

# 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<sup>-1</sup> to 69, 16 and 14 mg kg<sup>-1</sup>. However, efficiency decreased over time.
- Arsenic in *P. vittata* biomass was ~60% water soluble and 85% ethanol soluble. Addition of MgCl<sub>2</sub> helped formation of magnesium arsenate precipitate [Mg<sub>3</sub>(AsO<sub>4</sub>)<sub>2</sub>], reducing solution As concentration to < 2 mg L<sup>-1</sup>.

## 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<sup>-1</sup> 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 (Lessl et al., 2013).

Proper husbandry practices can increase the potential of PV to remediate As-contaminated sites (Lessl et., 2014). 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 (Tu et al., 2003). 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<sup>-1</sup> phosphate rock [PR, Ca<sub>10</sub>(PO<sub>4</sub>)<sub>6</sub>F<sub>2</sub> (CaCO<sub>3</sub>)<sub>x</sub>, <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<sub>3</sub>PO<sub>4</sub>, 1 M NaOH and 30% ethanol. Liquid-solid ratio was 25:1. After As extraction, MgCl<sub>2</sub> was added at Mg:As molar ratio of 4:1.

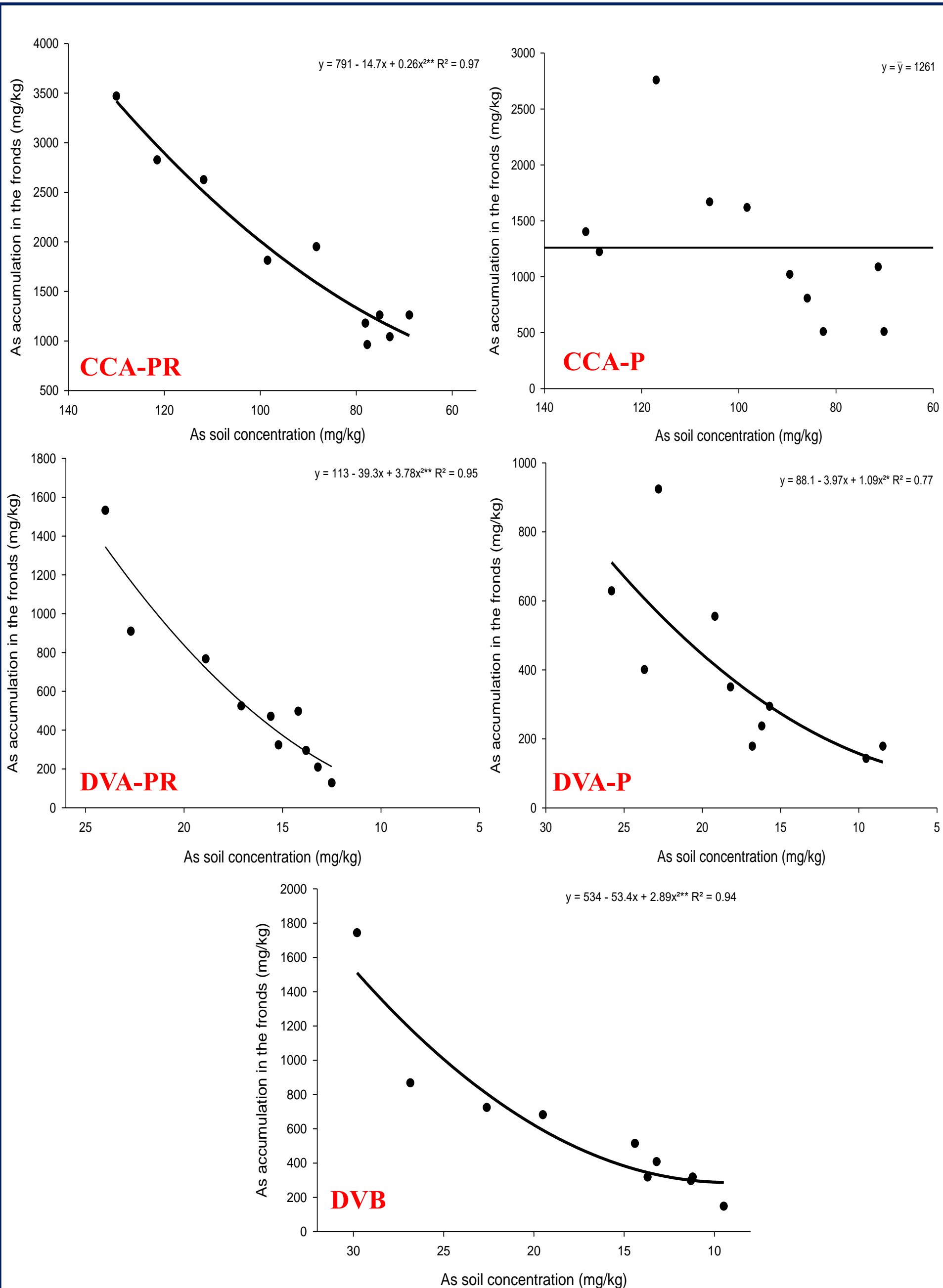
**Table 1.** Characterization of soils collected from a wood treatment facility (CCA) and two soils from a cattle dipping vat site (DVA and DVB) after 6 years (n=3).

	CCA	DVA	DVB
	-----mg kg <sup>-1</sup> -----		
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

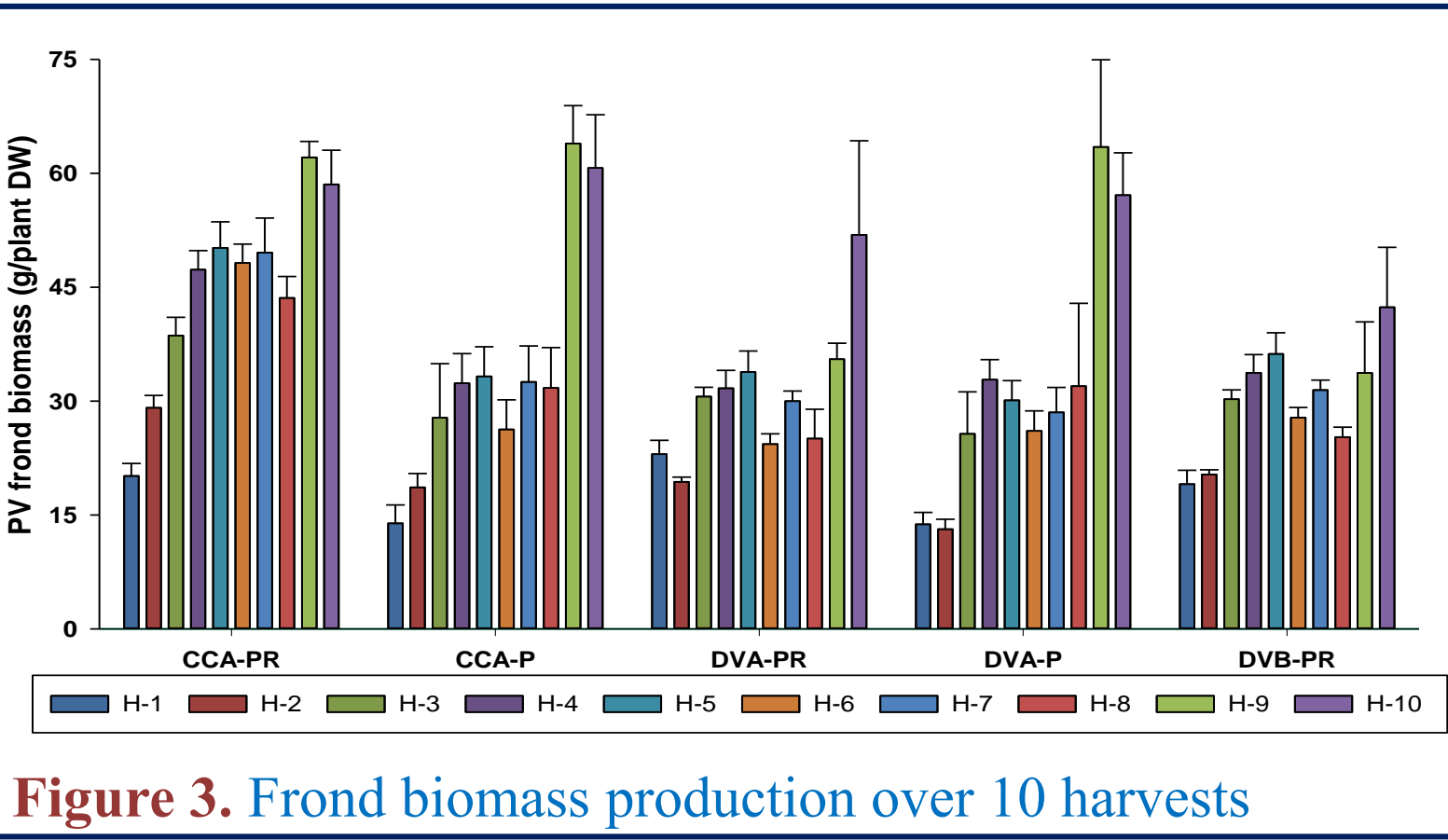


**Figure 2.** Correlation of As concentration in PV fronds to total As concentration in soil.

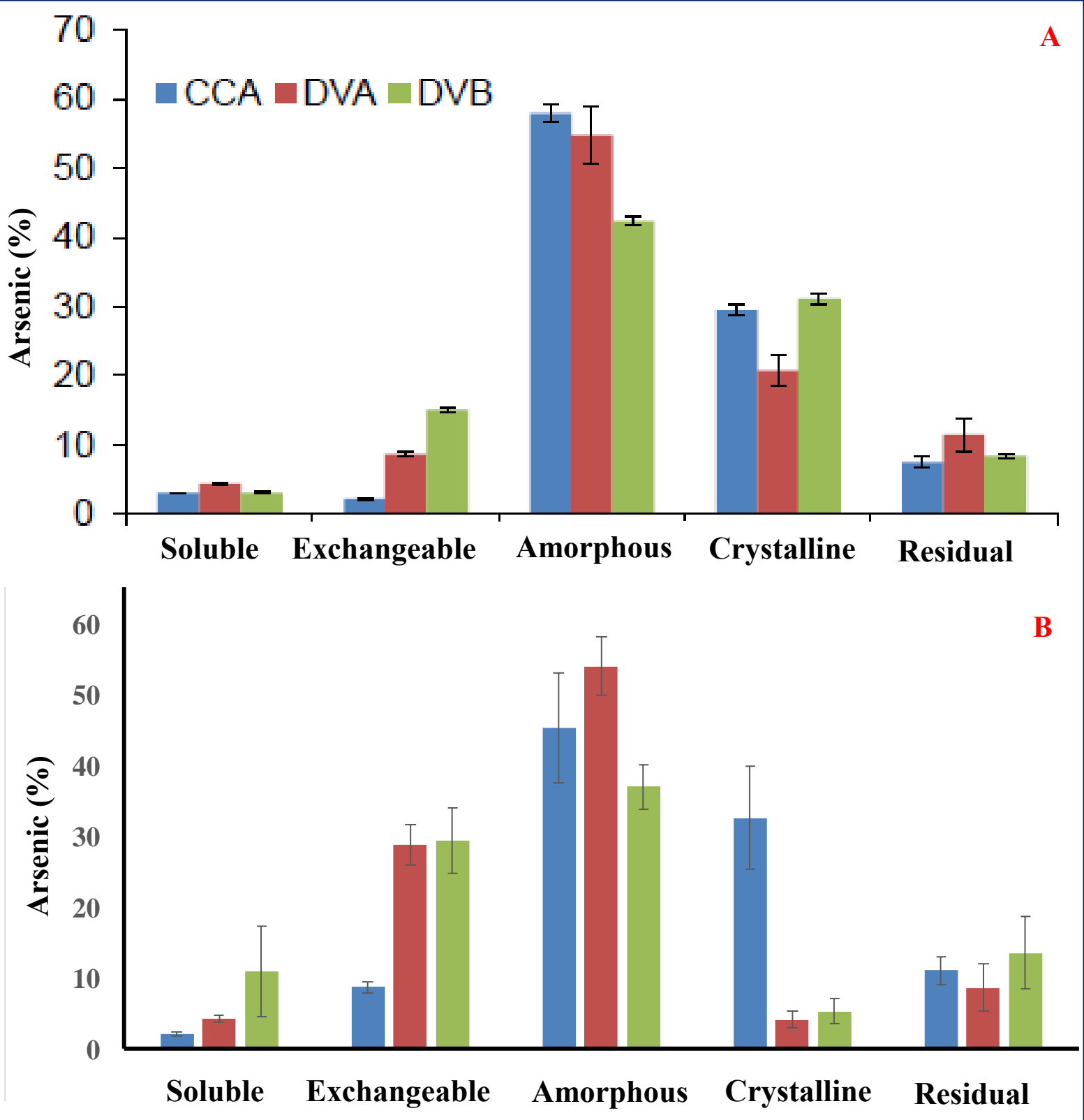
**Table 2.** Arsenic extraction from *Pteris vittata* frond biomass (n=3).

	Water	2.1% HCl	2.1% H <sub>3</sub> PO <sub>4</sub>	1 M NaOH	Ethanol 30%
1 <sup>st</sup> extraction (g)	0.67	3.2 ± 0.2	3.1 ± 0.2	1.9 ± 0.1	2.44
2 <sup>nd</sup> 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



**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*

## 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<sup>-1</sup> to 69, 16 and 14 mg kg<sup>-1</sup>, 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<sub>2</sub> helped formation of magnesium arsenate precipitate [Mg<sub>3</sub>(AsO<sub>4</sub>)<sub>2</sub>], reducing solution As concentration to < 2 mg L<sup>-1</sup>. 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<sub>3</sub>(AsO<sub>4</sub>)<sub>2</sub>].

## References

- Lessl, J., et al. Environ. Science & Technology. 2013.
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## Acknowledgments

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