator *Pteris vittata* were investigated in a greenhouse study. *P*. *vittata* was grown for 8 weeks in an arsenic-contaminated soil (131 mg As kg(-1)), which was spiked with 50 or 200 mg kg(-1) Cd, Ni, Pb, or Zn (as nitrates). *P*. *vittata* was effective in taking up arsenic (up to 4100 mg kg(-1)) and transporting it to the fronds, but little of the metals. Arsenic bioconcentration factors ranged from 14 to 36 and transfer factors ranged from 16 to 56 in the presence of the metals, both of which were reduced with increasing metal concentration. Fern biomass increased as much as 12 times compared to the original dry weight after 8 weeks of growth (up to 19 g per plant). Greater concentrations of Cd, Ni, and Pb resulted in greater catalase activity in the plant. Most of the arsenic in the plant was present as arsenite, the reduced form, indicating little impact of the metals on plant arsenic reduction. This research demonstrates the capability of *P. vittata* in hyperaccumulating arsenic from soils in the presence of heavy metals.

Fayiga, A. O., L. Q. Ma, et al. (2004). Effects of heavy metals on growth and arsenic accumulation in the arsenic hyperaccumulator *Pteris vittata* L. Environmental Pollution. A. O. Fayiga. 132: 289. The effects of Cd, Ni, Pb, and Zn on arsenic accumulation by the arsenic hyperaccumulator *Pteris vittata* were investigated in a greenhouse study. P. *vittata* was grown for 8 weeks in an arsenic-contaminated soil (131 mg As kg-1), which was spiked with 50 or 200 mg kg-1 Cd, Ni, Pb, or Zn (as nitrates). P. *vittata* was effective in taking up arsenic (up to 4100 mg kg-1) and transporting it to the fronds, but little of the metals. Arsenic bioconcentration factors ranged from 14 to 36 and transfer factors ranged from 16 to 56 in the presence of the metals, both of which were reduced with increasing metal concentration. Fern biomass increased as much as 12 times compared to the original dry weight after 8 weeks of growth (up to 19 g per plant). Greater concentrations of Cd, Ni, and Pb resulted in greater catalase activity in the plant. Most of the arsenic in the plant was present as arsenite, the reduced form, indicating little impact of the metals on plant arsenic reduction. This research demonstrates the capability of P. *vittata* in hyperaccumulating arsenic from soils in the presence of heavy metals.

Fayiga, A. O., L. Q. Ma, et al. (2005). Effects of arsenic species and concentrations on arsenic accumulation by different fern species in a hydroponic system. International Journal of Phytoremediation 7(3): 231-240. Two hydroponic experiments were conducted to evaluate factors affecting plant arsenic (As) hyperaccumulation. In the first experiment two As hyperaccumulators (*Pteris vittata* and P. *cretica* mayii) were exposed to I and 10 mg L-1 arsenite (AsIII) and monomethyl arsenic acid (MMA) for 4 wk Total As concentrations in plants (fronds and roots) and solution were determined. In the second experiment, P. *Vittata* and Nephrolepis exaltata (a non-As hyperaccumulator) were exposed to 5 mg L-1 arsenate (AsV) and 20 mgL(-1) AsIII for 1 and 15 d. Total As and AsIII concentrations in plants were determined. Compared to P. *cretica* mayii P. *vittata* was more efficient in arsenic accumulation (1075-1666 vs. 249-627 mg kg(-1) As in the fronds) partially because it is more efficient in As translocation. As translocation factor (As concentration ratio in fronds to roots) was 3.0-5.6 for P. *vittata* compared to 0.1 to 4.8 for P. *cretica.* Compared to N. exaltata, P. *vittata* was significantly more efficient in arsenic accumulation (38-542 vs. 4.8-71 mgkg(-1) As in the fronds) as well as As translocation (1.3-5.6 vs. 0.2-0.5). In addition, P. *vittata* was much more efficient in As reduction from AsV to AsIII (83-84 vs. 13-24% AsIII in the fronds). Little As reduction occurred after 1-d exposure to AsV in both species indicates that As reduction was not instantaneous even in an As hyperaccumulator. Our data were consistent with the hypothesis that both As translocation and As reduction are important for plant As hyperaccumulation.

Faylga, A. O., L. Q. Ma, et al. (2004). Effects of heavy metals on growth and arsenic accumulation in the arsenic hyperaccumulator *Pteris vittata* L. Environmental Pollution 132(2): 289-296. The effects of Cd, Ni, Pb, and Zn on arsenic accumulation by the arsenic hyperaccumulator *Pteris vittata* were investigated in a greenhouse study. *P. vittata* was grown for 8 weeks in an arsenic-contaminated soil (131 mg As kg-1), which was spiked with 50 or 200 mg kg-1 Cd, Ni, Pb, or Zn (as nitrates). P. *vittata* was effective in taking up arsenic (up to 4100 mg kg-1) and transporting it to the fronds, but little of the metals. Arsenic bioconcentration factors ranged from 14 to 36 and transfer factors ranged from 16 to 56 in the presence of the metals, both of which were reduced with increasing metal concentration. Fern biomass increased as much as 12 times compared to the original dry weight after 8 weeks of growth (up to 19 g per plant). Greater concentrations of Cd, Ni, and Pb resulted in greater catalase activity in the plant. Most of the arsenic in the plant was present as arsenite, the reduced form, indicating little impact of the metals on plant arsenic reduction. This research demonstrates the capability of P. *vittata* in hyperaccumulating arsenic from soils in the presence of heavy metals.

Federle, T.W., and B.S. Schwab. (1989). Mineralization of surfactants by microbiota of aquatic plants. (1989), Appl. Environ. Microbiol. 55:2092-2094.

Federov, Y.A., A.S. Bakurov, M.N. Fedorova, and M.F. Rasulev. (1987). Behavior of plutonium in the soil and its entry into plants. Sov. Soil. Sci. 19(1):46-51.

Feist, L. and D. Parker. (2001). Ecotypic Variation in Selenium Accumulation among Populations of *Stanleya Pinnata*. New Phytologist 149(1): 61-69.

Felix, H. (1997). Field trails for in-situ decontamination of heavy metal polluted soil using crops of metal-accumulating plants. Zeitschrift Pflanzenernahrung Bodenkunde. 160(5):525.

Fellows, R. J., Z. Wang, et al. (2003). Europium uptake and partitioning in oat (*Avena sativa*) roots as studied by laser-induced fluorescence spectroscopy and confocal microscopy profiling technique. Environmental Science & Technology 37(22): 5247-5253. The uptake of Eu3+ by elongating oat roots was studied by fluorescence spectroscopy, fluorescence lifetime measurement, and a laser excitation time-resolved confocal fluorescence profiling technique. The results of this work indicated that initial uptake of Eu3+ was highest within the undifferentiated cells of the root tip just behind the root cap, a region of *maximal* cell growth and differentiation and with incomplete formation of the Casparian strip around the central vascular cylinder. Distribution of assimilated Eu3+within the root's differentiation and elongation zone was nonuniform. Higher concentrations of Eu3+ were observed within the vascular cylinder, specifically in the phloem and developing xylem parenchyma. Elevated levels of the metal were also observed in the root hairs of the mature root zone. Fluorescence spectroscopic characteristics of the assimilated Eu3+ suggested that the Eu3+ exists as inner-sphere mononuclear complexes inside the root. This work also demonstrated the effectiveness of a time-resolved Eu3+ fluorescence spectroscopy and confocal fluorescence profiling techniques for the in vivo, real-time study of metal (Eu3+) accumulation by a functioning intact plant root. This approach can prove valuable for basic and applied studies in plant nutrition and environmental uptake of actinide radionuclides.

Fellows, R.J., S.D. Harvey, C.C. Ainsworth, and D.A. Cataldo. (1996). Biotic and abiotic transformation of munitions materials (TNT, RDX) by plants and soils. Potentials for attenuation and remediation of contaminants. International Phytoremediation Conference, May 8-10, 1996, Arlington, VA. International Business Communications, Southborough, MA.

Felsot, A.S., and E.K. Dzantor. (1997). Potential of biostimulation to enhance dissipation of aged herbicide residues in land-farmed waste. 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.

Fernandez, R., T. Whitwell, M. Riley and C. Bernard. (1999). Evaluating Semiaquatic Herbaceous Perennials for Use in Herbicide Phytoremediation. Journal of the American Society for Horticultural Science 124(5): 539-544.

Fernando, A. L., V. Godovikova, et al. (2004). *Micanthus* X *giganteus*: Contribution to a sustainable agriculture of a future/present - Oriented biomaterial. Advanced Materials Forum Ii. 455-456: 437-441. The main purpose of this work was to study the phytoremediation capacity of *Micanthus* x *giganteus* to soils contaminated with heavy metals and also to evaluate the environmental risks due to its utilisation as a biomaterial. Indeed, the concentration of metals in the aerial part of the plant might represent a question of its future use. Four levels of contamination were studied: P-0 = 0 t; P-50 = 50 t; P-100 = 100 t; P-200 = 200 t domestic sludge.ha(-1). The results obtained permit to conclude that in terms of the productivity there are significant differences among the plants obtained with different levels of contamination. P50 and P100 presented significantly higher values. In relation to the ash, nitrogen and phosphorous contents, the results showed an increase in mineral matter and an accumulation in nitrogen and phosphorous, in the plants, with the increase of the level of contaminants. But this increase was not significant. No significant differences were observed in the plants among the different levels of sludge, for most of the metals studied. This fact leads to the conclusion that the utilisation of the biomass, obtained in those contaminated fields, is possible, as a biomaterial. Thus, contributing not only to increase its economical value but also to a sustainable agriculture.

Ferrieri, A. P., M. R. Thorpe, et al. (2006). Stimulating natural defenses in poplar clones (OP-367) increases plant metabolism of carbon tetrachloride. International Journal of Phytoremediation 8(3): 233-243. Groundwater contamination by carbon tetrachloride (CCl4) presents a health risk as a potential carcinogen and pollutant that is capable of depleting the ozone layer. Although use of poplar trees in a phytoremediation capacity has proven to be cost effective for cleaning contaminated sites, minimizing leaf

emission of volatile contaminants remains a pressing issue. We hypothesized that recently fixed carbon plays a key role in CCl4 metabolism in planta yielding nonvolatile trichloroacetic acid (TCA) and that the extent of this metabolism can be altered by heightening plant defenses. Labeling intact leaves with (CO2)-C-11 (t(1/2) 20.4 m) can test this hypothesis, because the extremely short half-life of the tracer reflects only those processes involving recently fixed carbon. Using radio-HPLC analysis, we observed [C-11]TCA from leaf extract from poplar clones (OP-367) whose roots were exposed to a saturated solution of CCl4 (520 ppm). Autoradiography of [C-11]photosynthate showed increased leaf export and partitioning to the apex within 24 h of CCl4 exposure, suggesting that changes in plant metabolism and partitioning of recently ftred carbon occur rapidly. Additionally, leaf CCl4 emissions were highest in the morning, when carbon pools are low, suggesting a link between contaminant metabolism and leaf carbon utilization. Further, treatment with methyl jasmonate, a plant hormone implicated in defense signal transduction, reduced leaf CCl4 emissions two-fold due to the increased formation of TCA.

Ferro, A. (1997). Deep rooted poplars for the phytoremediation of groundwater impacted with petroleum hydrocarbons - Theory and applications. IBC's Second Annual Conference on Phytoremediation, June 18-19, 1997, Seattle, WA. International Business Communications, Southborough, MA.

Ferro, A. M., J. Kennedy, R. Kjelgren, J. Rieder and S. Perrin. (1999). Toxicity Assessment of Volatile Organic Compounds in Poplar Trees. Internat, J. Phytoremediation 1(1): 9-17.

Ferro, A. M., S. A. Rock, J. Kennedy, J. J. Herrick and D. L. Turner. (1999). Phytoremediation of Soils Contaminated with Wood Preservatives: Greenhouse and Field Evaluations. International Journal of Phytoremediation 1(3).

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Ferro, A., J. Chard, R. Kjelgren, B. Chard, D. Turner and T. Montague. (2001).Groundwater Capture Using Hybrid Poplar Trees: Evaluation of a System in Ogden, Utah. International Journal of Phytoremediation 3(1): 87-104.

Ferro, A., J. Kennedy, S. Nelson, G. Jauregui, B. McFarland, W. Doucette, and B. Bugbee. (1006). Uptake and biodegradation of volatile petroleum hydrocarbons in planted systems. International Phytoremediation Conference, May 8-10, 1996, Arlington, VA. International Business Communications, Southborough, MA.

Ferro, A., J. Kennedy, W. Doucette, S. Nelson, G. Jauregui, B. McFarland, and B. Bugbee. (1997). Fate of benzene in soils planted with alfalfa: Uptake, volatilization, and degradation. 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.

Ferro, A.M. (1993). Biodegradation of phenanthrene and pentachlorophenol mediated by vegetation. M.S. Thesis, Utah State University, Logan, UT.

Ferro, A.M. (1996). Phytoremediation of soils contaminated with pentachlorophenol and creosote. Abstracts of Papers of the American Chemical Society. 212:103-AGRO.

Ferro, A.M., J. Kennedy, and D. Knight. (1997). Greenhouse-scale evaluation of phytoremediation for soils contaminated with wood preservatives. Fourth International In Situ and On-Site Bioremediation Symposium, April 28 - May 1, 1997, New Orleans, LA. 3:309-314. Phytoremediation is the use of plants for the in situ cleanup of contaminated soils, sediments, and ground water. Evidence is accumulating that many types of organic chemical wastes biodegrade more rapidly in planted soils than in unplanted soils. A greenhouse-scale experiment evaluated phytoremediation for soils contaminated with pentachlorophenol (PCP) and polyaromatic hydrocarbons (PAHs). The following three treatment-types were included in the

study: 1) nutrient-amended soil planted with perennial ryegrass (*Lolium perenne*); 2) unplanted soil amended with nutrients; and 3) unplanted, unamended soil. Using conventional techniques for soil extraction and analysis, concentrations of PCP and 16 PAHs were determined at two-month intervals for eight months. Detailed results are presented for two analytes: PCP and pyrene. At the two-month sampling time, the concentrations of both analytes were significantly lower in the planted soil compared to the unplanted-amended soils. At 8 months, however, analyte concentrations were the same for the two treatments. Results obtained for other PAHs containing four aromatic rings were similar to those obtained for pyrene. However, for PAHs containing two, and those with five aromatic rings, the planted soil treatments showed only marginal increases in biodegradation compared to the unplanted-amended soils. These results suggested that rates of biodegradation for PCP and PAHs with four aromatic rings could be accelerated by the presence of plant roots. Final extents of removal are still being evaluated.

Ferro, A.M., J. Kennedy, and J. Herrick. (1998). Biodegradation of TNT in aerobic soil columns. 14th Annual Conference on Contaminated Soils. October 1998. University of Massachusetts at Amherst.

Ferro, A.M., L. Stacishin, W.J. Doucette, and B. Bugbee. (1994a). Crested wheatgrass accelerates the degradation of pyrene in soil. Emerging Technologies in Hazardous Waste Management VI, ACS Industrial & Engineering Chemistry Division Special Symposium, Volume I, September 19-21, 1994, Atlanta, GA.

Ferro, A.M., R.C. Sims, and B. Bugbee. (1994).Hycrest crested wheatgrass accelerates the degradation of pentachlorophenol in soil. J. Environ. Qual. 23:272-279. We investigated the effects of vegetation on the fate of pentachlorophenol (PCP) in soil using a novel high-flow sealed test system. Pentachlorophenol has been widely used as a wood preservative, and this highly toxic biocide contaminates soil and ground water at many sites. Although plants are known to accelerate the rates of degradation of certain soil contaminants, this approach has not been thoroughly investigated for PCP. The fate of [14C]PCP, added to soil at a concentration of 100 mg/kg, was compared in three unplanted and three planted systems. The plant used was Hycrest, a perennial, drought-tolerant cultivar of crested wheatgrass [*Agropyron desertorum* (Fischer ex Link) Schultes]. The flow-through test system allowed us to maintain a budget for 14C-label as well as monitor mineralization (breakdown to 14CO2) and volatilization of the test compound in a 155-d trial. In the unplanted systems, an average of 88% of the total radiolabel remained in the soil and leachate and only 6% was mineralized. In the planted systems, 33% of the radiolabel remained in the soil plus leachate, 22% was mineralized, and 36% was associated with plant tissue (21% with the root fraction and 15% with shoots). Mineralization rates were 23.1 mg PCP mineralized kg-1 soil in 20 wk in the planted system, and for the unplanted system 6.6 mg PCP kg-1 soil for the same time period. Similar amounts of volatile organic material were generated in the two systems (1.5%). Results indicated that establishing crested wheatgrass on PCP-contaminated surface soils may accelerate the removal of the contaminant.

Ferro, A.M., S.A. Rock., J. Kennedy, and J.J. Herrick. (1998). Phytoremediation of soils contaminated with wood preservatives: greenhouse and field evaluations. J. Soil Contamination, July.

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Fesenko, S.V., S.I. Spiridonov, and R.M. Alexakhin. (1997). Dynamics of 137Cs availability in a soil-plant system in areas of the composition of radioactive fallout. J. Environ. Radioactivity. 34:287.

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Fischerova, Z., P. Tlustos, et al. (2006). A comparison of phytoremediation capability of selected plant species for given trace elements. Environmental Pollution 144(1): 93-100. In our experiment, As, Cd, Pb, and Zn remediation possibilities on medium contaminated soil were investigated. Seven plant species with a different trace element accumulation capacity and remediation potential were compared. We found good accumulation capabilities and remediation effectiveness of *Salix dasyclados* similar to studied hyperaccumulators (*Arabidopsis halleri* and *Thlaspi caerulescens*). We have noticed better remediation capability in willow compared to poplar for most of the elements considered in this experiment. On the contrary, poplar species were able to remove a larger portion of Pb as opposed to other species. Nevertheless, the removed volume was very small. The elements found in plant biomass depend substantially on the availability of these elements in the soil. Different element concentrations were determined in natural soil solution and by inorganic salt solution extraction (0.01 mol L-1 CaCl2). Extracted content almost exceeded the element concentration in the soil solution. Element concentrations in soil solution were not significantly affected by sampling time.

Fitz, W. J. and W. W. Wenzel (2002). Arsenic transformations in the soil-rhizosphere-plant system: fundamentals and potential application to phytoremediation. Journal of Biotechnology 99(3): 259-278. This paper reviews major processes that potentially affect the fate of arsenic in the rhizosphere of plants. Rhizosphere interactions are deemed to play a key role in controlling bioavailability to crop plants and for a better understanding and improvement of phytoremediation technologies. Substantial progress has been made towards an understanding of As transformation processes in soils. However, virtually no information is available that directly addresses the fate of As in the rhizosphere. We are proposing a conceptual model of the fate of As in the soil-rhizosphere-plant system by integrating the state-of-the art knowledge available in the contributing disciplines. Using this model and recent studies on hyperaccumulation of As, we discuss research needs and the potential application of rhizosphere processes to the development of phytoremediation technologies for As-polluted soils.

Fitz, W. J. and W. W. Wenzel. (2002). Arsenic Transformations in the Soil-Rhizosphere-Plant System: Fundamentals and Potential Application to Phytoremediation. Journal OF Biotechnology 99(3): 259-278.

Fitz, W. J., W. W. Wenzel, et al. (2003). Rhizosphere characteristics of the arsenic hyperaccumulator *Pteris vittata* L. and monitoring of phytoremoval efficiency. Environmental Science & Technology 37(21): 5008-5014. Recently discovered As-hyperaccumulator ferns hold promise for phytoremediation of As-polluted soils. We investigated changes in the rhizosphere characteristics of *Pteris vittata* (Chinese Brake fern) relevant for its use in phytoextraction. Plants were grown in rhizoboxes filled with soil containing 2270 mg kg(-1) As. Dissolved organic carbon (DOC) concentrations in rhizosphere soil solution were increased by 86% and appeared to enhance total Fe solubility due to complexation reactions. Despite substantial removal of As by the fern, As was not significantly decreased in the rhizsophere soil solution after one cropping, apparently due to the large buffer capacity of the soil and possibly because of ion competition with DOC. However, the difference between 0.05 M (NH4)(2)SO4-extractable labile As in bulk and rhizosphere soil accounted for 8.9% of total As accumulated in the fern, indicating that As was mainly acquired from less available pools. Moreover, As depletion in the rhizosphere and limited resupply from less available pools were indicated by a 19.3% decreased As flux, measured using the technique of diffusive gradients in thin films (DGT). Modeling of the DGT-soil system was able to show that the rate of release from solid phase to solution in the rhizosphere was one-third of that in the bulk soil. Applying the remedial strategy of bioavailable contaminant stripping, which aims at diminishing the phytoavailable pollutant fraction, DGT can be used as a monitoring tool to evaluate the efficiency of phytoextraction and to study the potential resupply of bioavailable pools after phytoextraction has ceased.

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Fletcher, J. (1998). Screening plant species for phytoremediation of organic pollutants - laboratory versus field data. IBC Third Annual International Conference on Phytoremediation: Strategies and Evaluation of Phytoremediation's Performance in the Field. June 22-25, 1998, Huston, TX.

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Fletcher, J.S. (1997). Phytoremediation makes ecological and economical sense in site closures. The 4th International Petroleum Environmental Conference; Environmental Issues and Solutions in Exploration, Production, and Refining, September 9-12, 1997, San Antonio, TX.

Fletcher, J.S. and S.I. Shah. (1998). Long-term phytoremediation of organic soil pollutants. Tech Trends. EPA 542-N-98-005.

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Seventeen different plant species grown in sand culture were screened for their ability to release phenolic compounds from their roots. It was concluded that the concentration throughout the rhizosphere was below substrate levels, but for some plant species (i.e. mulberry) there was evidence that portions of the rhizosphere possessed levels of phenols sufficiently high enough to support microbial growth.

Fletcher, J.S., F.L. Johnson, and J.C. McFarlane. (1988). Database assessment of phytotoxicity data published on terrestrial vascular plants. Environ. Toxicol. Chem. 7:615-622.

Fletcher, J.S., J.C. McFarlane, and F.L. Johnson.(1990). Influence of greenhouse versus field testing and taxonomic differences on plant sensitivity to chemical treatment. Environ. Toxicol. Chem. 9:769-779.

Fletcher, J.S., P. Olson, and M.B. Leigh. (1997). The role of phytoremediation in intrinsic bioremediation. In B.C. Alleman, and A. Leeson, (eds.), In Situ and On Site Bioremediation: Volume 2, Papers from the Fourth International In Situ and On-Site Bioremediation Symposium, April 28-May 1, 1997, New Orleans, LA. Battelle Press.

Fletcher, J.S., P.K. Donnelly, and R.S. Hegde. (1995). Bioremediation of PCBs by plant root/bacteria systems. In Situ and On-Site Bioreclamation, The Third International Symposium, April 24-27, 1995, San Diego, CA. Battelle Memorial Institute.

Fletcher, J.S., P.K. Donnelly, and R.S. Hegde. (1995). Biostimulation of PCB-degrading bacteria by compounds released from plant roots. pp. 131-136. In R.E. Hinchee, D.B. Anderson, and R.E. Hoeppel (eds.), Bioremediation of Recalcitrant Organics. Battelle Press, Columbus, OH.

Fletcher, J.S., P.K. Donnelly, and R.S. Hegde. (1995). Plant assisted PCB degradation. pp. 42-43. 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.

Flocco, C. G., A. Lo Balbo, et al. (2002). Removal of phenol by alfalfa plants (*Medicago sativa* L.) grown in hydroponics and its effect on some physiological parameters. Acta Biotechnologica 22(1-2): 43-54. The plant-assisted removal of phenol, with special emphasis on the effects of this compound on some plant's physiological parameters, was investigated. Hydroponic cultures of alfalfa (*Medicago sativa* L., var. Romagnola) were employed as a model system. These cultures were exposed to two phenol concentrations: 100 and 500 mg/l. A first order kinetic approach was used to describe the removal of phenol from the solution. After 30 days of cultivation, the initial amount of phenol (100 mg/l) was reduced to non-detectable levels in the presence of plants. In the absence of plants, 20% of phenol remained in the solution. The half-life of phenol was reduced from 7.2 to 4.5 days in the presence of plants. After 25 days, the initial amount of 500 mg/l of phenol was reduced to non-detectable levels in the presence of plants not previously exposed to phenol and to approximately 20% with plants previously exposed to the contaminant. In the absence of plants, almost 40% remained in the solution. The presence of plants reduced the half-life of phenol from 18.3 days to 10.4 in the case of plants previously exposed and to 7.8 days in the case of plants without previous contact. Chlorophyll contents in alfalfa leaves of plants exposed to 100 mg/l of phenol were similar to those of control plants and a decrease in total chlorophyll content was observed when plants were exposed to 500 mg/l of phenol. The activity of soluble peroxidases of the roots increased in the presence of 100 mg/l of phenol but the amount of 500 mg/l had a negative effect on the peroxidase fraction. No changes were observed in the case of the ionically-bound cell wall fraction. The growth index of the plants exposed to 100 mg/l of phenol was comparable to that of non-exposed plants, while this parameter was negatively affected in the case of plants exposed to 500 mg/l of phenol. Although alfalfa plants were able to survive an exposure to 500 mg/l of phenol, their physiological parameters and their removal capacity were negatively affected.

Flocco, C. G., A. Lo Balbo, M. P. Carranza and A. M. Giulietti. (2002). Removal of Phenol by Alfalfa Plants (*Medicago Sativa* L.) Grown in Hydroponics and Its Effect on Some Physiological Parameters. Acta Biotechnologica 22(1-2): 43-54.

Flocco, C. G., A. Lobalbo, et al. (2002). Some physiological, microbial, and toxicological aspects of the removal of phenanthrene by hydroponic cultures of alfalfa (*Medicago sativa* L.). International Journal of Phytoremediation 4(3): 169-186. Alfalfa (*Medicago sativa* L.) and other plants bearing an important root system have been shown to be effective in the removal of organic compounds, including polycyclic aromatic hydrocarbons (PAHs). Phenanthrene is one of the main contaminants arising from the petrochemical industry and is included in the USEPA's list of priority toxic pollutants. Hydroponic cultures of alfalfa were employed as a model system to evaluate their capability of removing phenanthrene and to study the plant-pollutant interaction without the interference of a soil matrix. The removal of phenanthrene was followed over a period of 30 days. The half-life of phenanthrene in hydroponics (initial concentration 50 mg L-1) was reduced 2.7 times when plants were present. Growth index, chlorophyll content of leaves, and peroxidase activity of the roots of plants exposed to phenanthrene were lower than the corresponding values of nonexposed plants. Phenanthrene produced an acute negative effect on the total bacterial counts but also caused an increase in degraders/total bacteria ratio. The Ames Salmonella plate incorporation assay was employed to screen for potential genotoxic metabolites, which could be generated by metabolic activation of the parent compound. None of the samples exhibited a positive response. While lack of a positive response to this test is not a definitive evidence of the absence of genotoxic substances, these results suggest that the plant-assisted removal of phenanthrene merits further investigation.

Flocco, C. G., A. Lobalbo, M. P. Carranza, M. Bassi, A. M. Giulietti and W. P. Mac Cormack. (2002). Some Physiological, Microbial, and Toxicological Aspects of the Removal of Phenanthrene by Hydroponic Cultures of Alfalfa. International Journal of Phytoremediation 4(3).

Flocco, C. G., M. P. Carranza, et al. (2004). Removal of azinphos methyl by alfalfa plants (*Medicago sativa* L.) in a soil-free system. Science of the Total Environment. C. G. Flocco. 327: 31. The objective of this study was to investigate the removal of azinphos methyl assisted by alfalfa plants, with special emphasis on the effects of this compound on some plant's physiological parameters. Hydroponic cultures of alfalfa (*Medicago sativa* L., var Romagnola) were employed as a model system. These cultures were

exposed to a nutrient medium containing 10 mg/l of azinphos methyl. A first-order kinetic approach was used to describe the removal of azinphos methyl from the solution. After 20 days of culture, the initial amount of azinphos methyl was reduced to non-detectable levels in the presence of plants. In the absence of plants, 20% of azinphos methyl remained in the solution after 30 days of treatment. The half-life of the pesticide was reduced from 10.8 to 3.4 days in the presence of plants. The growth index of alfalfa plants exposed to azinphos methyl was negatively affected. Chlorophyll contents were reduced after 24 h of treatment and thereafter the levels were comparable to that of control plants. The peroxidase activity of alfalfa roots was not affected by the presence of azinphos methyl. In conclusion, alfalfa plants were able to survive when exposed to an effective concentration of 10 mg/l of azinphos methyl in the root zone, with some alterations on their physiological parameters.

Flocco, C. G., M. R. Carranza, et al. (2004). Removal of azinphos methyl by alfalfa plants (*Medicago sativa* L.) in a soil-free system. Science of the Total Environment 327(1-3): 31-39. The objective of this study was to investigate the removal of azinphos methyl assisted by alfalfa plants, with special emphasis on the effects of this compound on some plant's physiological parameters. Hydroponic cultures of alfalfa (*Medicago sativa* L., var Romagnola) were employed as a model system. These cultures were exposed to a nutrient medium containing 10 mg/l of azinphos methyl. A first-order kinetic approach was used to describe the removal of azinphos methyl from the solution. After 20 days of culture, the initial amount of azinphos methyl was reduced to non-detectable levels in the presence of plants. In the absence of plants, 20% of azinphos methyl remained in the solution after 30 days of treatment. The half-life of the pesticide was reduced from 10.8 to 3.4 days in the presence of plants. The growth index of alfalfa plants exposed to azinphos methyl was negatively affected. Chlorophyll contents were reduced after 24 h of treatment and thereafter the levels were comparable to that of control plants. The peroxidase activity of alfalfa roots was not affected by the presence of azinphos methyl. In conclusion, alfalfa plants were able to survive when exposed to an effective concentration of 10 mg/l of azinphos methyl in the root zone, with some alterations on their physiological parameters.

Flocco, C. G., S. D. Lindblom, et al. (2004). Overexpression of enzymes involved in glutathione synthesis enhances tolerance to organic pollutants in *Brassica juncea*. International Journal of Phytoremediation 6(4): 289-304. Transoenic Indian mustard (*Brassica juncea*) overexpressing y-glutamylcysteine synthetase (ECS) or glutathione synthetase (GS) were shown previously to have twofold higher levels Of glutathione and total nonprotein thiols. as well as enhanced cadmium tolerance and accumulation. Here, the hypothesis was tested that these transgenics have enhanced tolerance to organic pollutants, based on the reasoning that many organic xenobiotics are detoxified via conjugation to glutathione. Both the ECS and GS transgenics showed enhanced tolerance to atrazine: while root growth of wildtype seedlings was inhibited 50% by 100 mg L-1 atrazine. ECS and GS root,growth was inhibited 20-30% ($P < 0.05$). The tolerance of the transgenics to CDNB (1-chloro-2,4-dinitrobenzene), metolachlor. and phenanthrene was also some-what higher than wild type, but these differences were not as pronounced. Each of the organics treatments significantly enhanced total nonprotein thiol levels in all plant types (2 to 12-fold). Overall, these results Suggest that GSH biosynthesis is limiting for atrazine detoxification in Indian mustard and that overexpression of enzymes involved in GSH biosynthesis offers a promising approach to create plants with the enhanced capacity to tolerate not only heavy metals. but also certain organics.

Flocco, C. G., S. D. Lindblom, et al. (2004). Overexpression of enzymes involved in glutathione synthesis enhances tolerance to organic pollutants in *Brassica juncea*. International Journal of Phytoremediation 6(4): 289-304. Transoenic Indian mustard (*Brassica juncea*) overexpressing y-glutamylcysteine synthetase (ECS) or glutathione synthetase (GS) were shown previously to have twofold higher levels Of glutathione and total nonprotein thiols. as well as enhanced cadmium tolerance and accumulation. Here, the hypothesis was tested that these transgenics have enhanced tolerance to organic pollutants, based on the reasoning that many organic xenobiotics are detoxified via conjugation to glutathione. Both the ECS and GS transgenics showed enhanced tolerance to atrazine: while root growth of wildtype seedlings was inhibited 50% by 100 mg L-1 atrazine. ECS and GS root,growth was inhibited 20-30% ($P < 0.05$). The tolerance of the transgenics to CDNB (1-chloro-2,4-dinitrobenzene), metolachlor. and phenanthrene was also some-what higher than wild type, but these differences were not as pronounced. Each of the organics treatments significantly enhanced total nonprotein thiol levels in all plant types (2 to 12-fold). Overall,

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Floccos, C. G. (2005). Overexpression of enzymes involved in glutathione synthesis enhances tolerance to organic pollutants in *Brassica juncea*. (vol 6, pg 289, 2004). International Journal of Phytoremediation 7(1): 85.

Flores-Tavizon, E., M. T. Alarcon-Herrera, et al. (2003). Arsenic tolerating plants from mine sites and hot springs in the semi-arid region of Chihuahua, Mexico. Acta Biotechnologica 23(2-3): 113-119. Phytoremediation is an emergent field of great potential for the removal of metals, metalloids and other contaminants from soil, water and sediments. The use of native plants with high tolerance and capacity to accumulate the metal to be removed is a very convenient approach. High levels of arsenic (As) have been found at several natural sources in the northern and and semi-arid regions of Mexico. The state of Chihuahua is, among others, one in which As has been detected in sources of natural drinking water. The aim of the present work was to identify indigenous plants in the state of Chihuahua with As tolerance and accumulating capacity. Water samples from different mine sites and hot springs were inspected. At these sites, the As concentration varied in the range of 110-191 mug/l in water and 40-2100 mug/g in soils. A native plant identified as Eleocharis sp. (Cyperaceae), collected from the nearby surroundings of a hot spring site, was found to contain an As concentration of 301 mug/g. The arsenic bioconcentration (BCF) and translocation (TF) factors for this plant exceeded 1 (5.22 and 7.37, respectively), which classifies it as an arsenic-tolerant plant with potential use in phytoextraction. The TF of Brickellia veronicaefolia, *Nicotiana*glauca and Baccharis salicifolia were above one, but they had very low BCF coefficients, which limited their potential to be considered for a phytoremediation process.

Fonkou, T., P. Agendia, et al. (2005). Heavy metal concentrations in some biotic and abiotic components of the olezoa wetland complex (Yaounde-Cameroon, West Africa). Water Quality Research Journal of Canada 40(4): 457-461. Concentrations of cadmium (Cd), copper (Cu), zinc (Zn) and lead (Pb) in water, sediments, fish organs and plants from two ponds of the Olezoa wetland complex were analyzed. Plants investigated were *Cyperus papyrus*, *Enydra fluctuans*, *Ipomoea aquatica* and *Echinocloa pyramidalis*. The fish species studied was the walking catfish Clarias lazera and the heavy metal concentrations were measured in the digestive tract, gills, flesh and liver. Average concentrations in water were 6 x 10(-2) ppm for Cd, 14.53 ppm for Cu, 2.88 ppm for Zn and 17.69 ppm for Ph. These values were low compared to those recorded in the sediments, plants and fish organs. Results revealed an increase of heavy metal concentrations from water to plants and fish organs, with magnification factors ranging from 580 to 5700 and from 577 to 8173, respectively. In the sediments and the floating mat of the eutrophic fish ponds, these factors ranged from 491 to 1065 and 624 to 758, respectively. In the fish organs, particularly, the following accumulation gradients were foreseen: gills -> flesh -> digestive tract -> liver for Cd and Pb; and flesh -> gills -> digestive tract -> liver for Cu and Zn. The four plants studied appeared to be good candidates for phytoremediation of water metal pollution. The quantity of heavy metals in this wetland complex is considerable and will constitute a potential hazard for biota.

Forni, C., A. Cascone, et al. (2002). Sulphadimethoxine and *Azolla filiculoides* Lam.: a model for drug remediation. Water Research 36(13): 3398-3403. Plants can be an interesting tool for in situ remediation of drug contaminated waters. In a laboratory model *Azolla filiculoides* Lam., an aquatic fern known to absorb pollutants. has been exposed to an environmental persistent antibiotic commonly used in intensive farming. sulphadimethoxine (S), to test its bioremediation capability. In a 5 week experiment. plants were cultivated outdoor at four drug concentrations (50, 150. 300 and 450 mg 1(-1)) in N-free mineral medium. Drug affects growth rate (as biomass yield per week), N-2-fixation, heterocyst frequency, but plants are able to survive. Notwithstanding. at all concentrations tested drug was actively removed from the medium and the accumulation in the biomass is in order of magnitude up to mg g(-1) plant dry weight (1000 ppm). Drug uptake and degradation rates increase with S concentrations in the culture medium. The efficacy of the model was very high, These results demonstrated that *Azolla* can be taken into consideration as a tool for sulphonamides environmental monitoring and decontamination.

Francesconi, K., P. Visoottiviseth, W. Sridokchan and W. Goessler. 2002). Arsenic Species in an Arsenic Hyperaccumulating Fern, Pityrogramma Calomelanos: A Potential Phytoremediator of Arsenic-Contaminated Soils. Science of The Total Environment 284(1-3): 27-35.

Francova, K., M. Sura, et al. (2003). Preparation of plants containing bacterial enzyme for degradation of polychlorinated biphenyls. Fresenius Environmental Bulletin 12(3): 309-313. The purpose of this investigation was to engineer genetically modified plants bearing the bacterial gene bphC coding for 2,3-dihydroxybiphenyl-1,2-dioxygenase. Gene bphC from *Comamonas testosteroni* B-356 was cloned into plasmid pBI 121 containing CaMV 35S promotor and kanamycine resistance and introduced into *Agrobacterium tumefaciens* LBA 4404. Plasmid pBI 121(B-356-bphC) was then transfered into *Nicotiana tobacum* L var. Wisconsin 38. Successful gene cloning in the plant was confirmed after transferring of the regenerants to selective medium by the root formation on rooting-supporting medium in the presence of kanamycine and by amplification of bphC from plant DNA using primers that are specific to the cloned gene.

Frank, H., A. Vincon, J. Reiss and H. Scholl. (1990). Trichloroacetic Acid in the Foliage of Forest Trees. 13(November): 733-736.

Fraser, L. H., S. Carty, et al. (2004). Phytoremediation: wetland plants and their relative efficiency at treating agricultural runoff. Recent Research Developments in Crop Science. Vol. 1, Part II. L. H. Fraser. Trivandrum, Research Signpost: 379. This review introduces the current understanding of treatment wetlands, including the effect of temperature on artificial wetland processes. The biogeochemical processes important within a wetland system, such as pH, conductivity, dissolved oxygen and biochemical oxygen demand are discussed. The nitrogen and phosphorus cycles are detailed and their impact on aquatic systems are evaluated. The global pattern of eutrophication is addressed. Phytoremediation is defined as well as an exploration of worldwide use of treatment wetland systems and their overall effectiveness for domestic waste water treatment. Descriptions of past research conducted to determine macrophytic importance within treatment wetland systems and species-specific treatment capabilities are illustrated. Macrophytes in use included *Scirpus*, *Typha*, *Phragmites*, Eleocharis and *Cyperus*.

Fraser, L. H., S. M. Carty, et al. (2004). A test of four plant species to reduce total nitrogen and total phosphorus from soil leachate in subsurface wetland microcosms. Bioresource Technology 94(2): 185-192. Four wetland plant species (*Scirpus validus*, *Carex lacustris*, *Phalaris arundinacea*, and *Typha latidolia*) were grown in monoculture and as a four-species mixture to compare effectiveness of nutrient removal in controlled 18.93-1 outdoor subsurface treatment wetland microcosms. A nutrient treatment that mimicked single-resident domestic effluent consisted of two levels of nitrogen (N) and phosphorus (P) [low (56 mg/l N and 31 mg/l P) and high (112 mg/l N and 62 mg/l P)] of nutrient solution applied three times weekly. The plants were established and maintained for one year before the nutrient treatment and monthly water sampling commenced; water sampling began July 31, 2001 and ended October 23, 2001. We tested four hypotheses: (1) vegetated microcosms are more effective at reducing concentrations of total N and total P from soil leachate than unvegetated, (2) there is a differential species effect on the potential to reduce N and P, (3) plant mixtures are more effective than monocultures at reducing N and P, and (4) the microcosms will be least effective at reducing N and P concentrations in October compared to August. We found support for hypotheses 1, 2, and 4, but our results are inconclusive for the third hypothesis. Total N and total P in the soil leachate were significantly higher from unvegetated microcosms compared to vegetated. S. *validus* was most effective and P. *arundinacea* was generally least effective at reducing N and P in monocultures, with treatment capabilities similar to unvegetated microcosms. The four-species mixture was generally highly effective at nutrient removal, however the results were not significantly different from the monocultures. At the end of the growing season (October) treatment efficiency was significantly less than earlier months, especially for the unvegetated treatment.

Fraser, L. H., S. M. Carty, et al. (2004). A test of four plant species to reduce total nitrogen and total phosphorus from soil leachate in subsurface wetland microcosms. Bioresource Technology. L. H. Fraser. 94: 185. Four wetland plant species (*Scirpus validus*, *Carex lacustris*, *Phalaris arundinacea*, and *Typha latidolia*) were grown in monoculture and as a four-species mixture to compare effectiveness of nutrient

removal in controlled 18.93-l outdoor subsurface treatment wetland microcosms. A nutrient treatment that mimicked single-resident domestic effluent consisted of two levels of nitrogen (N) and phosphorus (P) [low (56 mg/l N and 31 mg/l P) and high (112 mg/l N and 62 mg/l P)] of nutrient solution applied three times weekly. The plants were established and maintained for one year before the nutrient treatment and monthly water sampling commenced; water sampling began July 31, 2001 and ended October 23, 2001. We tested four hypotheses: (1) vegetated microcosms are more effective at reducing concentrations of total N and total P from soil leachate than unvegetated, (2) there is a differential species effect on the potential to reduce N and P, (3) plant mixtures are more effective than monocultures at reducing N and P, and (4) the microcosms will be least effective at reducing N and P concentrations in October compared to August. We found support for hypotheses 1, 2, and 4, but our results are inconclusive for the third hypothesis. Total N and total P in the soil leachate were significantly higher from unvegetated microcosms compared to vegetated. *S*. *validus* was most effective and *P*. *arundinacea* was generally least effective at reducing N and P in monocultures, with treatment capabilities similar to unvegetated microcosms. The four-species mixture was generally highly effective at nutrient removal, however the results were not significantly different from the monocultures. At the end of the growing season (October) treatment efficiency was significantly less than earlier months, especially for the unvegetated treatment.

Freeman, J. L., D. Garcia, et al. (2005). Constitutively elevated salicylic acid signals glutathione-mediated nickel tolerance in *Thlaspi* nickel hyperaccumulators. Plant Physiology (Rockville) 137(3): 1082-1091. Progress is being made in understanding the biochemical and molecular basis of nickel (Ni)/zinc (Zn) hyperaccumulation in *Thlaspi*; however, the molecular signaling pathways that control these mechanisms are not understood. We observed that elevated concentrations of salicylic acid (SA), a molecule known to be involved in signaling induced pathogen defense responses in plants, is a strong predictor of Ni hyperaccumulation in the six diverse *Thlaspi* species investigated, including the hyperaccumulators *Thlaspi goesingense*, *Thlaspi* rosulare, *Thlaspi oxyceras*, and *Thalaspi caerulescens* and the nonaccumulators *Thlaspi arvense* and *Thlaspi perfoliatum*. Furthermore, the SA metabolites phenylalanine, cinnamic acid, salicyloyl-glucose, and catechol are also elevated in the hyperaccumulator *T. goesingense* when compared to the nonaccumulators *Arabidopsis* (*Arabidopsis thaliana*) and *T arvense*. Elevation of free SA levels in *Arabidopsis*, both genetically and by exogenous feeding, enhances the specific activity of serine acetyltransferase, leading to elevated glutathione and increased Ni resistance. Such SA-mediated Ni resistance in *Arabidopsis* phenocopies the glutathione-based Ni tolerance previously observed in *Thlaspi*, suggesting a biochemical linkage between SA and Ni tolerance in this genus. Intriguingly, the hyperaccumulator *T. goesingense* also shows enhanced sensitivity to the pathogen powdery mildew (*Erysiphe cruciferarum*) and fails to induce SA biosynthesis after infection. Nickel hyperaccumulation reverses this pathogen hypersensitivity, suggesting that the interaction between pathogen resistance and Ni tolerance and hyperaccumulation may have played a critical role in the evolution of metal hyperaccumulation in the *Thlaspi* genus.

Freitag, D., I. Scheunert, F. Korte, and W. Klien. (1984). Long-term fate of 4-Chloroaniline-14C in soil and plants under outdoor conditions. A contribution to terrestrial exotoxicology of chemicals. J. Agric. Food Chem. 32:203-208.

Freitas, H., M. N. V. Prasad, et al. (2004). Analysis of serpentinophytes from north-east of Portugal for trace metal accumulation -- relevance to the management of mine environment. Chemosphere. H. Freitas. 54: 1625. In north-east of Portugal, the serpentinized area is about 8000 ha with a characteristic geology and flora. The serpentine plant community and respective soils were analysed to examine the trace metal budget in different tissues of the plants exhibiting resistance to trace metals. One hundred and thirty five plant species belonging to 39 families and respective soils have been analysed for total Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn. Substantial amounts of Ni, Cr, Co and Mn were detected in plant tissues. The significance of serpentine flora, need for conservation of these fragile and environmentally invaluable plant resources for possible use for in situ remediation of metalliferous substrates are presented in this paper.

French, C. E., S. J. Rosser, et al. (1999). Biodegradation of explosives by transgenic plants expressing pentaerythritol tetranitrate reductase. Nature Biotechnology 17(5): 491-494. Plants offer many advantages over bacteria as agents for bioremediation; however, they typically lack the degradative capabilities of

specially selected bacterial strains. Transgenic plants expressing microbial degradative enzymes could combine the advantages of both systems. To investigate this possibility in the context of bioremediation of explosive residues, we generated transgenic tobacco plants expressing pentaerythritol tetranitrate reductase, an enzyme derived from an explosive-degrading bacterium that enables degradation of nitrate ester and nitroaromatic explosives. Seeds from transgenic plants were able to germinate and grow in the presence of 1 mM glycerol trinitrate (GTN) or 0.05 mM trinitrotoluene, at concentrations that inhibited germination and growth of wild-type seeds. Transgenic seedlings grown in liquid medium with 1 mM GTN showed more rapid and complete denitration of GTN than wild-type seedlings. This example suggests that transgenic plants expressing microbial degradative genes may provide a generally applicable strategy for bioremediation of organic pollutants in soil.

French, C. E., S. J. Rosser, G. J. Davies, S. Nicklin and N. C. Bruce. (2000). Biodegradation of Explosives by Transgenic Plants Expressing Pentaerylthitol Tetranitrate Reductase. Nature Biotechnology 17: 491-494.

French, C. J., N. M. Dickinson, et al. (2006). Woody biomass phytoremediation of contaminated brownfield land. Environmental Pollution 141(3): 387-395. Economic and environmental regeneration of post-industrial landscapes frequently involves some element of re-afforestation or tree planting. We report field trials that evaluate whether woody biomass production is compatible with managing residual trace element contamination in brownfield soils. Large-scale mapping of contamination showed a heterogenous dispersion of metals and arsenic, and highly localised within-site hotspots. Yields of *Salix*, *Populus* and *Alnus* were economically viable, showing that short-rotation coppice has a potentially valuable role in community forestry. Mass balance modelling demonstrated that phytoextraction potentially could reduce contamination hotspots of more mobile elements (Cd and Zn) within a 25-30-year life cycle of the crops. Cd and Zn in sterns and foliage of *Salix* were 4-13 times higher than EDTA-extractable soil concentrations. Lability of other trace elements (As, Pb, Cu, Ni) was not increased 3 years after planting the coppice; woody biomass may provide an effective reduction of exposure (phytostabilisation) to these less mobile contaminants.

French, C. J., N. M. Dickinson, et al. (2006). Woody biomass phytoremediation of contaminated brownfield land. Environmental Pollution. C. J. French. 141: 387. Economic and environmental regeneration of post-industrial landscapes frequently involves some element of re-afforestation or tree planting. We report field trials that evaluate whether woody biomass production is compatible with managing residual trace element contamination in brownfield soils. Large-scale mapping of contamination showed a heterogenous dispersion of metals and arsenic, and highly localised within-site hotspots. Yields of *Salix*, *Populus* and *Alnus* were economically viable, showing that short-rotation coppice has a potentially valuable role in community forestry. Mass balance modelling demonstrated that phytoextraction potentially could reduce contamination hotspots of more mobile elements (Cd and Zn) within a 25-30-year life cycle of the crops. Cd and Zn in stems and foliage of *Salix* were 4-13 times higher than EDTA-extractable soil concentrations. Lability of other trace elements (As, Pb, Cu, Ni) was not increased 3 years after planting the coppice; woody biomass may provide an effective reduction of exposure (phytostabilisation) to these less mobile contaminants.

Frerot, H., C. Lefebvre, et al. (2006). Specific interactions between local metallicolous plants improve the phytostabilization of mine soils. Plant and Soil 282(1-2): 53-65. At present, no efficient technique is available for cleaning up soils which are highly polluted by heavy metals. Limiting the movement of pollutants out of the contaminated area by creating a dense and persistent plant cover appears to be the more reasonable approach. In this context, phytostabilization is a technique that uses metallicolous plants to revegetate highly polluted soils. This paper presents the results of an experiment performed in situ using metallicolous ecotypes of four plant species native to the Mediterranean French region, and grown in different combinations at a polluted site over two years. The soils were highly polluted with zinc, cadmium and lead. The aim was to find the best species mixture in terms of cover, biomass and duration. The four species used were the biennial legume Anthyllis vulneraria, two perennial grasses, *Festuca* arvernensis and Koeleria vallesiana, and the perennial forb Armeria arenaria. Mixtures which included A. vulneraria, and especially when in combination with F. arvernensis, showed the highest values of cover

and biomass. After flowering, the biennial individuals of A. vulneraria disappeared but subsequent germination and survival of seedlings occurred abundantly under the two grasses. Mixtures with A. arenaria showed the lowest values of cover and biomass. Soil nitrogen increased in the plots with A. vulneraria as well as the concentration of essential nutrients (N P K) in the aerial parts of the two grasses. In contrast, the concentration of metals (Zn Pb Cd) decreased in the aboveground biomass of the latter in the same plots. These results show that reciprocal facilitation effects can act in heavy metal polluted environments, and that phytostabilization efforts in the Mediterranean region can be improved by using mixtures including local metallicolous legume and grass species.

Frerot, H., C. Petit, et al. (2003). Zinc and cadmium accumulation in controlled crosses between metallicolous and nonmetallicolous populations of *Thlaspi caerulescens* ( *Brassicaceae*). New Phytologist 157(3): 643-648. Growth and heavy metal (Zn and Cd) hyperaccumulation were investigated in metallicolous and nonmetallicolous Mediterranean populations of *Thlaspi caerulescens* ( *Brassicaceae*), and in offspring from controlled crosses between these populations. Seeds for the growth and crossing experiments were collected from a number of sites varying in heavy metal contamination. Tissue Zn and Cd content was determined by atomic absorption spectrophotometry. Offspring from crosses between nonmetallicolous populations had the highest Zn concentration (c. 30 000 mug g(-1)), compared with 20 000 mug g(-1) for the nonmetallicolous parents. The metallicolous parents and the other crosses had only 10 000 mug g(-1). Offspring from crosses including a nonmetallicolous parent still had a significantly higher Zn uptake than the metallicolous parents. A trend towards a higher Cd uptake was observed in offspring from crosses with a metallicolous parent. We suggest that the most probable hypothesis is that the differences in Zn hyperaccumulation between crosses could be explained by a monogenic system with two alleles. The dominant allele would restrict Zn hyperaccumulation at 10 000 mug g(-1) whereas the recessive allele would be responsible for a two to three-fold increase in Zn hyperaccumulation. Alternatively, the existence of modifier genes could explain the differences between offspring from crosses between nonmetallicolous populations and their respective field parents. The results suggest that plant breeding applied to this species could help to improve Zn phytoextraction.

Freundlich isotherms were determined. A higher nitrogen percent of aminated E.C. showed a higher adsorption capacity than other derivatives. The kinetic adsorption models indicate that the decolourization was complete in a relatively short time (10 min) and the reaction taking place is of the first order. The equilibrium data fit well with the Freundlich model of adsorption for the six dyes. Only dye IV (C.I.A Acid Blue 25) conform both Freundlich and Langmuir adsorption isotherms.

Frey, B., C. Keller, K. Zierold and R. Schulin. (2000). Distribution of Zn in Functionally Different Leaf Epidermal Cells of the Hyperaccumulator *Thlaspi caerulescens*. Plant Cell Environ. 23(7): 675-687.

Fritioff, A. and M. Greger (2003). Aquatic and terrestrial plant species with potential to remove heavy metals from stormwater. International Journal of Phytoremediation 5(3): 211-224. Remediation of stormwater polluted with heavy metals should be possible in percolation systems, ponds, or wetlands. The aim of this work was to find plant species for such systems that are efficient in the uptake of Zn, Cu, Cd, and Pb. Plants were collected from percolation and wetland areas and analyzed for heavy metal concentrations. Results showed that submersed and free-floating plants had the capacity to take up high levels of Cu, Zn, and Pb into their shoots. With roots having a concentration factor above 1, the terrestrial plants show efficient stabilization of Cd and Zn and emergent plants show corresponding stabilisation of Zn. In addition, *Potamogeton natans, Alisma plantago-aquatica, and Filipendula ulmaria* were used in a controlled experiment. The shoots of *P. natans* and the roots of *A. plantago-aquatica* were found to accumulate even higher concentrations of Zn, Cu, and Pb than found in the field-harvested plants. Similar results were found for Cd in shoots and Pb in roots of *F. ulmaria*. Our conclusion is that submersed plant species seem to be the most efficient for removal of heavy metals from stormwater.

Fritioff, A. and M. Greger (2006). Uptake and distribution of Zn, Cu, Cd, and Pb in an aquatic plant *Potamogeton natans*. Chemosphere. 63: 220. A better understanding of metal uptake and translocation by aquatic plants can be used to enhance the performance of constructed wetland systems for stormwater treatment. Specifically, this study examines whether the uptake of Zn, Cu, Cd, and Pb by *Potamogeton*

*natans* is via the leaves, stems, or roots, and whether there is translocation from organs of uptake to other plant parts. Competition between the metals at uptake and at the level of the cell wall-bound part of the metals accumulated in stem and leaf tissue was also examined. The results show that Zn, Cu, Cd, and Pb were taken up by the leaves, stems, and roots, with the highest accumulation found in the roots. At the elevated metal concentrations common in stormwater the uptake of Cu, but not of Zn, Cd, or Pb, by the roots was somewhat limited at uptake due to competition with other metals. Between 24% and 59% of the metal content was bound to the cell walls of the plant. Except in the case of Pb, the cell wall-bound fraction was generally smaller in stems than in leaves. No translocation of the metals to other parts of the plant was found, except for Cd which was translocated from leaf to stem and vice versa. Dispersion of metals from sediment to water through *P. natans* is therefore unlikely.

Fritioff, A., L. Kautsky, et al. (2005). Influence of temperature and salinity on heavy metal uptake by submersed plants. Environmental Pollution 133(2): 265-274. Submersed plants can be useful in reducing heavy metal concentrations in stormwater, since they can accumulate large amounts of heavy metals in their shoots. To investigate the effects of water temperature and salinity on the metal uptake of two submersed plant species, Elodea canadensis (Michx.) and *Potamogeton natans* (L.), these plants were grown in the presence of Cu, Zn, Cd, and Pb at 5, 11, and 20 degreesC in combination with salinities of 0, 0.5, and 5parts per thousand. The metal concentrations in the plant tissue increased with increasing temperature in both species; the exception was the concentration of Pb in Elodea, which increased with decreasing salinity. Metal concentrations at high temperature or low salinity were up to twice those found at low temperature or high salinity. Plant biomass affected the metal uptake, with low biomass plants having higher metal concentrations than did high biomass plants.

Frizzo, T. C. E. and M. L. Porto (2004). Vegetation zoning and its relation to the occurence of ores in Volta Grande mine, Lavras do Sul, RS, Brazil. Iheringia Serie Botanica 59(1): 5-12. The knowledge of vegetation in regions of copper and gold ore has become of great importance for the development of rehabilitation of clean technologies in areas degraded by mining (phytoremediation) and in the mineral bioprospecting. Based on Landscape Ecology studies were carried out to verify the relation between the spatial and phytosociological patterns of vegetation units and subunits at Volta Grande mine, in Lavras do Sul, RS, Brazil, and the presence of ore. According to the results, the distribution of vegetation units and subunits migth be related to the geomorphological position, to the declivity, and to grazing. The vegetation unit Schinus lentiscifolius - Heterothalamus alienus seems to be related to the existence of copper and gold ores, being necessary to compare this area with other mineralized and non-mineralized areas in order to use such data in mineral prospecting.

Fuhrmann, M. and A. Lanzirotti (2005). Am-241, Cs-137, Sr and Pb uptake by tobacco as influenced by application of Fe chelators to soil. Journal of Environmental Radioactivity 82(1): 33-50. To determine the potential for phytoextraction of Am-241 and other contaminants from soil, accumulation of Am-241, Cs-137, Sr, Fe, Al, Pb, and Mg by tobacco was determined for soil applications of two concentrations of ethylenediaminetetraacetic acid (EDTA), citric acid, and ascorbic acid. In tobacco receiving EDTA at 3.1 mmol/kg of Soil, Am-241 content of plants averaged 15 Bq/kg (ranging up to 26 Bq/kg) while Fe concentrations became constant at 4.5 mmol/kg. Soil treatment with 18.8 mmol/kg EDTA resulted in average Am-241 concentrations of 29 Bq/kg (19 times higher than controls). Uptake of Pb was similar to Am-241. In these samples, Fe increased to a maximum of almost 18 mmol/kg and Am-241 content increased linearly with both Fe and Al. Plants receiving ascorbic and citric acids took up smaller quantities of Am-241, Pb, and Fe, even though these reagents were able to elute about as much Fe from the soil as EDTA. Synchrotron microbeam X-ray fluorescence (SXRF) was used to determine radial distributions of elements in roots and stems with and without EDTA treatment. SXRF maps indicate differences in behavior between Fe and Pb that are consistent with the bulk plant observations and provide insight into changes in metal content of the roots in the presence of EDTA.

Fuhrmann, M., M. Lasat, et al. (2003). Uptake and release of cesium-137 by five plant species as influenced by soil amendments in field experiments. Journal of Environmental Quality 32(6): 2272-2279. Phytoextraction field experiments were conducted on soil contaminated with 0.39 to 8.7 Bq/g of Cs-137 to determine the capacity of five plant species to accumulate Cs-137 and the effects of three soil treatments

on uptake. The plants tested were redroot pigweed (*Amaranthus* retroflexus L. var. *aureus*); a mixture of redroot pigweed and spreading pigweed (*A. graecizans* L.); purple amaranth (*A. cruteus* L.) x Powell's amaranth (*A. powellii* S. Watson), referred to here as the amaranth hybrid; Indian mustard [*Brassica juncea* (L.) Czern.]; and cabbage (*Brassica oteracae* L. var. *capitata*). For control plants, the concentration ratios (CR) of Cs-137 were greatest for redroot pigweed and the amaranth hybrid, with average CR values of 1.0 +/- 0.24 and 0.95 +/- 0.14, respectively. The lowest value was for Indian mustard at 0.36 +/- 0.10. The soil treatments included (i) application of NH4NO3 solution to the soil after plants had matured, (ii) addition of composted manure to increase organic matter content of the soil, (iii) combination of the manure and ammonium solution treatments, and (iv) controls. The ammonium solution gave little overall increase in accumulation of Cs-137. The use of composted manure also had little influence, but the combination of the composted manure with application of ammonium solutions had a distinctly negative effect on plant uptake of Cs-137. On average the fraction of Cs-137 taken up from the soil was reduced by 57.4 +/- 1.2% compared with controls. This was the result of release of competing ions, primarily Ca, from the manure and was observed across all five plant species tested. The application of ammonium solution took place in the last two weeks before harvest. The reduction of plant Cs-137 content, by addition of the ammonium solution, as it interacted with the manure, indicates that substantial quantities (CS)-C-137 can be released from the shoots of plants as a result of sudden changes in soil solution chemistry.

Fuhrmann, M., M. Lasat, et al. (2003). Uptake and release of cesium-137 by five plant species as influenced by soil amendments in field experiments. Journal of Environmental Quality. M. Fuhrmann. 32: 2272. Phytoextraction field experiments were conducted on soil contaminated with 0.39 to 8.7 Bq/g of 137Cs to determine the capacity of five plant species to accumulate 137Cs and the effects of three soil treatments on uptake. The plants tested were redroot pigweed (*Amaranthus retroflexus* L. var. *aureus*); a mixture of redroot pigweed and spreading pigweed (A. *graecizans* L.); purple amaranth (A. *cruteus* L.) x Powell's amaranth (A. powellii S. Watson), referred to here as the amaranth hybrid; Indian mustard [*Brassica juncea* (L.) Czern.]; and cabbage (*Brassica oleracea* L. var. *capitata*). For control plants, the concentration ratios (CR) of 137Cs were greatest for redroot pigweed and the amaranth hybrid, with average CR values of 1.0 +- 0.24 and 0.95 +- 0.14, respectively. The lowest value was for Indian mustard at 0.36 +- 0.10. The soil treatments included (i) application of NH4NO3 solution to the soil after plants had matured, (ii) addition of composted manure to increase organic matter content of the soil, (iii) combination of the manure and ammonium solution treatments, and (iv) controls. The ammonium solution gave little overall increase in accumulation of 137Cs. The use of composted manure also had little influence, but the combination of the composted manure with application of ammonium solutions had a distinctly negative effect on plant uptake of 137Cs. On average the fraction of 137Cs taken up from the soil was reduced by 57.4 +- 1.2% compared with controls. This was the result of release of competing ions, primarily Ca, from the manure and was observed across all five plant species tested. The application of ammonium solution took place in the last two weeks before harvest. The reduction of plant 137Cs content, by addition of the ammonium solution, as it interacted with the manure, indicates that substantial quantities 137Cs can be released from the shoots of plants as a result of sudden changes in soil solution chemistry.

Fuhrmann, M., M. M. Lasat, et al. (2002). Uptake of cesium-137 and strontium-90 from contaminated soil by three plant species; application to phytoremediation. Journal of Environmental Quality 31(3): 904-909. A field test was conducted to determine the ability of three plant species to extract Cs-137 and Sr-90 from contaminated soil. Redroot pigweed (*Amaranthus retroflexus* L.), Indian mustard [*Brassica juncea* (L.) Czern.], and tepary bean (*Phaseolus acutifolius* A. Gray) were planted in a series of spatially randomized cells in soil that was contaminated in the 1950s and 1960s. We examined the potential for phytoextraction of Sr-90 and Cs-137 by these three species. Concentration ratios (CR) for Cs-137 for redroot pigweed, Indian mustard, and tepary bean were 2.58, 0.46, and 0.17, respectively. For Sr-90 they were substantially higher: 6.5, 8.2, and 15.2, respectively. The greatest accumulation of both radionuclides was obtained with redroot pigweed, even though its CR for Sr-90 was the lowest, because of its relatively large biomass. There was a linear relationship between the Cs-137 concentration in plants and its concentration in soil only for redroot pigweed. Uptake of Sr-90 exhibits no relationship to Sr-90 concentrations in the soil. Estimates of time required for removal of 50% of the two contaminants, assuming two crops of redroot pigweed per year, are 7 yr for Sr-90 and 18 yr for Cs-137.

Fuller, R.D., E.D.P. Nelson, and C.J. Richardson. (1982). Reclamation of red mud (bauxite residues) using alkaline-tolerant grasses with organic amendments. J. Environ. Qual. 11:533-539. *Distichlis spicata* var. *stricta* (desert saltgrass), *Sporobolus airoides* (alkali *sacaton*), *Agropyron amithii* (western wheatgrass), and *A*. *elongatum* (tall wheatgrass), alkaline-tolerant grasses of the western United States, were tested as species to colonize and cover red mud (bauxite residue) with minimum use of soil amendments. A gradient in red mud texture at a residue impoundment (coarse at edge to fine in the center) located in Mobile, Ala., was correlated with soil pH that ranged from 9.15 (coarse) to 11.9 (fine). Saturation-extract Na concentrations ranged from 394 to 4,990 mg/L and Al concentrations from 4.3 to 1,004 mg/L. Exchangeable Na percentage ranged from 52.6 to 91.1. Without amelioration red mud impoundments lacking subsurface drainage remain unvegetated indefinitely. Sewage sludge additions to red mud (2 cm on surface, or 1:2 by volume) produced significantly greater growth compared with red mud controls with *D*. *spicata* var. *stricta*, *A*. *elongatum*, and *S*. *airoides* in greenhouse pot experiments. Other organic amendments (wheat straw, paper pulp waste, glucose, and pine needles) and complete nutrient additions failed to produce a consistent response. Sewage sludge caused similar growth increases with *D*. *spicata* var. *stricta* in field experiments on drained red mud lakes. Sewage sludge may increase growth via several mechanisms: (I) lowering red mud pH, ii) adding macro- and micro-nutrients, (iii) increasing nutrient availability through chelation, and (iv) lowering potential Al toxicity.

Futuyma, Douglas J. (1995). The use of evolutionary biology. Science. 267, Jan. 6, 1995. 41-42.