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Hyperaccumulators

Compiled by Mary Stevanus
Water Quality Information Center
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1. **Accumulation mechanisms and heavy metal tolerance of a nickel hyperaccumulator.**
   Gabbrielli, R., Mattioni, C., and Vergnano, O.
   J Plant Nutr 14: 10 pp.1067-1080. (1991).
   NAL Call #: QK867.J67
   Descriptors: alyssum, nickel, cobalt, zinc, metal-ions metal-tolerance ion-uptake roots, growth-rate translocation, shoots, mineral-content malic-acid serpentine-soils alyssum-bertolonii bioaccumulation-
   Abstract: Alyssum bertolonii Desv., a crucifer which grows only in Tuscany on serpentine soil, is characterized by high Ni concentration in its leaves and a high tolerance to this element. In this research, the Co and Zn tolerance of A. bertol onii has

been tested and compared with that of Ni. Although the Zn concentration in the serpentine soil on which the plant grows is lower than that of Co, root growth showed no significant difference for these two elements. In excised roots, on the other hand, Co and Zn compete with Ni uptake and accumulation. Seedlings do not show any inhibition in the translocation of these three elements. They are all rapidly carried to and accumulate in the shoots, but the uptake and translocation of Zn does not show the saturation trend found for Ni and Co. The same gel filtration fractions contain the three elements in association with malic acid, involved in Ni tolerance.

2. **Al inhibits both shoot development and root growth in als3, an Al-sensitive Arabidopsis mutant.**
   Larsen, P. B., Kochian, L. V., and Howell, S. H.
   Plant physiol 114: 4 pp.1207-1214. (Aug 1997).
   NAL Call #: 450-P692
   Descriptors: arabidopsis-thaliana shoots, plant-development roots, growth, inhibition, leaves, aluminum, phytotoxicity, injuries, stress-response callose, biosynthesis, mutants, wild-strains genotypes, genetic-variation phenotypes, symptoms, plant -morphology plant-anatomy ultrastructure-
   Abstract: In als3, an Al-sensitive Arabidopsis mutant, shoot development and root growth are sensitive to Al. Mutant als3 seedlings grown in an Al-containing medium exhibit severely inhibited leaf expansion and root growth. In the presence of Al, unexpanded leaves accumulate callose, an indicator of Al damage in roots. The possibility that the inhibition of shoot development in als3 is due to the hyperaccumulation of Al in this tissue was examined. However, it was found that the levels of Al that accumulated in shoots of als3 are not different from the wild type. The inhibition of shoot development in als3 is not a consequence of nonspecific damage to roots, because other metals (e.g. LaCl3 or CuSO4) that strongly inhibit root growth did not block shoot development in als3 seedlings. Al did not block leaf development in excised als3 shoots grown in an Al-containing medium, demonstrating that the Al-induced damage in als3 shoots was dependent on the presence of roots. This suggests that Al in hibition of als3 shoot development may be a delocalized response to Al-induced stresses in roots following Al exposure.

3. **The consequence of selection for copper tolerance on the uptake and accumulation of copper in Mimulus guttatus.**
   Tilstone, G. H. and Macnair, M. R.
   Ann bot 80: 6 pp.747-751. (Dec 1997).
   NAL Call #: 450-An7
   Descriptors: mimulus-guttatus copper, metal-tolerance mineral-uptake selective-breeding genotypes, concentration, roots, shoots, symplast, plant, plant-composition major-genes modifiers, california, apoplast-
   Abstract: Previous research has shown that copper tolerance in Mimulus guttatus Fischer ex DC. is controlled by a single major gene and can be enhanced by a number of minor genes (or modifiers). Here we report the uptake of copper by three lin es which all possessed the major tolerance gene but differed in the modifier genes: the major gene only (IT), the major gene plus increased (HT6) and decreased (LT6) modifiers. HT6 showed the highest copper tolerance and IT the lowest. Copper uptake was i nvestigated at five copper concentrations and over 30 d to analyse the concentration of copper

accumulated in roots and shoots and the partitioning of apoplastic and symplastic root copper. Significant differences were found for root copper concentration with the IT line accumulating the highest levels. Fifty-two per cent of the root copper in the IT line is symplastic and this increases to 60% in LT6 and 64% in HT6. Significant differences were recorded for shoot copper concentration with HT6 accumulat ing the highest and IT the lowest. At the highest external copper concentration the HT line accumulated nearly 800 micrograms g-1 in its shoot, approaching levels reported for copper hyperaccumulation.

4. **Deterrence of herbivory by zinc hyperaccumulation in Thlaspi caerulescens (Brassicaceae).**
   Pollard, A. J. and Baker, A. J. M.
   New phytol 135: 4 pp.655-658. (Apr 1997).
   NAL Call #: 450-N42
   Descriptors: thlaspi, zinc, mineral-uptake mineral-excess herbivores, schistocerca-gregaria deroceras-panormitanum pieris-brassicae foliage, defense-mechanisms nutrient-solutions feeding-preferences leaves-
5. **Direct measurement of 59Fe-labeled Fe2+ influx in roots of pea using a chelator buffer system to control free Fe2+ in solution.**
   Fox, T. C., Shaff, J. E., Grusak, M. A., Norvell, W. A., Chen, Y., Chaney, R. L., and Kochian, L. V.
   Plant physiol 111: 1 pp.93-100. (May 1996).
   NAL Call #: 450-P692
   Descriptors: pisum-sativum roots, iron, nutrient-uptake measurement, chelating-agents buffers, nutrient-transport translocation, mutants, genetic-variation ferrozine-buffered-uptake-solutions
   Abstract: Fe2+ transport in plants has been difficult to quantify because of the inability to control Fe2+ activity in aerated solutions and nonspecific binding of Fe to cell walls. In this study, a Fe(II)-3-(2-pyridyl)-5,6-diphenyl-1,2,4 tria zine-4'4"-disulfonic acid buffer system was used to control free Fe2+ in uptake solutions. Additionally, desorption methodologies were developed to adequately remove nonspecifically bound Fe from the root apoplasm. This enabled us to quantify unidirectio nal Fe2+ influx via radiotracer (59Fe) uptake in roots of pea (Pisum sativum cv Sparkle) and its single gene mutant brz, an Fe hyperaccumulator. Fe influx into roots was dramatically inhibited by low temperature, indicating that the measured Fe accumulati on in these roots was due to true influx across the plasma membrane rather than nonspecific binding to the root apoplasm. Both Fe2+ influx and Fe translocation to the shoots were stimulated by Fe deficiency in Sparkle. Additionally, brz, a mutant that con stitutively exhibits high ferric reductase activity, exhibited higher Fe2+ influx rates than +Fe-grown Sparkle. These results suggest that either Fe deficiency triggers the induction of the Fe2+ transporter or that the enhanced ferric reductase activity s omehow stimulates the activity of the existing Fe2+ transport protein.
6. **The ecological significance of nickel hyperaccumulation: a plant chemical defense.**
   Martens, S. N. and Boyd, R. S.
   Oecologia 98: 3/4 pp.379-384. (1994).
   NAL Call #: QL750.O3
   Descriptors: cruciferae, nickel, uptake, defense-mechanisms insect-pests herbivores,

pieris-rapae pieridae, acrididae, serpentine-soils serpentine-communities pest-resistance streptanthus-polygaloides euchloe-hyantis

7. **Effects of heavy metals on the growth and mineral composition of a nickel hyperaccumulator.**
   Varennes, A. de, Torres, M. O., Coutinho, J. F., Rocha, M. M. G. S., and Neto, M. M. P. M.
   J plant nutr 19: 5 pp.669-676. (1996).
   NAL Call #: QK867.J67
   Descriptors: alyssum, nickel, cadmium, chromium, copper, lead, zinc, metal-ions ion-uptake plant-composition phytotoxicity, dry-matter-accumulation bioremediation, polluted-soils alyssum-pintodasilvae
   Abstract: Alyssum pintodasilvae Dudley is a nickel (Ni) hyperaccumulator endemic to serpentine soils of northeast Portugal. In one experiment, the effects of cadmium (Cd), chromium (Cr), copper (Cu), Ni, lead (Pb), and zinc (Zn) on the growth and mineral composition of this species were evaluated. The growth of A. pintodasilvae, measured by dry mater accumulation, was not influenced by the presence of Cr, Cu, Pb, Ni, or Zn in the soil, but Cd applications led to significant decreases in dry ma tter yield. The addition of heavy metals to the soil resulted in increased uptake and translocation by A. pintodasilvae but only Ni was accumulated to high levels. In a second experiment, two cuts of A. pintodasilvae, grown on a Ni-enriched soil, were com pared. Nickel concentrations were higher in the second cut, suggesting the possibility of continued growth and harvest of this plant to detoxify Ni-contaminated soils.
8. **The hepatoprotective cytochrome P-450 enzyme inhibitor isolated from the Nigerian medicinal plant Cochlospermum planchonii is a zinc salt.**
   Aliyu, R., Okoye, Z. S. C., and Shier, W. T.
   J ethnopharmacol 48: 2 pp.89-97. (Oct 1995).
   NAL Call #: RS160.J6
   Descriptors: medicinal-plants rhizomes, plant-extracts cytochrome-p-450 enzyme-inhibitors zinc, formates-salts isolation, liver, nigeria, hepatoprotective-agents
   Abstract: Aqueous extracts of Cochlospermum planchonii Hook.f. (Cochlospermaceae) rhizomes are used by native medical practitioners in northern Nigeria to treat jaundice. An extract prepared by a laboratory adaptation of their method was hepat oprotective in carbon tetrachloride-treated rats (CCl4), and it inhibited cytochrome P-450 enzymes, which constitutes a plausible hepatoprotective mechanism. A crystalline inhibitor (0.3% of dry weight of rhizomes) was isolated using inhibition of two rat cytochrome P-450 enzymes, aminopyrine-N-demethylase and aniline hydroxylase, as bioassays to guide fractionation by solvent partitioning, polyamide column chromatography, preparative thin layer chromatography and fractional crystallization. The inhibitor was identified as zinc formate by inductively coupled plasma atomic emission spectroscopy, nuclear magnetic resonance spectroscopy and comparison with synthetic material by powder X-ray diffraction crystallography. Synthetic and plant-derived zinc format e were equally effective as inhibitors of cytochrome P-450 enzymes and as hepatoprotective agents in carbon tetrachloride-treated rats. Cochlospermum planchonii rhizomes contain unusually high levels of manganese and zinc, although much higher levels have been observed in plants considered to be hyperaccumulators of these metals.

9. **Hyper-accumulation of astaxanthin in a green alga Haematococcus pluvialis at elevated temperatures.**
   Tjahjono, A. E., Hayama, Y., Kakizono, T., Terada, Y., Nishio, N., and Nagai, S.
   Biotechnol lett 16: 2 pp.133-138. (Feb 1994).
   NAL Call #: QR53.B56
   Descriptors: chlorophyta, astaxanthin, biosynthesis, algae-culture carotenogenesis-
   Abstract: When a green alga Haematococcus pluvialis was cultivated at 30 degrees C, astaxanthin production was 3-fold more increased than at 20 degrees C. With acetate supplementation to 30 degrees C culture, the alga synthesized over 2-fold m ore carotenoid than without addition. Tiron, a radical scavenger, however, severely blocked the stimulated carotenogenesis, suggesting that endogenously generated active oxygen was responsible for the highly stimulated carotenogenesis. From these results, possible roles of the elevated cultivation temperatures for hyperaccumulation of astaxanthin were discussed.
10. **Hyperaccumulation, complexation and distribution of nickel in Sebertia acuminata.**
    Sagner, S., Kneer, R., Wanner, G., Cosson, J. P., Deus Neumann, B., and Zenk, M. H.
    Phytochemistry Oxford 47: 3 pp.339-347. (Feb 1998).
    NAL Call #: 450-P5622
    Descriptors: sapotaceae, nickel, detoxification, plant-composition plant-tissues citric-acid nuclear-magnetic-resonance ion-balance nitrate, sap, insect-repellents drosophila-melanogaster mineral-uptake latex, phloem, xylem, iron, zinc, copper, la tex-tubes plant-glands lactifers-
    Abstract: The nickel content in different parts of the hyperaccumulating tree Sebertia acuminata was analysed by atomic absorption spectroscopy. Nickel was found to be mainly located in laticifers. The total nickel content of a single mature t ree was estimated to be 37 kg. By gel filtration and NMR spectroscopy, citric acid was unequivocally identified as counter ion for about 40% of this metal present. Nitrate was assumed to be a further partner for a complete ionic balance. Phytochelatins we re not found to be involved in nickel detoxification in Sebertia. The localization of nickel complexes inside the laticifers was demonstrated by light microscopy as well as by scanning electron microscopy in combination with an EDX system for the analysis of elements. A repellent effect of the plant sap was observed on the fruit fly Drosophila melanogaster indicating that in hyperaccumulating plants nickel functions as an agent to prevent predation.
11. **Hyperaccumulation of nickel by Arenaria rubella (Caryophyllaceae) from Washington State.**
    Kruckeberg, A. R., Peterson, P. J., and Samiullah, Y.
    Madrono West Am J Bot 40: 1 pp.25-30. (Jan/Mar 1993).
    NAL Call #: 450-M26
    Descriptors: arenaria-caryophyllaceae species, plant-composition nickel, concentration, uptake, washington-
12. **Lead phytoextraction: species variation in lead uptake and translocation**.
    Huang,-J.W.; Cunningham,-S.D.
    New-phytol. Cambridge : Cambridge University Press. Sept 1996. v. 134 (1) p. 75-84.
    NAL Call #: 450-N42 *Descriptors:* metal-ions. polluted-soils. bioremediation-. zea-mays. ambrosia-artemisiifolia. triticum-aestivum. thlaspi-. lead-. translocation-. nutrient-

solutions. soil-pollution. roots-. plant-composition. brassica-juncea. hydroponics-. shoots-. chelates-. soil-amendments. cultivars-. growth-. ion-uptake.

13. **Negative control of heavy metal uptake by the Saccharomyces cerevisiae BSD2 gene.**
Liu, X. F., Supek, F., Nelson, N., and Culotta, V. C.
J biol chem 272: 18 pp.11763-11769. (May 2, 1997).
NAL Call #: 381-J824
Descriptors: saccharomyces-cerevisiae polypeptides, structural-genes copper, cadmium, heavy-metals metal-ions ion-uptake ion-transport endoplasmic-reticulum mutants-
Abstract: We have previously shown that mutations in the Saccharomyces cerevisiae BSD2 gene suppress oxidative damage in cells lacking superoxide dismutase and also lead to hyperaccumulation of copper ions. We demonstrate here that bsd2 mutant cells additionally accumulate high levels of cadmium and cobalt. By biochemical fractionation and immunofluorescence microscopy, BSD2 exhibited localization to the endoplasmic reticulum, suggesting that BSD2 acts at a distance to inhibit metal uptake fro m the growth medium. This BSD2 control of ion transport occurs independently of the CTR1 and FET4 metal transport systems. Genetic suppressor analysis revealed that hyperaccumulation of copper and cadmium in bsd2 mutants is mediated through SMF1, previous ly shown to encode a plasma membrane transporter for manganese. A nonsense mutation removing the carboxyl-terminal hydrophobic domain of SMF1 was found to mimic a smf1 gene deletion by eliminating the copper and cadmium toxicity of bsd2 mutants and also b y precluding the bsd2 suppression of superoxide dismutase deficiency. However, inactivation of SMF1 did not eliminate the elevated cobalt levels in bsd2 mutants. Instead, this cobalt accumulation was found to be specifically mediated through the SMF1 homo logue, SMF2. Hence, BSD2 prevents metal hyperaccumulation by exerting negative control over the SMF1 and SMF2 metal transport systems.

14. **Nickel accumulation by serpentine species of Streptanthus (Brassicaceae): field and greenhouse studies.**
Kruckeberg, A. R. and Reeves, R. D.
Madrono 42: 4 pp.458-469. (Oct/Dec 1995).
NAL Call #: 450-M26
Descriptors: cruciferae, nickel, uptake, concentration, plant-tissues serpentine-soils hyperaccumulation-

15. **Nickel hyperaccumulation defends Streptanthus polygaloides (Brassicaceae) against pathogens.**
Boyd, R. S., Shaw, J. J., and Martens, S. N.
Am j bot 81: 3 pp.294-300. (Mar 1994).
NAL Call #: 450-Am36
Descriptors: cruciferae, nickel, plant-composition disease-resistance erysiphe-polygoni xanthomonas-campestris-pv -campestris alternaria-brassicicola pathogenicity, infectivity-
Abstract: The Ni-hyperaccumulating annual, Streptanthus polygaloides, may contain as much as 16,400 ppm Ni (dry weight) in its tissues. The function of Ni hyperaccumulation is not known. We tested the hypothesis that one function of Ni hyperac cumulation in S. polygaloides is defense against pathogens. Growth of pathogenic organisms on Ni-hyperaccumulating plants (averaging 5,630 ppm Ni, produced by growing plants on high-Ni soil) was compared to pathogen growth on nonhyperaccumulating plants (averaging 124 ppm Ni, produced by growing plants on low-Ni soil). Plants containing

hyperaccumulated Ni were more slowly infected by a powdery mildew (Erysiphe polygoni) than low-Ni plants. Two strains of the bacterial pathogen Xanthomonas campestris pv. campestris (one a genetically engineered bioluminescent strain) grew in low-Ni plants but not high-Ni plants. Growth of X. campestris pv. campestris was markedly inhibited by Ni concentrations of 400 ppm in artificial media. Growth of the fungus Alternari a brassicicola, which was necrotrophic on S. polygaloides, also was inhibited on high-Ni leaves relative to low-Ni leaves. These results demonstrated negative effects of hyperaccumulated Ni on a taxonomically wide range of pathogenic organisms, supporting the hypothesis that Ni hyperaccumulation defends S. polygaloides against plant pathogens.

16. **Nickel-resistant bacteria from anthropogenically nickel-polluted and naturally nickel-percolated ecosystems.**
Stoppel, R. D. and Schlegel, H. G.
Appl environ microbiol 61: 6 pp.2276-2285. (June 1995).
NAL Call #: 448.3-Ap5
Descriptors: soil-bacteria bacteria, isolation, waste-water-treatment industrial-wastes nickel, metal-tolerance dna-probes dna-hybridization identification, soil-chemistry plasmids, nickel, chlorides, new-caledonia zaire, europe, usa, nickel-conta ining-soils nickel-chloride
Abstract: DNA fragments harboring the nickel resistance determinants from bacteria isolated from anthropogenically polluted ecosystems in Europe and Zaire were compared with those harboring the nickel resistance determinants from bacteria isol ated from naturally nickel-percolated soils from New Caledonia by DNA-DNA hybridization. The biotinylated DNA probes were derived from the previously described Alcaligenes eutrophus CH34, Alcaligenes xylosoxidans 31A, Alcaligenes denitrificans 4a-2, and k lebsiella oxytoca CCUG 15788 and four new nickel resistance-determining fragments cloned from strains isolated from soils under nickel-hyperaccumulating trees. Nine probes were hybridized with endonuclease-cleaved plasmid and total DNA samples from 56 nic kel-resistant strains. Some of the New Caledonian strains were tentatively identified as Acinetobacter, Pseudomonas mendocina, Comamonas, Hafnia alvei, Burkholderia, Arthrobacter aurescens, and Arthrobacter ramosus strains. The DNA of most strains showed homologies to one or several of the following nickel resistance determinants: the cnr and ncc operons of the strains A. eutrophus CH34 and A. xylosoxidans 31A, respectively, the nre operon of strain 31A, and the nickel resistance determinants of K. oxytoc a. On the basis of their hybridization reactions the nickel resistance determinants of the strains could be assigned to four groups: (i) cnr/ncc type, (ii) cnr/ncc/nre type, (iii) K. oxytoca type, and (iv) others. The majority of the strains were assigned to the known groups. Among the strains from Belgium and Zaire, exclusively the cnr/ncc and the cnr/ncc/nre types were found. Among the New Caledonian strains all four types were represented. Homologies to. the nre operon were found only in combination w ith the cnr/ncc operon. The homologies to the cnr/ncc operon were the most abundant and were detected alone or together with homologies to the nre operon. Only the DNA of the strains isolated from soil in Scotland and the United States and that of five of the New Caledonian strains did not show any detectable homologies to any of our probes. The nickel resistance fragment isolated from Burkholderia strain 32W-2 was studied in some detail. This 15-kb BamHI fragment

conferred resistance to 1 to 5 mM NiCl2 t o Escherichia coli and resistance to up to 25 mM NiCl2 to A. eutrophus. It showed strong homologies to both the cnr/ncc operon and the nre operon and conferred strictly regulated (inducible) nickel resistance to A. eutrophus.

17. **Physiological characterization of root Zn2+ absorption and translocation to shoots in Zn hyperaccumulator and nonaccumulator species of Thlaspi.**
Lasat, M. M., Baker, A. J. M., and Kochian, L. V.
Plant physiol 112: 4 pp.1715-1722. (Dec 1996).
NAL Call #: 450-P692
Descriptors: thlaspi, thlaspi-arvense zinc, metal-tolerance ion-uptake roots, absorption, plasma-membranes translocation, symplast, saturation, shoots, transport-processes kinetics, nutrient-availability thlaspi-caerulescens
Abstract: Radiotracer techniques were employed to characterize 65Zn2+ influx into the root symplasm and translocation to the shoot in Thlaspi caerulescens, a Zn hyperaccumulator, and Thlaspi arvense, a nonaccumulator. A protocol was developed that allowed us to quantify unidirectional 65Zn2+ influx across the root-cell plasma membrane (20 min of radioactive uptake followed by 15 min of desorption in a 100 micromolar ZnCl2 + 5 mM CaCl2 solution). Concentration-dependent Zn2+ influx in both Thla spi species yielded nonsaturating kinetic curves that could be resolved into linear and saturable components. The linear kinetic component was shown to be cell-wall-bound Zn2+ remaining in the root after desorption, and the saturable component was due to Zn2+ influx across the root-cell plasma membrane. This saturable component followed Michaelis-Menten kinetics, with similar apparent Michaelis constant values for T. caerulescens and T. arvense (8 and 6 micromolar, respectively). However, the maximum init ial velocity for Zn2+ influx in T. caerulescens root cells was 4.5-fold higher than for T. arvense, indicating that enhanced absorption into the root is one of the mechanisms involved in Zn hyperaccumulation. After 96 h 10-fold more 65Zn was translocated to the shoot of T. caerulescens compared with T. arvense. This indicates that transport sites other than entry into the root symplasm are also stimulated in T. caerulescens. We suggest that although increased root Zn2+ influx is a significant component, t ransport across the plasma membrane and tonoplast of leaf cells must also be critical sites for Zn hyperaccumulation in T. caerulescens.

18. **Quantitative genetics of zinc hyperaccumulation in Thlaspi caerulescens.**
Pollard, A. J. and Baker, A. J. M.
New phytol 132: 1 pp.113-118. (Jan 1996).
NAL Call #: 450-N42
Descriptors: thlaspi, zinc, plant-composition shoots, leaves, concentration, size, plant-communities individual-characteristics heritability, genetic-variation quantitative-genetics metal-tolerance polluted-soils bioremediation, england, sib-famil ies

19. **Responses of six crop species to solution zinc2+ activities buffered with HEDTA.**
Parker, D. R.
Soil-Sci-Soc-Am-j. [Madison, Wis.] Soil Science Society of America. Jan/Feb 1997. v. 61 (1) p. 167-176.
NAL Call #: 56.9-So3
Descriptors: zea-mays triticum-aestivum elymus-elongatus medicago-sativa lycopersicon-esculentum glycine-max seedlings, zinc, mineral-deficiencies ion-activity

plant-composition dry-matter-accumulation phosphorus, phytotoxicity, nutrient-nutrient-interactions species-differences

Abstract: Zinc contamination has long hampered the use of conventional nutrient solutions for attaining reproducible and severe Zn deficiencies. Chelator-buffered solutions show promise for precisely imposing micronutrient deficiencies, but fu rther studies are needed to fully evaluate the method and to develop methods to avoid Zn-deficiency-induced P toxicity. In a greenhouse study, seedlings of maize (Zea mays L. 'Golden Cross Bantam'), wheat (Triticum aestivum L. 'Yecora Rojo'), tall wheatgr ass (Elytrigia pontica [Podp.] Holub 'Orbit'), alfalfa (Medicago sativa L. 'Germain's WL-320'), soybean (Glycine max [L.] Merr. 'Vinton 81'), and tomato (Lycopersicon esculentum L. 'Jackpot') were grown for 16 to 29 d in solutions containing 0.4 to 12 mic romolar total Zn. Computed Zn2+ activities were buffered at 4 to 123 pmol L-1 by a 50 micromolar excess of HEDTA, and solution P was maintained at 10 +/, 3 micromolar. Zinc deficiencies ranged from mild to severe, dry matter yield minima ranged from 32 to 89% of controls, and critical Zn2+ activities for the onset of deficiency ranged from approximately 10 to 65 pmol L-1. The relative sensitivity of the six species to low Zn was maize > tomato > wheat > alfalfa approximately equal to tall wheatgr ass > soybean. Shoot Zn concentrations were consistent with the widely reported critical range of 15 to 20 mg kg-1. Zinc deficiency in the three grass species led to hyperaccumulation of P to phytotoxic levels, and leaf symptoms largely reflected this toxicity. Leaf P concentrations in the three dicots tended to be lower, but may have been within the phytotoxic range. Thus, even with P concentrations that approach soil solution values, the P toxicity that. often accompanies Zn deficiency in solution-c ulture experiments was not eliminated. The effects of Zn deficiency on shoot concentrations of nutrients other than P were variable, although divalent cations tended to be elevated in Zn-deficient shoots.

20. **Scientist using plants to clean up metals in contaminated soil.**

Bernstein, E.

N-Y-Times. [New York, N.Y. : H.J. Raymond & Co.]. Sept 8, 1992. p. B8. pp.

NAL Call #: 286.8-N488

Descriptors: apocynum, ambrosia, genetic-engineering waste-treatment heavy-metals hyperaccumulators, bioremediation-

21. **Shoot-to-root signal transmission regulates root Fe(III) reductase activity in the dgl mutant of pea.**

Grusak, M. A. and Pezeshgi, S.

Plant physiol 110: 1 pp.329-334. (Jan 1996).

NAL Call #: 450-P692

Descriptors: pisum-sativum shoots, roots, iron, reduction, proton-pump ion-transport signals, ferroxidase, enzyme-activity developmental-stages mutants, genetic-variation cultivars, genotypes-

Abstract: To understand the root, shoot, and Fe-nutritional factors that regulate root Fe-acquisition processes in dicotyledonous plants, Fe(III) reduction and net proton efflux were quantified in root systems of an Fe-hyperaccumulating mutant (dgl) and a parental (cv Dippes Gelbe Viktoria [DGV]) genotype of pea (Pisum sativum). Plants were grown with (+Fe treated) or without (-Fe treated) added Fe(III)-N,N'-ethylenebis[2-(2-hydroxyphenyl) -glycine] (2 micromolar); root Fe(III) reduction was m easured in solutions containing growth nutrients, 0.1 mM Fe(III)-ethylenediaminetetraacetic acid,

and 0.1 mM Na2-bathophenanthrolinedisulfonic acid. Daily measurements of Fe(III) reduction (d 10-20) revealed initially low rates in +Fe-treated and -Fe-trea ted dgl, followed by a nearly 5-fold stimulation in rates by d 15 for both growth types. In DGV, root Fe(III) reductase activity increased only minimally by d 20 in +Fe-treated plants and about 3-fold in -Fe-treated plants, beginning on d 15. Net proton e fflux was enhanced in roots of -Fe-treated DGV and both dgl growth types, relative to +Fe-treated DGV. In dgl, the enhanced proton efflux occurred prior to the increase in root Fe(III) reductase activity. Reductase studies using plants with reciprocal sho ot:root grafts demonstrated that shoot expression of the dgl gene leads to the generation of a transmissible signal that enhances Fe(III) reductase activity in roots. The dgl gene product may alter or interfere with a normal component of a signal transduc tion mechanism regulating Fe homeostasis in plants.

22. **Uptake and transport of zinc in the hyperaccumulator Thlaspi caerulescens and the non-hyperaccumulator Thlaspi ochroleucum.**
    Shen, Z. G., Zhao, F. J., and McGrath, S. P.
    Plant cell environ 20: 7 pp.898-906. (July 1997).
    NAL Call #: QK710.P55
    Descriptors: thlaspi, zinc, metal-ions ion-uptake species-differences translocation, metal-tolerance plant-composition roots, shoots, malic-acid phytotoxicity, citric-acid chlorosis-
    Abstract: Growth and zinc uptake of the hyperaccumulator species Thlaspi caerulescens J. & C. Presl and the non-hyperaccumulator species Thlaspi ochroleucum Boiss. & Heldr. were compared in solution culture experiments. T. caerulescens was was able to tolerate 500 mmol m-3 (32.5 g m-3) Zn in solution without growth reduction, and up to 1000 mmol m-3 (65 g m-3) Zn without showing visible toxic symptoms but with a 25% decrease in dry matter (DM) yield. Up to 28 g kg-1 of Zn in shoot DM w as obtained in healthy plants of T. caerulescens. In contrast, T. ochroleucum suffered severe phytotoxicity at 500 mmol m-3 Zn. Marked differences were shown in Zn uptake, distribution and re-distribution between the two species. T. caerulescens had much higher concentrations of Zn in the shoots, whereas T. ochroleucum accumulated higher concentrations of Zn in the roots. When an external supply of 500 mmol m-3 Zn was withheld, 89% of the Zn accumulated previously in the roots of T. caerulescens was trans ported to the shoots over a 33 d period, whereas in T. ochroleucum only 32% was transported. T. caerulescens was shown to have a greater internal requirement for Zn than other plants. Increasing the supply of Zn from 1 to 10 mmol m-3 gave a 19% increase i n the total DM of this species. Even the shoots from the 1 mmol m-3 Zn treatment which showed Zn deficiency contained 10 times greater Zn concentrations than the widely reported critical value for Zn deficiency to occur in many other plant species. The re sults obtained suggest that strongly expressed constitutive sequestration mechanisms exist in the hyperaccumulator T. caerulescens, which detoxify the large amount of Zn present in shoot tissues and decrease its physiological. availability in the cytosol . Both T. caerulescens and T. ochroleucum had constitutively high concentrations of malate in shoots, which were little affected by different Zn treatments. Although malate may play a role in Zn chelation because of the high concentrations present, it can not explain the species specificity of Zn tolerance and hyperaccumulation.
23. **Use of elemental sulphur to enhance a cadmium solubilization and its vegetative removal from contaminated soil.**

Tichy, R., Fajtl, J., Kuzel, S., and Kolaf, L.
Nutr cycl agroecosyst 46: 3 pp.249-255. (1996/1997).
NAL Call #: S631.F422
Descriptors: polluted-soils heavy-metals contamination, rehabilitation, acidification, sulfur, cadmium, solubility, bioavailability, sinapis-alba ion-uptake soil-ph biomass, removal, phytoremediation, hyperaccumulating-plants
Abstract: To a soil artificially contaminated with cadmium, orthorhombic sulphur flower and a hydrophillic microbially produced elemental sulphur were added to induce the soil acidification. The soil was incubated in pots under open-sky condit ions. pH, sulphate, and cadmium solubility were recorded in time. Soil acidification with microbially produced sulphur proceeded without any delay and at considerably higher rates, compared to the sulphur flower. Cadmium solubilization was solely controll ed by the soil pH during the experiments. Similar experiments with cultivation of common mustard (Sinapis alba, cultivar JARA) were performed, evaluating both changes of cadmium solubilization and uptake by biomass. Cadmium concentration in shoots increas ed with decreasing pH. However, biomass was negatively affected by the decreasing pH. Combining these two effects, a pH-optimum for maximum cadmium removal from the soil by plants was found at pH = 5-5.5.

24. **Use of wild type and nickel resistant Neurospora crassa for removal of Ni2+ from aqueus medium.**
Shravan Kumar, C., Sivarama Sastry, K., and Maruthi Mohan, P.
Biotechnol Lett 14: 11 pp.1099-1202. (Nov 1992).
NAL Call #: QR53.B56
Descriptors: neurospora-crassa nickel, metal-ions resistance, mycelium, ion-uptake culture-media pollution-
Abstract: A novel nickel resistant, hyperaccumulating N. crassa nir-2 mutant, isolated by us, sequestered 90% of Ni2+ from medium with 120 mg/l Ni2+. The parent wild strain showed comparable efficiency only at much lower concentrations (< 1 0 mg/l). The initial rapid rate and efficiency of Ni2+ removal could be maintained beyond 2 h by fresh addition of mycelial biomass. The results have been discussed from the stand point of the utility of metal resistant fungi in the control of environment al pollution.

25. **Zinc hyperaccumulation in Thlaspi caerulescens. II. Influence on organic acids.**
Tolra, R. P., Poschenrieder, C., and Barcelo, J.
J plant nutr 19: 12 pp.1541-1550. (1996).
NAL Call #: QK867.J67
Descriptors: thlaspi, zinc, mineral-uptake nutrient-uptake nutrient-availability malic-acid citric-acid succinic-acid oxalic-acid biosynthesis, plant-composition shoots, roots, metal-tolerance
Abstract: The influence of different zinc (Zn) concentrations (1.5 to 1500 micromolar) on organic acid levels in roots and shoots of the Zn-hyperaccumulator plant Thlaspi caerulescens was investigated. In shoots, malate was the most abundant o rganic acid (164 to 248 micromol/g f.w.), followed by citrate, succinate, and oxalate. A significant correlation between soluble Zn and both malate and oxalate was observed in shoots, but not in roots. In shoots, a significant correlation between inorgani c cation equivalents and organic acid anion equivalents was found. These observations and the finding, that organic acid concentrations were high even under suboptimal Zn supply (1.5 micromolar)

suggest that in T. caerulescens the high organic acid concen tration in shoots is a constitutive property. The variation of the organic acid concentrations seem to be a consequence of the cation-anion balance rather than a specific Zn tolerance mechanism. The constitutively high organic acid concentration may be re sponsible for the high Zn and iron (Fe) tissue concentrations required for optimum growth in T. caerulescens.

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