Bioavailability of arsenic in a proposed urban agriculture site: effects of phytoremediation

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INTRODUCTION

- **A major barrier to** proliferation of **urban agriculture is soil contamination.**
- **Arsenic (As) soil contamination is widespread in urban areas,** a result of mining activities, coal combustion, pesticide use, and irrigated agriculture.
- **Arsenic in the soil exists in several different chemical forms**, which become soluble, and therefore mobile and toxic, under different geochemical circumstances. Only some forms are available for plant uptake.
- **Phytoremediation could reduce the amount of plant-available arsenic.** Phytoremediation with the As-hyperaccumulating fern *Pteris vittata* L. is an experimental method to remediate soils with shallow As contamination by using the fern to remove arsenic from the soil. Unlike conventional remediation techniques, which are expensive, phytoremediation could be accessible to urban farmers. **However,** estimates of **remediation times** using phytoremediation are **long**, on the order of decades.
- **Fertilization** of *P. vittata* **could decrease** remediation times, by affecting **As speciation and bioavailability** in soils, particularly if **phosphate** is applied.

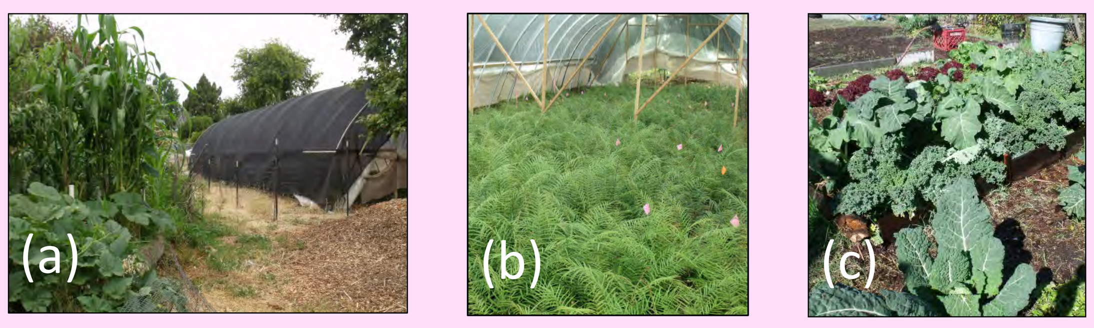

Figure 1. Arsenic phytoextraction with the brake fern occurs in a hoop house (a and b) in an arsenic-contaminated vacant lot, with food crops growing nearby in raised beds (a) and (c).

OBJECTIVE

To determine the bioavailability of arsenic in contaminated vacant lot soils, both unremediated and remediated by phytoextraction.

METHODS

Four soils (unremediated) were collected from an arsenic-contaminated vacant lot in Berkeley, CA (Fig. 2a). Two soils were then selected for phytoextraction in a **greenhouse experiment** (Fig. 2b), and soil was sampled post-experiment to serve as remediated soil. To approximate arsenic bioavailability, total arsenic from unremediated and remediated soils was divided into fractions using a **sequential extraction procedure** (Fig 2c).

Figure 2.

Soils:

Soil A: 160 ppm As, loam (22% clay)
Soil B: 91 ppm As, clay loam (27% clay)
Soil C: 98 ppm As, sandy loam (17% clay)
Soil D: 30 ppm As, silty clay loam (36% clay)

Greenhouse study: *P. vittata* ferns were planted in Soil A and Soil B and allowed to grow for 8-10 weeks before treatments were applied (3 replicates per treatment). Fronds were sampled at treatment application and then monthly. At 4 months, the whole fern was harvested, biomass measured, and soil sampled.

Sequential extractions: Arsenic was extracted from unremediated field soils and remediated (post-greenhouse study) soil samples using the extraction scheme of Wenzel et al. (2001)[1]: **(1) 0.05 M $(NH_4)_2SO_4$, 20°C/4 h; (2) 0.05 M $(NH_4)H_2PO_4$, 20°C/16 h; (3) 0.2 M NH_4^+-oxalate buffer in the dark, pH 3.25, 20°C/4 h; (4) 0.2 M NH_4^+-oxalate buffer + 0.1 M ascorbic acid, pH 3.25, 96°C/0.5 h.** Extracted arsenic is considered to represent: **(1) non-specifically sorbed; (2) specifically-sorbed; (3) amorphous and poorly-crystalline hydrous oxides of iron and aluminum; (4) well-crystallized hydrous oxides of iron and aluminum.** Arsenic in Fraction 5, the residual phase, was calculated by subtracting the total extracted in Fractions 1-4 from total arsenic.

Data analysis: Arsenic concentrations in plant tissue, soil, and soil extracts were analyzed using ICP-OES. After ANOVA, differences between means were assessed using the Tukey test.

DISCUSSION & CONCLUSIONS

- **Most arsenic** in these soils, before and after phytoextraction, is tied up with iron oxides and **is not readily available** – regardless of soil composition.
- **Phytoremediation** can **reduce** the amount of **less available arsenic** (F3 and F4), but does not affect more available arsenic (F1 and F2) (which remained small). The brake fern likely accesses the less-available fractions by **emitting acidic root exudates**.
- If vegetable crops also emit acidic root exudates, **arsenic could become more available in the vegetable rhizosphere.**
- **High phosphorus application increases labile (F1) arsenic**, regardless of arsenic and clay content – potentially making arsenic available for **leaching**.

FUTURE WORK

- Determine arsenic availability to vegetable crops using greenhouse experiments.
- Further elucidate the form of arsenic in these soils using X-ray absorption spectroscopy.
- Investigate arsenic-phosphate cycling in these soils using meso-scale column systems.

RESULTS: ARSENIC AVAILABILITY IN UNREMEDIATED SOILS

- **Low amounts of arsenic are present in the most available form** (F1), regardless of total concentration of arsenic in the soil.
- **Arsenic behaves similarly in soils with higher percent clay** (Soil B and Soil D), with a similar percent extracted despite different total arsenic concentrations.

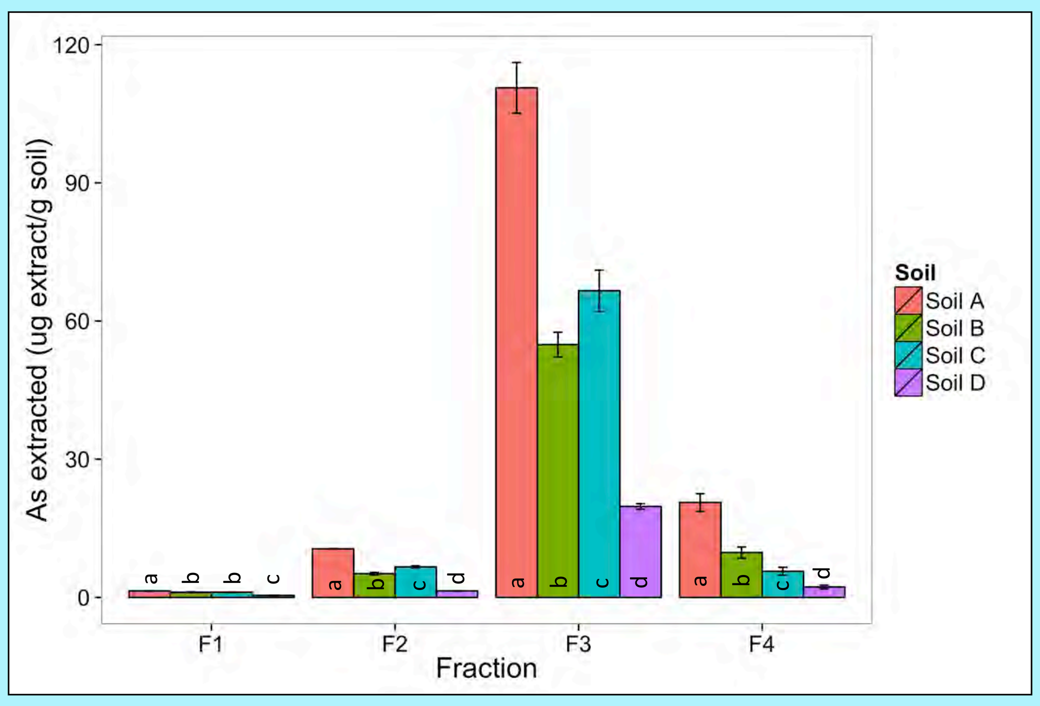

Figure 3. Arsenic concentration extracted from unremediated soils. n=3.

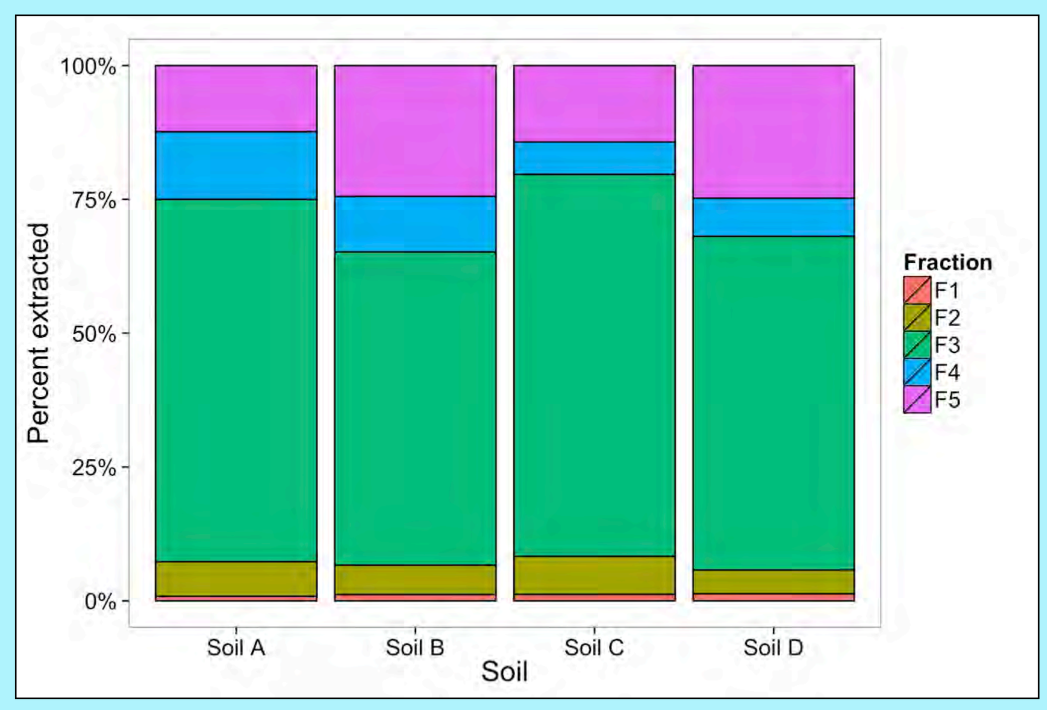

Figure 4. Percent arsenic extracted from unremediated soils. n=3.

RESULTS: ARSENIC AVAILABILITY AFTER PHYTOREMEDIATION WITH FERTILIZATION

- **Fern growth reduced** As associated with amorphous (F3) and crystalline (F4) Fe oxides in Soil A, but not Soil B.
- **Labile (F1) As increased only** in soil supplied with high concentrations of **inorganic P,** but not other fertilizers.

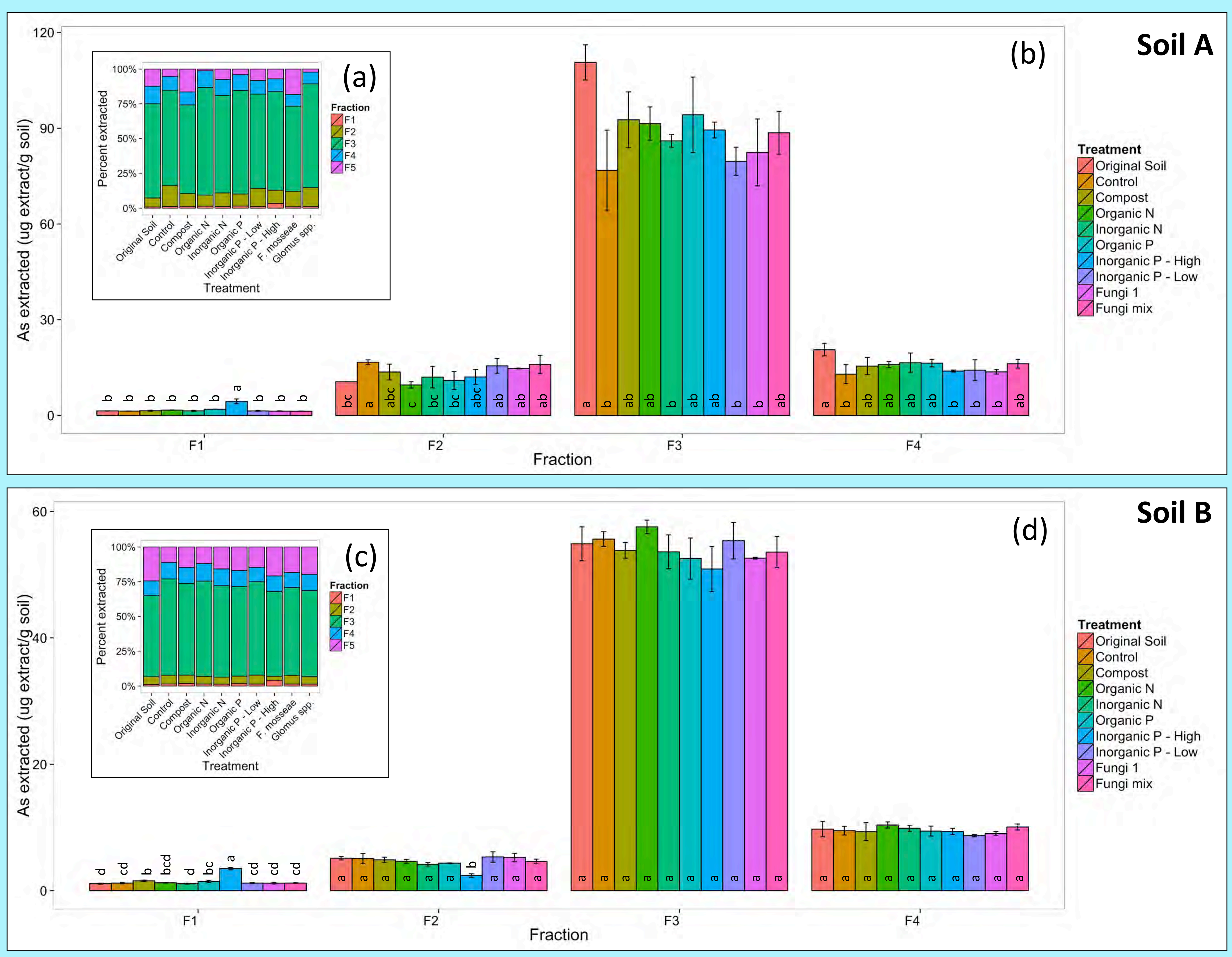

Figure 5. Fractionation of As in Soil A ((a) percent and (b) concentration) and Soil B ((c) percent and (d) concentration). n=3. Within a fraction for each soil type, means with the same letters are not significantly different at p<0.05.

REFERENCES
[1] Wenzel, W.W., et al. (2001). Anal. Chim. Acta 436, 309–323.

ACKNOWLEDGEMENTS
We thank the University of California Global Food Initiative, the National Science Foundation Graduate Research Fellowship Program (under Grant No. DGE 1106400) and the Research Institute for Humanity and Nature (Kyoto, Japan) for their support. We thank Sharon Licht and all interns.