Phytoremediation of Arsenic

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Introduction

Arsenic is listed as the #1 hazardous substance according to the U.S. Agency for Toxic Substances and Disease Registry

Picture of Arsenic mineral (source: www.wikipedia.com, 2006)

Arsenic Background

Sources of Arsenic contamination:

- mine waste (primarily sulfide, iron and tin)
- tanneries
- metal smelters
- geothermal activity

Arsenic has been used in the following:

- embalming fluids
- paint pigments
- insecticides
- herbicides
- defoliants
- metal alloys

Arsenic Background

- Poisonous effects of arsenic date back to 17th and 18th centuries when it was used to kill several kings, termed "*Poison of kings*"
- Minnesota, Wisconsin, Michigan, North Dakota, and South Dakota have elevated amounts of arsenic in groundwater
- 10 ppb World Health Organization drinking water standard, estimated that over 50 million people worldwide are drinking water with arsenic concentrations in excess of this standard
- Highly toxic due enzyme inhibition, is suspected as causal agent in various forms of cancer and skin lesions
- Arsenic poisoning symptoms include severe stomach pain, nausea, headaches and usually leads to death if untreated

Effects of Arsenic Poisoning

Skin lesions

(source: www.sos-arsenic.net, 2006)

Most Common Soil Arsenic Species

- Arsenic is typically found in the soil in the following forms: Arsentate, Arsenite, dimethyl arsenic acid and monomethyl arsenic acid
- Inorganic forms arsenate, or As (V), and arsenite, or As (III), most common in soil
- *Arsenate prevails under aerobic conditions, is less toxic and less mobile than arsenite, due to stronger soil sorption*

Current Arsenic Remediation Techniques

- *Soil removal* - excavation
- *Capping* - place hard cover over soil
- *Solidification and stabilization* - inject polymers and other stabilizing compounds into ground
- *Acid-washing* -Use aqueous acidic solution to extract water-soluble arsenic

Disadvantages: $400,000 per hectacre, safety, some don’t remove arsenic

What is phytoremediation?

Phytoremediation: The removal of a substance from the air, soil, or water via a microorganism or plant

Several subdivisions of phytoremediation: phytovolatilization, phytoextraction, phytostabilization, and rhizofiltration

Why use phytoremediation?

- Low Cost
- Environmentally-friendly
- Much lower occupational risk
- Arsenic is a chemical analog to phosphorus (i.e. it’s easily taken up by plants)

Why is arsenic toxic for most plants?

- Arsenic toxicity threshold for most plants is (40-200) mg As per kg DW depending on soil conditions
- Arsenate replaces phosphate when taken up, and disrupts production of ATP, which results in cell death
- Arsenic is inhibitory towards cell function because it reacts with sulfydryl enzymes and disrupts their activity

Arsenic Accumulating Plants

- *Pteris* ferns
- *Pityrogramma calomelanos*
- *Lemna gibba* (duckweed)
- *Lepidium sativum* (watercress)
- *Lupinus albus* (white lupin)
- Mustard Plants

Pteris vittata

Factors affecting arsenic accumulation

Arsenic sorption to soil is the primary process that immobilizations this metal, depends on soil pH, amount of organic matter, and texture

- Soil pH: Arsenate absorbed to soil (4-7), Arsenite (7-10)
- Presence of Ferric and Aluminum arsenic compounds (lower water solubility)
- Bioavailability (water solubility)

Definitions of a hyperaccumulator

- Plant accumulates greater than 1000 mg of contaminant per kg DW (Brooks, 1998)
- Bio-concentration Factor (BF) > 1 , ratio of plant to soil arsenic concentration
- Translocation Factor (TF) > 1 , ratio of aboveground biomass to root system arsenic concentration
- Accumulation concentration of a contaminant greater than 100 times than the highest value for a non-hyperaccumulating plant

Why use a hyperaccumulator?

- Decrease amount of time needed to remediate contaminated area
- Reduce volume of contaminated biomass
- Makes phytoremediation a realistic option

Arsenic hyperaccumulators

- *Pteris vittata, biaurita, quadriaurita, and ryukyuensis*
- *Pityrogramma calomelanos*

Mechanisms of arsenic accumulation

- Take up arsenate in the soil and reduce it to arsenite in plant tissue
- Translocate arsenic from roots to shoots via xylem sap
- Chelate free arsenic in cytoplasm and bind it to cell wall via phytochelatins (PCs)
- Vacuolar storage also reduces free arsenic in the cytoplasm
- Mycorrhizal symbiosis, which enhances nutrient absorption area and uptake kinetics (allows for improved phosphate and arsenate uptake)

Pteris vittata study results

Table 1. Arsenic concentrations in P. vittata

Treatments	Soil Arsenic (ppm)	Plant Arsenic (ppm)	
		2 weeks	6 weeks
Control	6	755	438
As-contaminated soil*	400	3,525	6,805
Low As[1]	50	5,131	3,216
Medium As[1]	500	7,849	21,290
High As[1]	1,500	15,861	22,630

*Arsenic-contaminated soil was collected from the site where P. vittata was obtained

1 Artificially contaminated soil was spiked with three levels of water-soluble potassium arsenate

(Source: Ma et. al, 2001)

Pityrogramma calomelanos study results

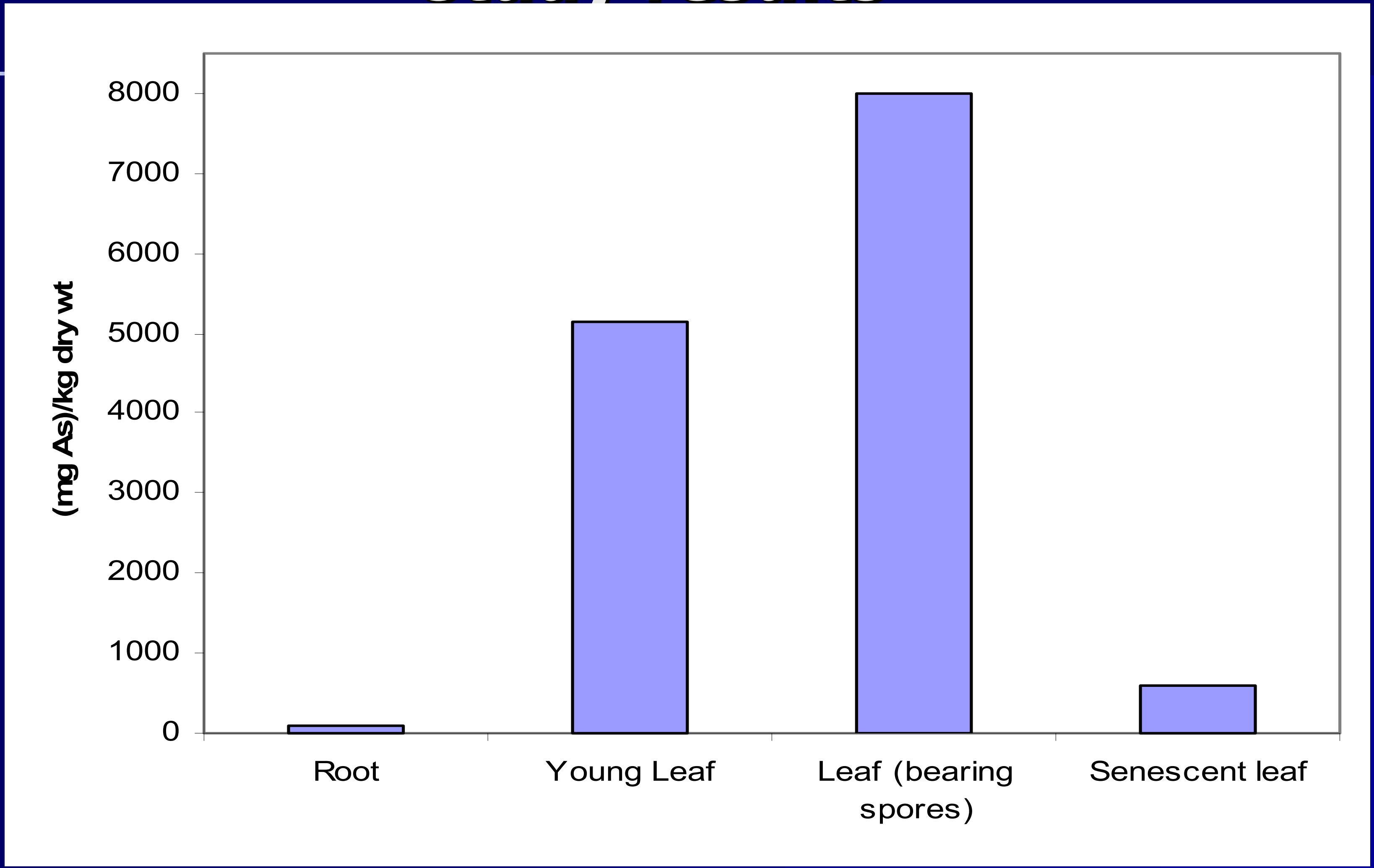

Figure 2. Concentration of arsenic per kg dry weight of *P. calomelanos* for different regions of the plant (Visoottiviseth et al., 2002).

Disposal of Plant Biomass

- Significant amounts of arsenic can leach from biomass (threat to groundwater) (Tu et al., 2003)
- Arsenite in biomass oxidizes back to arsenate
- Marine algae capable of biotransforming arsenic into non-toxic forms (Francesconi et al., 2002)
- Biomass can NOT be burned, results in release of toxic As_2O_3

Conclusions

- Many plants have demonstrated capability for phytoremediation of arsenic contaminated soils (*P. vittata, P. calomelanos*, etc.)
  1) Plants translocate arsenic in roots to shoots
  2) Plants reduce As(V) to As(III) in plant tissue

- Question which remains:

  Why do plants transform arsenate into arsenite (more toxic form) in plant biomass?

- More research still needed to discover arsenic-accumulating plants that grow over a range of climates and soil conditions