Phytoremediation of As-contaminated soils by As-hyperaccumulator *Pteris vittata*: long-term efficiency and biomass disposal

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Abstract

- Arsenic (As) is toxic to plants, animals and humans. As-hyperaccumulator *Pteris vittata* (PV) can be used in As-contaminated soil remediation. However, disposal of the As-laden biomass might present a drawback of the phytoremediation process.
- The ability of *P. vittata* in taking up As from three As-contaminated soils was assessed over 6 years using pots containing 162 kg soil, each supporting 9 plants. Besides, As extraction from PV biomass was assessed using water and 30% ethanol solution.
- *P. vittata* reduced soil As concentrations by 45-47%, from 129, 26.6 and 29.8 mg kg^{-1} to 69, 16 and 14 mg kg^{-1}. However, efficiency decreased over time.
- Arsenic in *P. vittata* biomass was ~60% water soluble and 85% ethanol soluble. Addition of $MgCl_2$ helped formation of magnesium arsenate precipitate [$Mg_3(AsO_4)_2$], reducing solution As concentration to < 2 mg L^{-1}.

Introduction

Due to its mutagenic and carcinogenic potential and the increase of contaminated areas, Arsenic is a major environmental concern. Phytoremediation is a low-cost green technology that can remedy contaminated soils. *Pteris vittata* (PV) is an As hyperaccumulator (Ma et al., 2001). Hyperaccumulator plants have the ability to absorb and accumulate more than 1000 mg kg^{-1} of metal by dry mass. Besides, PV roots are reported to release large amounts of root exudates that can solubilize As from insoluble forms such as Al-As and Fe-As in soils.

Proper husbandry practices can increase the potential of PV to remediate As-contaminated sites. However, As-laden biomass disposal might present a drawback of the phytoremediation process. Usually the biomass is either disposed at regulated landfills or incinerated. Besides, As in dried-fronds can be mobile, which can be leached out leading to secondary contamination. Therefore, it is essential to develop an effective pre-treatment strategy prior to biomass disposal.

Materials and Methods

- Three soils were collected, one from an abandoned wood treatment facility (CCA) and two from an abandoned cattle dipping vat site (DVA and DVB).
- Soil was air-dried, sieved through a 2 mm screen, and mixed with 15 g kg^{-1} phosphate rock [PR, $Ca_{10}(PO_4)_6F_2$ $(CaCO_3)_x$, <1 mm]. Each soil (CCA-PR, DVA-PR, and DVB-PR) was placed into a pot containing 162 kg and 30 cm deep.
- Similarly-sized *P. vittata* plants were spaced 15 cm apart 9 per container with 4 replicates. For comparative analysis, *P. vittata* ferns were set up in un-amended soil in addition to pots with no PR and plants (CCA-P and DVA-P).
- Frond harvests and soil samples were taken every 6 months over the past 6 years. Fronds were clipped to ~20 cm from the rhizome (leaving new fiddleheads). Soil cores were taken from four points in each container of two depths 0-15 cm and 15-30 cm. Sequential extraction was performed to analyze the nature of As depletion.
- Arsenic from biomass was extracted using water, 2.1% nitric acid, 2.1% H_3PO_4, 1 M NaOH and 30% ethanol. Liquid-solid ratio was 25:1. After As extraction, $MgCl_2$ was added at Mg:As molar ratio of 4:1.

Table 1. Characterization of soils collected from a wood treatment facility (CCA) and two soils from a cattle dipping vat site (DVA and DVB) after 6 years (n=3).

	CCA	DVA	DVB
	---------------------------mg kg^{-1}---------------------------		
As initial*	129 ± 5.6	29.9 ± 1.1	25.5 ± 0.9
As	69 ± 8.7	16 ± 1.6	14 ± 2.6
Cr	170 ± 12	7.9 ± 1.2	31.2 ± 7.0
Mn	141 ± 15	37 ± 2.9	25 ± 2.9
Fe	4003 ± 127	580 ± 31	2657 ± 329
Cu	80 ± 4.0	1.2 ± 0.8	1.2 ± 0.3
Zn	306 ± 18	14 ± 3.9	27 ± 6.0

* Initial soil As concentration

± standard deviation

Figure 1. Remediation experiment site with shading

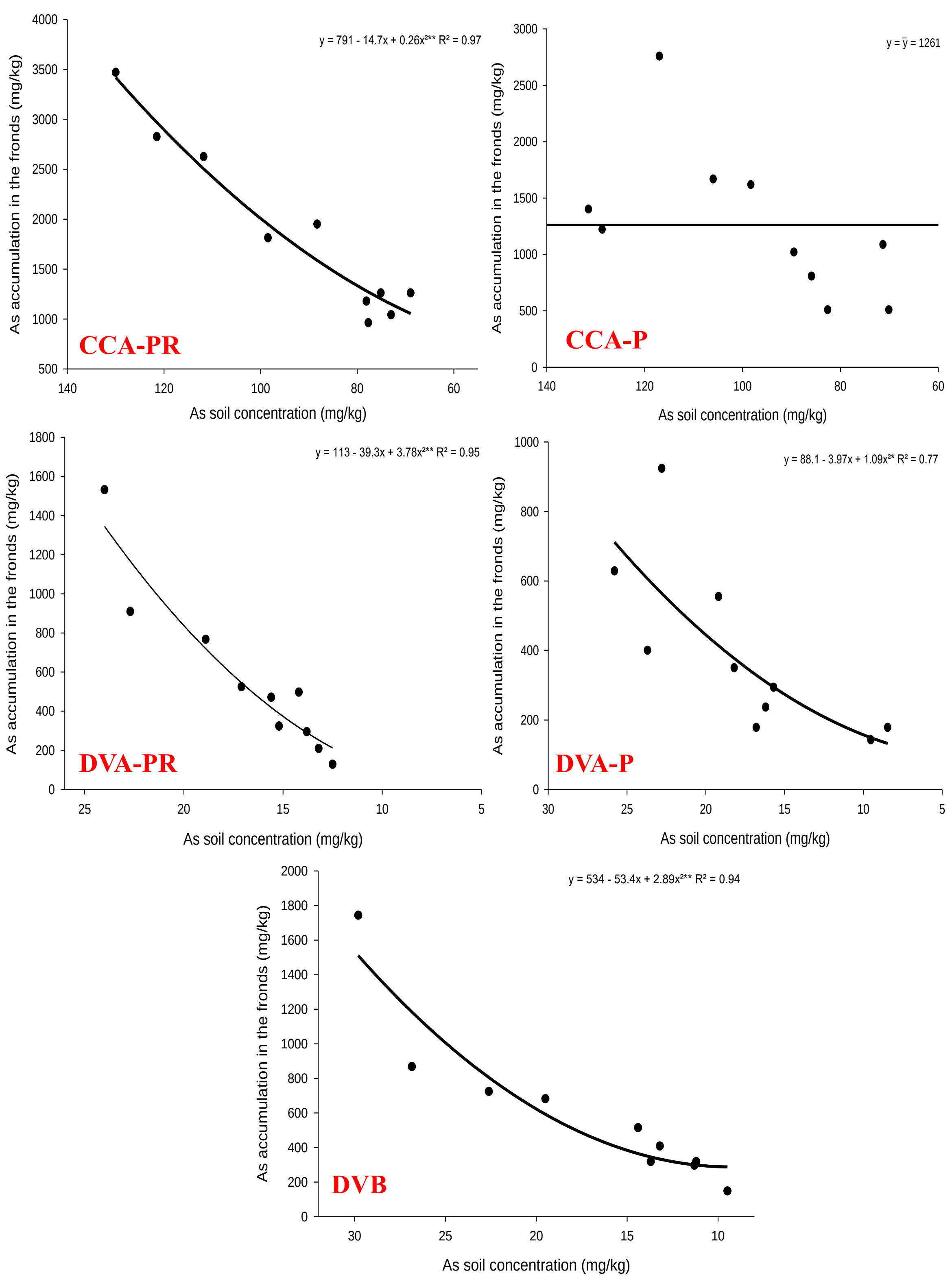

Figure 2. Correlation of As concentration in PV fronds to total As concentration in soil.

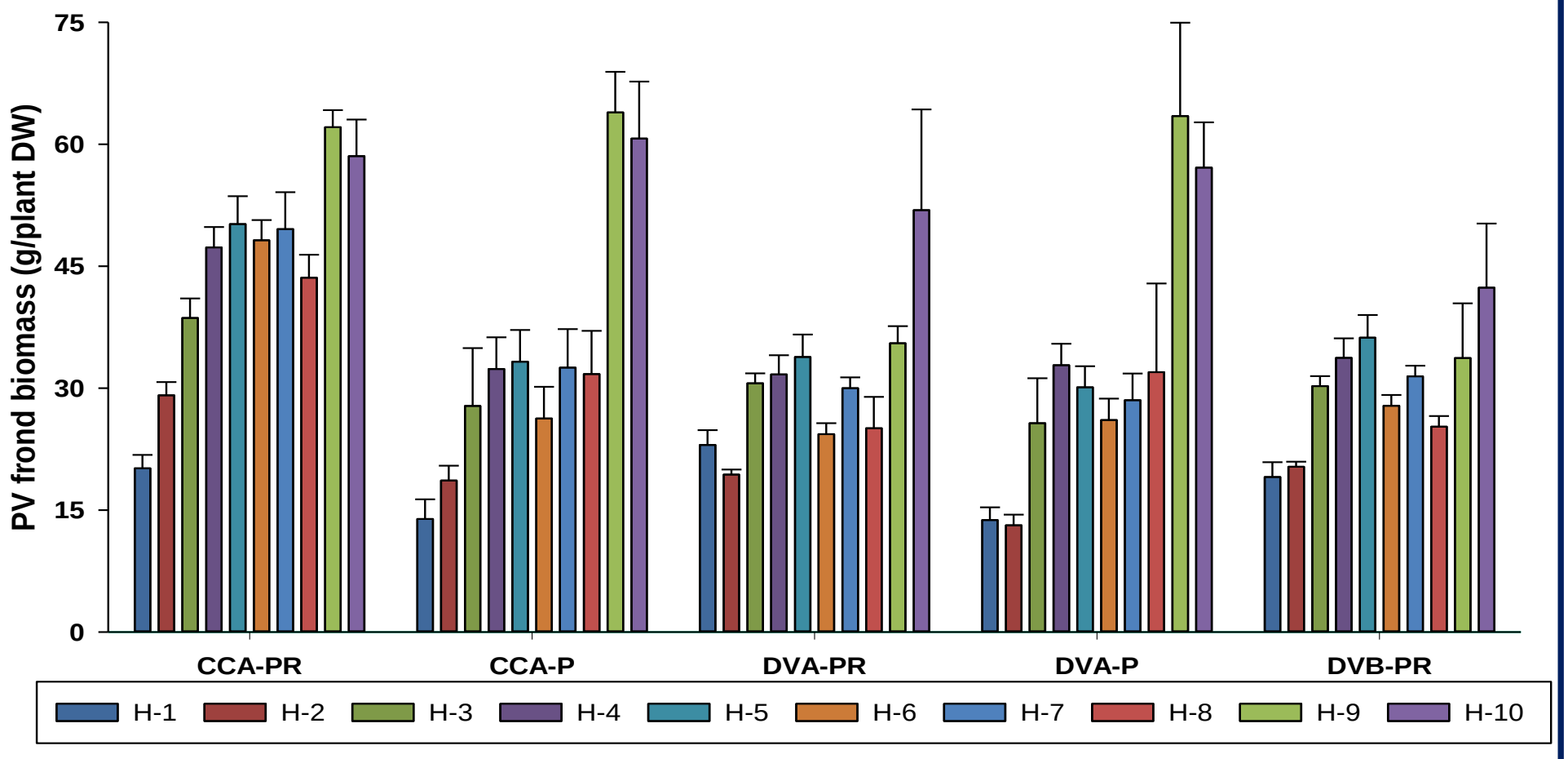

Figure 3. Frond biomass production over 10 harvests

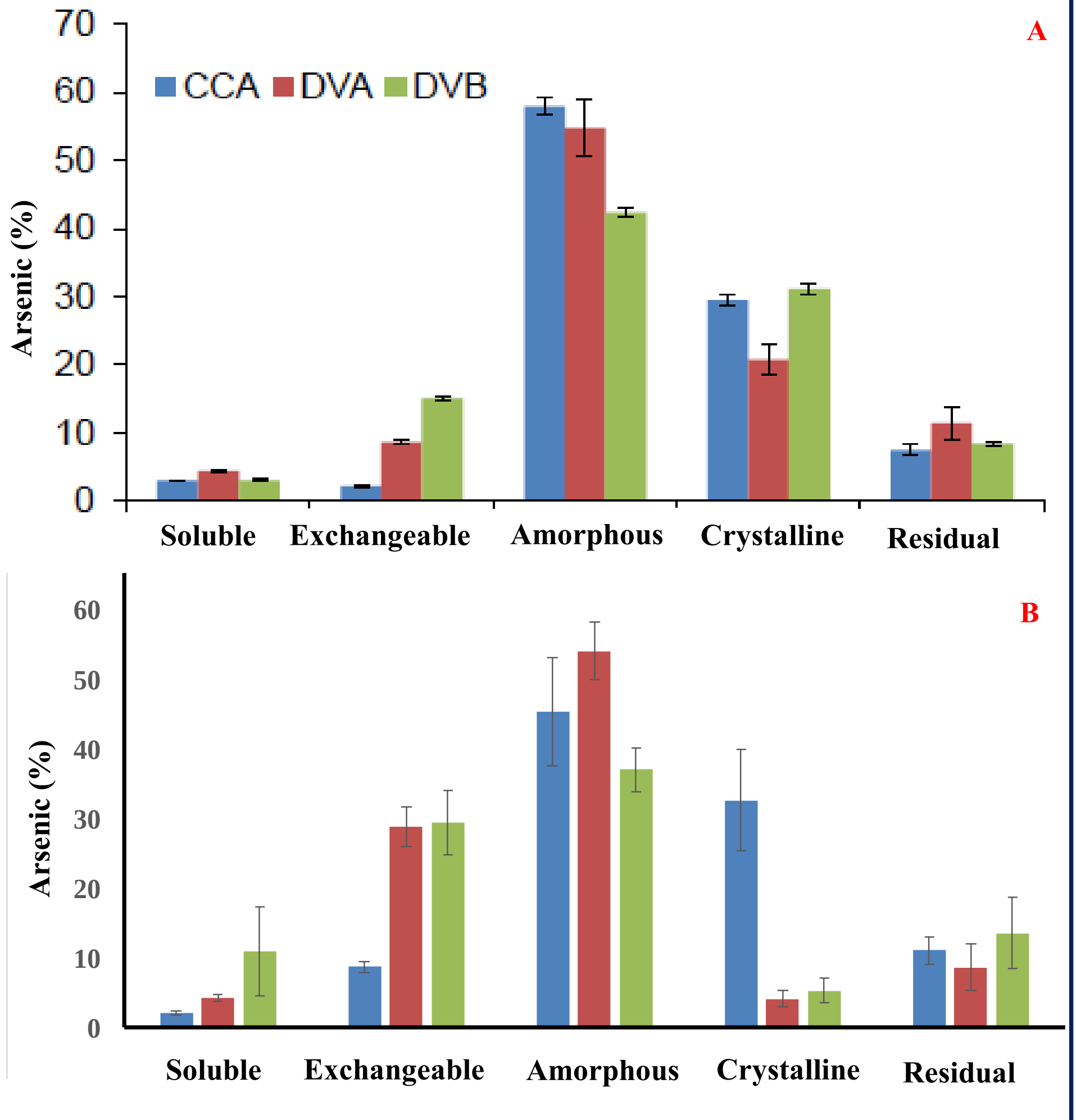

Figure 4. Soil arsenic fractionation (%) of the PR treatments soils before (A) and after (B) 6 years of remediation with *P. vittata*

Table 2. Arsenic extraction from *Pteris vittata* frond biomass (n=3).

	Water	2.1% HCl	2.1% H_3PO_4	1 M NaOH	Ethanol 30%
1st extraction (g)	0.67	3.2 ± 0.2	3.1 ± 0.2	1.9 ± 0.1	2.44
2nd extraction (2.1% HCl) (g)	-	1.3 ± 0.2	1.06 ± 0.1	0.67 ± 0.2	0.44
Remaining in biomass (g)	0.52	0.41 ± 0.18	0.44 ± 0.18	0.31 ± 0.01	0.51
Recovery (%)	108	132	125	75	85
Total (g)	1.10	3.99	3.99	3.99	3.99

± standard deviation

Results

- *P. vittata* reduced soil As concentrations in CCA, DVA and DVB soils by 45-47%, from 129, 26.6 and 29.8 mg kg^{-1} to 69, 16 and 14 mg kg^{-1}, respectively. However, the ability of *P. vittata* to remediate arsenic-contaminated soils was decreasing over time.
- Arsenic concentrations of frond biomass in PR amended CCA and DVA were higher than non-amended treatments.
- Arsenic removal was the greatest from the amorphous hydrous oxide-bound and crystalline fractions, with no difference between treatments (data not shown).
- Arsenic in fronds biomass was 67% water soluble, while ethanol extraction removed 85%.
- Addition of $MgCl_2$ helped formation of magnesium arsenate precipitate [$Mg_3(AsO_4)_2$], reducing solution As concentration to < 2 mg L^{-1}. In ethanol extraction, this formation was spontaneous due to Mg removal from chlorophyll.

Conclusions

- *P. vittata* was effective to remediate arsenic-contaminated soils. However, efficiency decreased over time.
- *P. vittata* was able to extract non-labile As in soil, a unique ability of *P. vittata*.
- Ethanol presented an advantage to extract As from PV frond biomass due to spontaneous formation of magnesium arsenate precipitate [$Mg_3(AsO_4)_2$].

Acknowledgments

- This research is supported in part by the University of Florida and funding from the CNPq - The Brazilian National Council for Scientific and Technological Development (Process No. 246758/2012-0) received by Evandro B. da Silva