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Phytoremediation Applications for Arsenic Contaminated Soil and Water

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Arsenic in Soils

- Arsenic was used extensively as an agricultural pesticide (lead arsenate, arsenic trioxide, calcium arsenate) and as a wood preservative (CCA).
- Soil arsenic is increasingly receiving more attention due to housing developments on former agricultural lands.
- Traditionally remediated through excavation and disposal.
  - Effective for small areas, cost prohibitive for large areas
- Arsenic exists in oxidized soils primarily as an anion (arsenate).
  - Low solubility
  - Primarily surface soil (0-15 cm) contamination.
  - Relatively low regulatory limits ranging from less than 1 mg/kg to approximately 20 mg/kg

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Arsenic in Drinking Water and Groundwater

- Groundwater and drinking water contamination is largely due to natural sources.
- Recent decreases in the arsenic limits for drinking water to 10 µg/L has caused demand for alternative treatments for small drinking water systems.
- Widespread arsenic contamination of water supplies in other countries (i.e., Bangledesh) has increased attention given to arsenic.

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edenfern **Discovery and Development**

- **Ferns in *Pteris* genus reported as hyperaccumlators demonstrating shoot arsenic concentrations greater than 20,000 mg/kg (Ma et al., 2001).**
- **Effectively accumulates arsenic at low and high soil concentrations.**
- **University of Florida filed U.S. and International patents, exclusively licensed to Edenspace for phytoremediation.**
- **Field demonstrations conducted at two sites (New Jersey and North Carolina.**

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Arsenic Uptake by *P. vittata* from Contaminated Soil

Soil	2 Weeks	6 Weeks
Control (6 mg/kg)	755	438
CCA (400 mg/kg)	3,525	6,805
Spiked 50 mg/kg	5,131	3,215
Spiked 500 mg/kg	7,849	21,290
Spiked 1500 mg/kg	15,861	22,630

(Ma et al., 2001)

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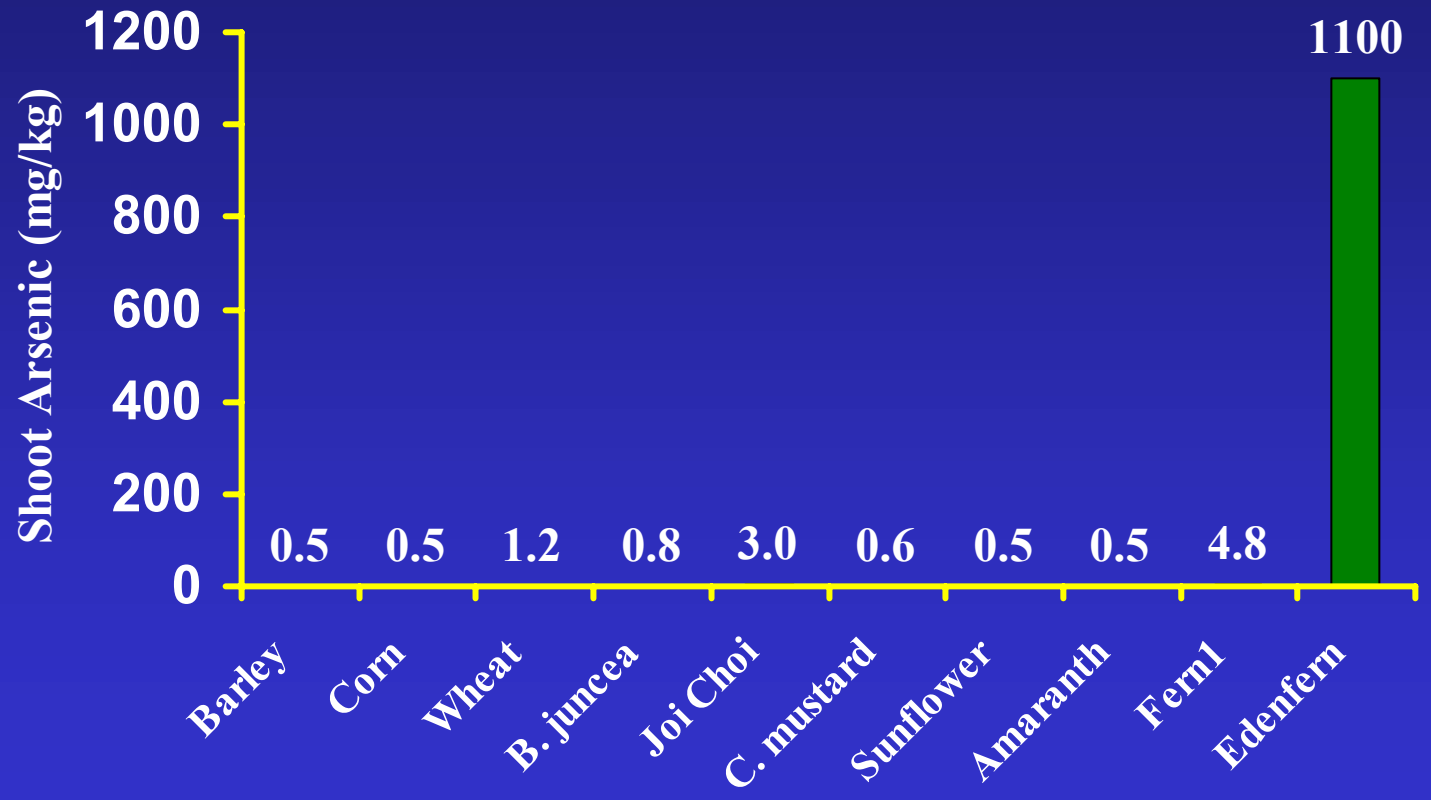
Arsenic Accumulation in Different Crop Plants



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Phytofiltration Studies

- NIH funded research to investigate potential treatment methods for arsenic contaminated drinking water.
- Evaluate arsenic uptake rates and processes at low (< 200 µg/L) concentrations.

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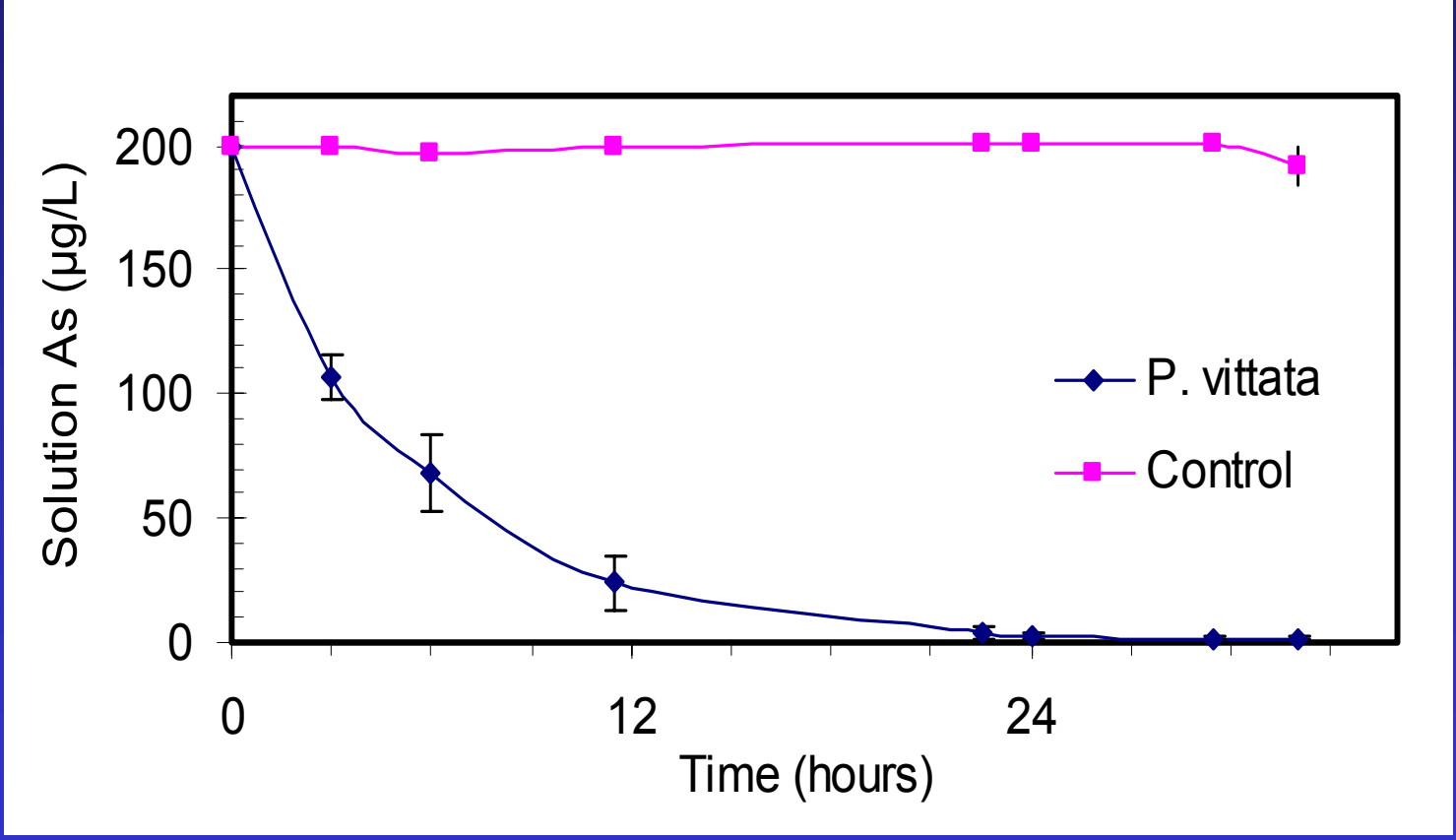
Arsenic Removal from Water by *P. vittata*



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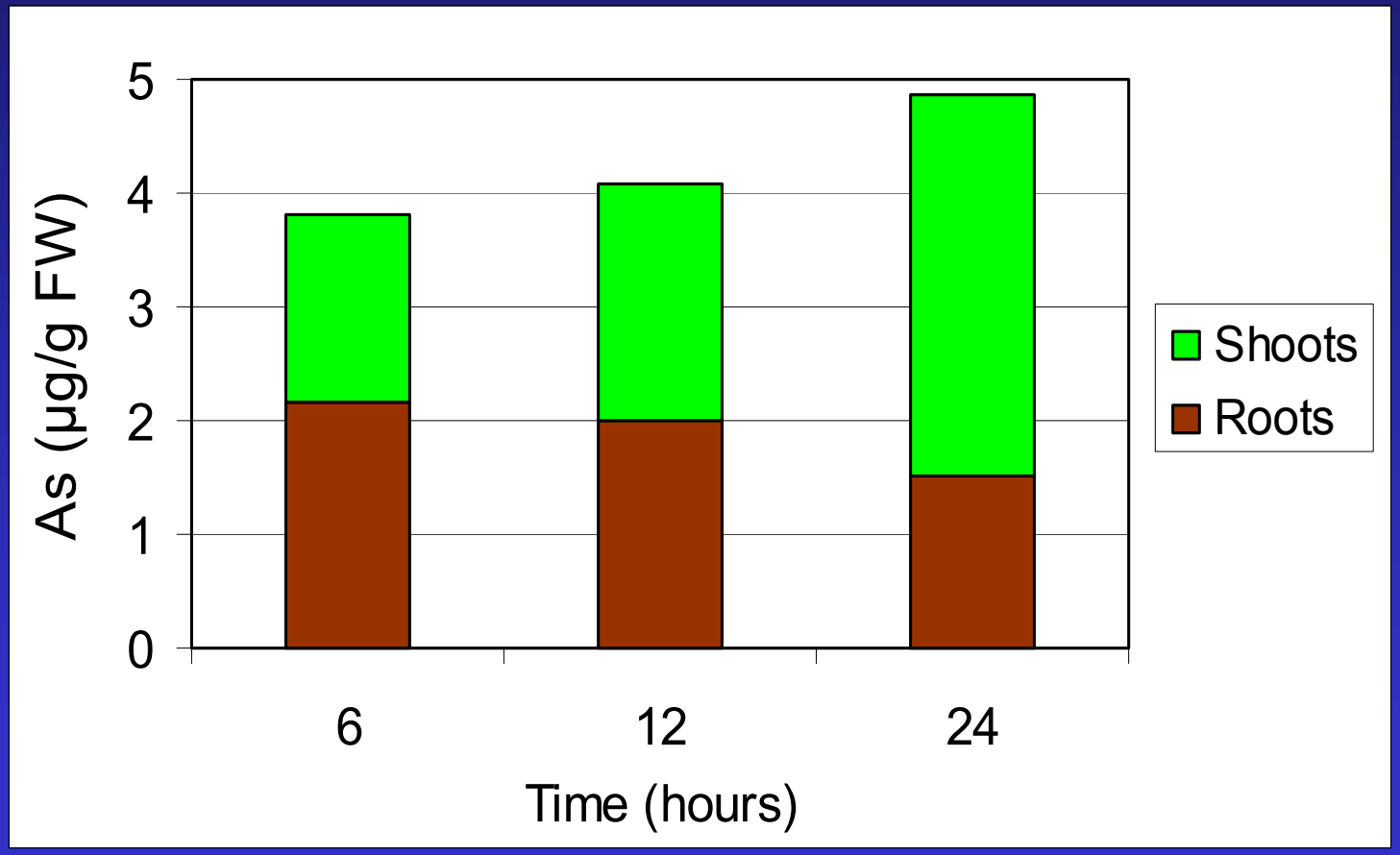
Root-Shoot Distribution (*P. mayii*)



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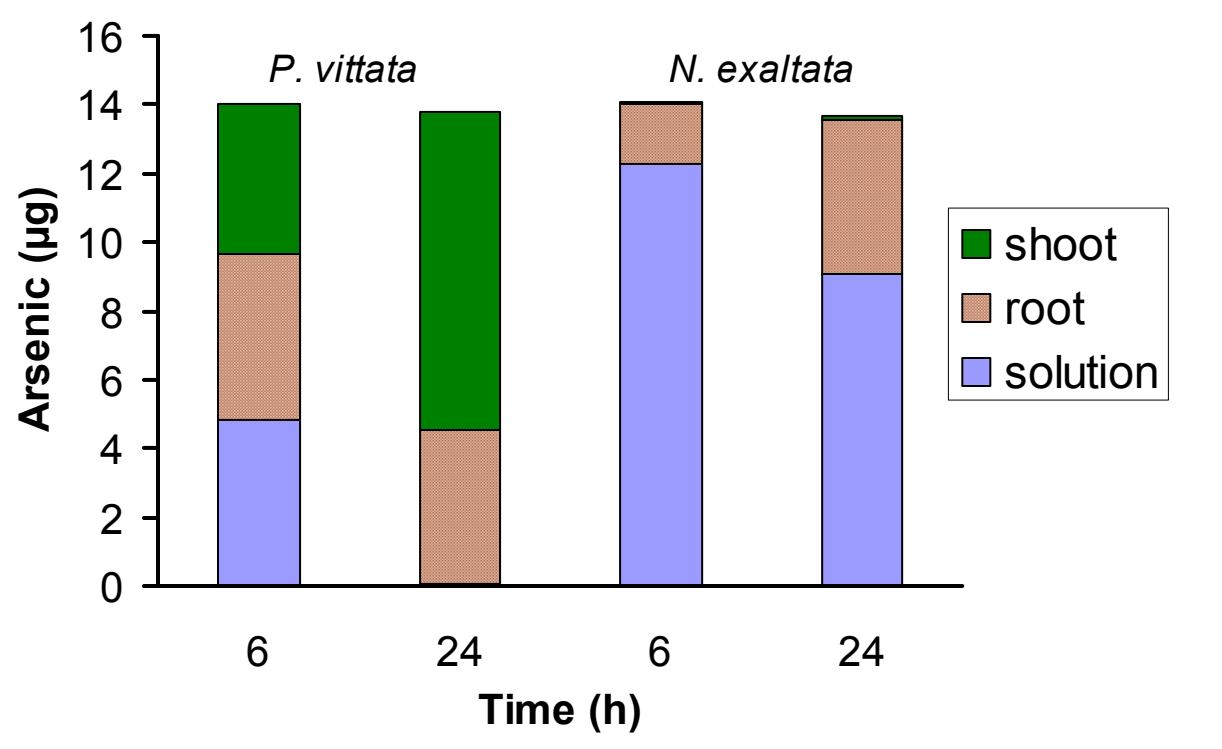
Arsenic Distribution in *P. vittata* and *N. exaltata*



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Soil Phytoextraction

- Laboratory Studies
  - Treatability studies (commercial sites)
  - USDA and EPA funded (SBIR) studies to investigate arsenic removal in soils contaminated from CCA and pesticide sources.
- Target soil concentrations less than 100 mg/kg
- Field applications and demonstrations
- Residential applications

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Phytometric Parameters

Soil	pH	EC	Water-Soluble [As]	Total [As]
		dS/m	mg/kg	mg/kg
CCA 1	6.9	0.12	<0.6	5
CCA 2	6.5	0.26	1.2	500
CCA 3	6.4	0.49	1.7	2500
NJ 1	5.3	0.22	0.6	46
NJ 2	5.3	0.25	0.9	40

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Arsenic Bioavailability

Fraction	CCA 1	CCA 2	NJ 1	NJ 2
	←----------% of Total As----------→			
Labile	21	21	16	19
Weakly Sorbed	0	7	38	40
Occluded	35	15	40	36
Organic	20	11	6	5
Residual	24	46	0	0

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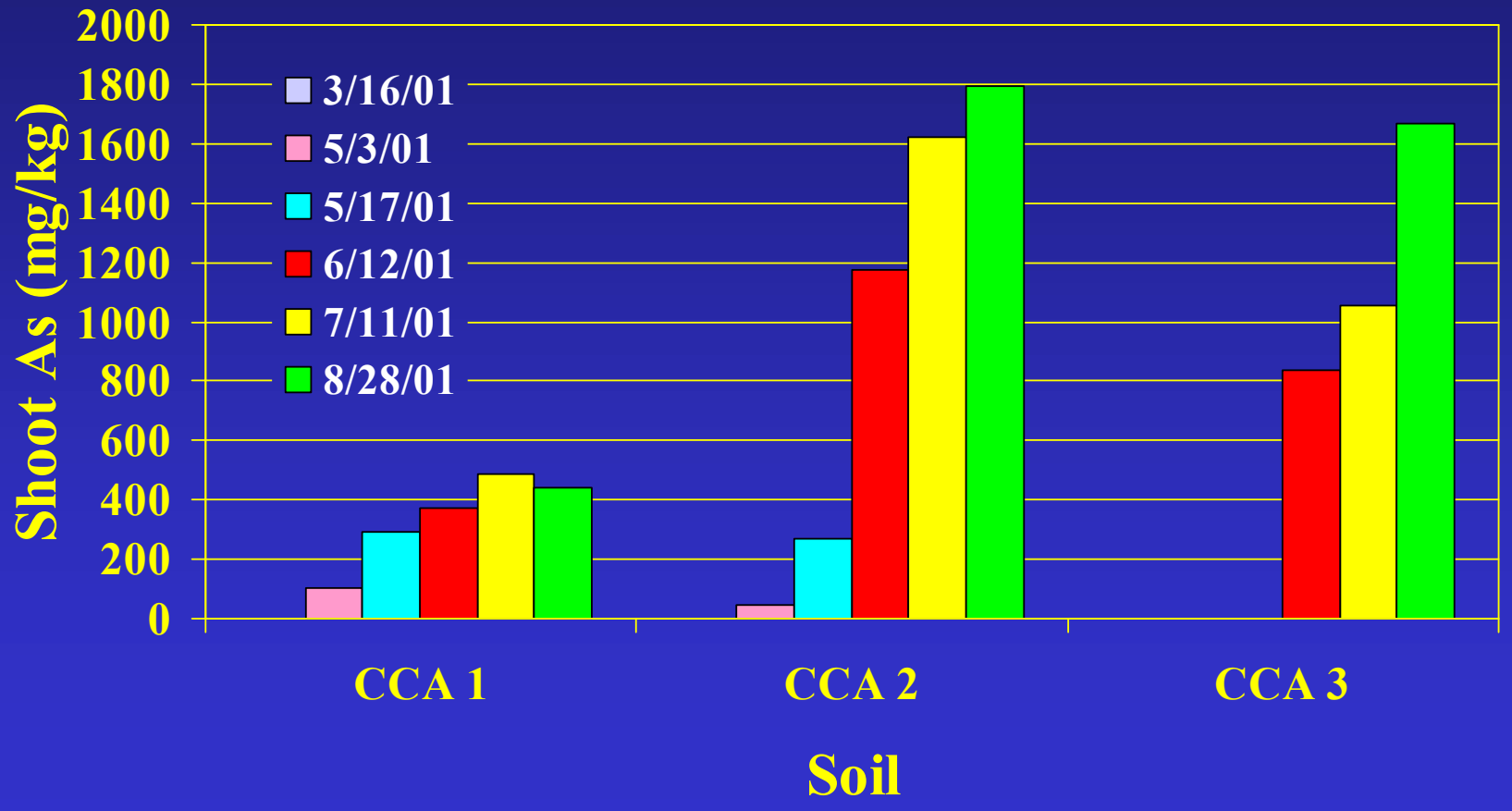
Plant Uptake of Arsenic from CCA Soil

Growth Chamber Study



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Arsenic Accumulation in edenfern

(4 weeks after transplanting - growth chamber study)

Fern Species	Fern As Concentration (mg/kg)	
	Site B (Soil As = 46 mg/kg)	Site C (Soil As = 40 mg/kg)
P. vittata	418	387
P. mayii	1270	860
P. parkerii	1627	1481

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Arsenic Phytoextraction Field Studies

- Studies conducted with US Army Corps of Engineers (Vicksburg)
- New Jersey
  - Former apple orchard (lead arsenate pesticide use)
  - Soil arsenic concentrations up to 150 mg/kg, typically 15 to 60 mg/kg
  - Arsenic is located in the surface soil (0 to 15 cm), distribution follows the tree driplines.
- Wilmington, North Carolina
  - Dredge materials
  - Soil arsenic concentrations average approximately 10 mg/kg

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Field Performance of edenfern

12-Weeks Growth (New Jersey - 2001)

	Shoot [As]	Biomass	Soil [As] Recovered in Biomass
	mg/kg	kg/ha	mg/kg
P. vittata	900	13050	5.9
P. mayii	2013	6100	6.1
P. parkerii	1416	5050	3.6

Soil As = 40 to 75 mg/kg

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Shoot Accumulation of Arsenic by *P. vittata* New Jersey - 2002

Plot	17-Jul	7-Aug	5-Sep
15 cm spacing			
	------Shoot As (mg/kg)------		
A	67	220	395
B	201	418	661
30 cm spacing			
A	91	216	389
B	183	1062	1739

Soil As = 10 to 50 mg/kg

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Wilmington, NC - *P. vittata*

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Fern Growth and Biomass Yields

- Fern growth in New Jersey in 2001 was very good (>13,000 kg/Ha for P. vittata. Growth in 2002 was significantly less.
- Biomass yields in 2002 at the Wilmington site for P. vittata ranged from 4000 kg/Ha (1st year plants) to more than 20,000 kg/Ha (2nd year plants)

	Wilmington, NC - Yield (kg/Ha DW)	
	1st Year Plants	2nd year Plants
P. vittata	4092	20511
P. mayii	4105	4357
P. parkerii	1348	2430

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Residential Arsenic Demonstration

- The National Capital Area Federation of Garden Clubs includes 4,000 individuals and 126 garden clubs in Maryland, Virginia and the District of Columbia.
- Edenspace requested 30 volunteers to test use of the edenfern™ in residential soil to remove CCA-derived arsenic.
- A kickoff meeting was held in April, 2002 at the River Farm headquarters of the American Horticultural Society to distribute fern plants and instructions.
- Ferns were planted, tended and sampled by homeowners and gardeners. Plants were sampled at the end of September.
- Samples collected by study participants have shown fern arsenic concentrations as high as 3500 mg/kg

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Summary

- The edenfern shows promise as a means to address arsenic contamination in soils and water
- Uptake and translocation occurs rapidly
- Accumulation occurs at low levels of water-soluble As (i.e., < 2 mg/kg) in soil and ppb levels in solution.
- Bioconcentration factors as high as 100 fold at high and low levels of soil arsenic
- Initial field results indicate about 20 mg/kg soil As can be recovered due to plant uptake over an entire growing season.