Can Brake Ferns (*Pteris vittata*) Efficiently Remediate Urban Soils Contaminated with Arsenic? Optimizing Phytoremediation through Fertilizer Use.

S.L. Matzen*, A. Olson, C. Pallud

Environmental Science, Policy and Management, University of California, Berkeley, USA (*smatzen@berkeley.edu)

The Green Initiative Fund
University of California, Berkeley

INTRODUCTION

As urban agriculture reclaims contaminated land, soil remediation methods that are cost-effective, sustainable, and broadly applicable are urgently needed. If proven viable, *in situ* remediation methods could be combined with urban agriculture to decrease exposure to legacy contaminants, improve urban soil health, and increase local food production.

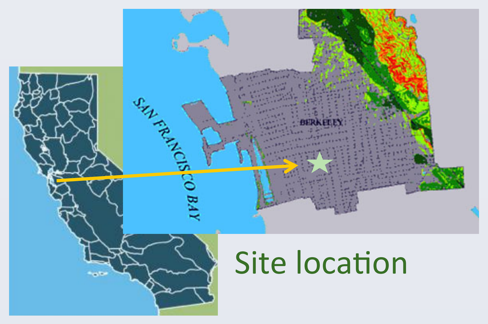
Arsenic (As) soil pollution is gaining recognition as a widespread urban problem. Arsenic contamination can result from use of arsenical pesticides, treated wood, mining activities, and coal burning. In a 2008 study of almost 2,000 yards in cities across the US, 20% contained arsenic above a 10 mg kg^{-1} action level [1].

Phytoremediation with the arsenic-hyperaccumulating fern *Pteris vittata* (pictured above) [2] has emerged as a technology to remediate soils with shallow contamination. While the mechanisms of arsenic uptake and accumulation in *P. vittata* have received attention in numerous greenhouse and hydroponic experiments, only a few studies have investigated the fern's performance under field conditions, which is crucial to developing successful remediation methods. The goal of this study is to develop new protocols to increase in situ arsenic phytoremediation efficiency and remediation time.

OBJECTIVES

To determine the effects of organic and inorganic fertilization on *P. vittata* frond biomass, arsenic uptake rate by *P. vittata*, and on cumulative arsenic removal from soil.

METHODS



Site location

The field site is an abandoned railroad right-of-way (sandy loam) mildly contaminated with As (20-100 ppm), located in Berkeley (CA) and characterized by a Mediterranean climate. A 24m x 6m plot was tilled and limed (0.3 kg m^{-2}) before 1,600 *P. vittata* ferns were planted at 30 cm spacing.

We tested 5 treatments, applied to fern beds at standard agricultural rates:

1) compost
2) organic nitrogen as blood meal (5 g N m^{-2})
3) inorganic nitrogen as $(NH_4)_2SO_4$ (5 g N m^{-2})
4) organic phosphorus as bone meal (20 g PO_4^{3-} m^{-2})
5) inorganic phosphorus as phosphate rock (20 g PO_4^{3-} m^{-2})

For comparison, we established a control plot with no treatments applied to ferns.

After 8 months of growth, all mature and senescing fronds were harvested. Ten percent of ferns in each treatment group were randomly selected to comprise our representative sample. Fronds were kept separated by individual fern throughout analysis process. Arsenic concentrations were analyzed using ICP-AES. Using one-way analysis of variance, significant differences in treatment effects were determined using Duncan's new multiple range test, at $p<0.05$. This poster presents results from the first third of our fern samples.

SOIL CHARACTERISTICS

	Time	Depth (cm)	Control – No ferns	Control – Ferns	Compost	Blood Meal	$(NH_4)_2SO_4$	Bone Meal	Phosphate Rock
pH	T0	0-15	6.93±0.12						
		15-30	6.9 **						
	H1	0-15	6.63±0.04	7.31±0.03	7.08±0.11	6.66±0.09	6.11±0.02	6.58±0.04	6.68±0.02
		15-30	7.02±0.07	7.46±0.04	7.22±0.10	6.64±0.28	6.59±0.18	6.82±0.08	7.01±.012
C/N	T0	0-15	12.73±0.85						
		15-30	13.76±0.60						
	H1	0-15	16.09±0.37	15.42±0.29	15.15±0.05	15.56±0.37	16.19±0.90	14.97±0.66	15.75±0.54
		15-30	14.21±0.68	14.99±1.44	15.53±0.87	18.10±1.83	16.49±0.14	17.13±1.05	16.12±0.10

Table 1. Soil pH and C/N values for experimental plots at two depths. Reported values are averages of 3 replicates, except for Control – Ferns and Compost values, which are averages of 6 replicates. H1 refers to first harvest (8 months of fern growth) **Due to limited sample size, this indicates one composite sample of 3 replicates

RESULT 1: Biomass production

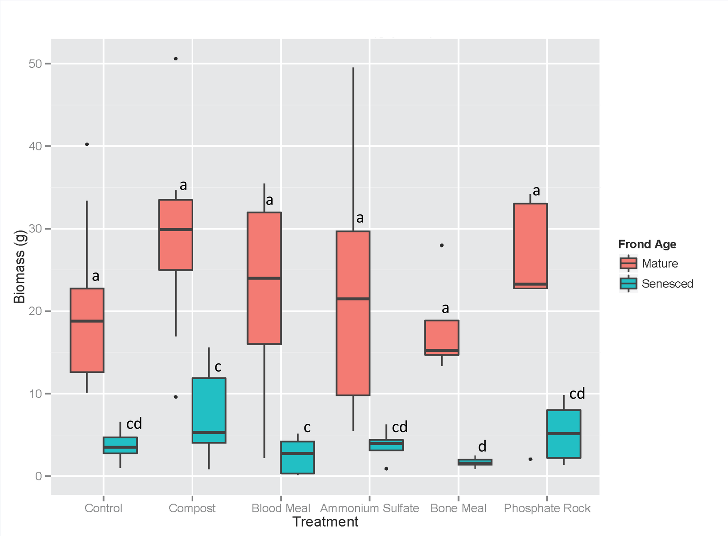


Figure 1. Effects of soil treatment on weight of harvested biomass. n=10 for Control and Compost; n=5 for other treatments. Means with the same letters are not significantly different at $p<0.05$.

RESULT 2: Arsenic accumulation in fern fronds

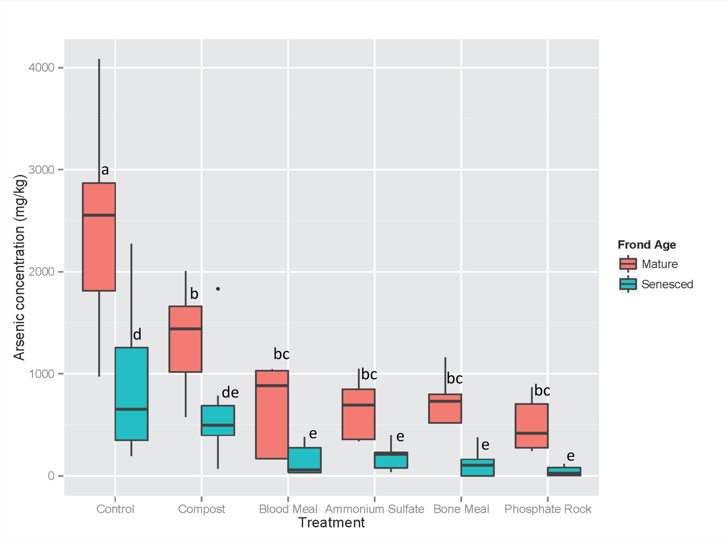


Figure 2. Effects of soil treatment on arsenic concentration in harvested biomass. n=10 for Control and Compost; n=5 for other treatments. Means with the same letters are not significantly different at $p<0.05$.

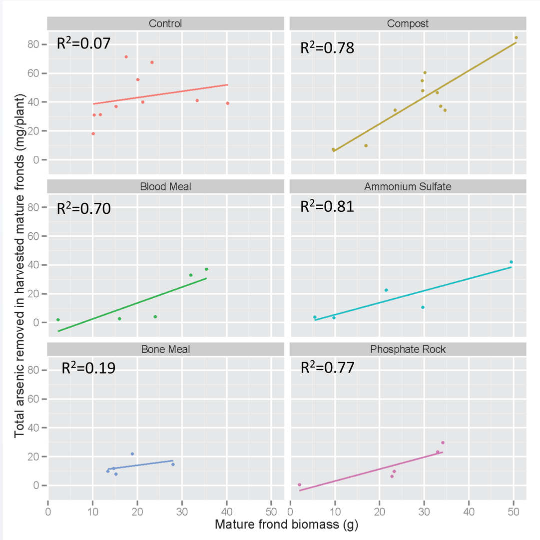


Figure 3. Effects of soil treatment on total arsenic removed per plant. n=10 for Control and Compost; n=5 for other treatments.

RESULT 3: Arsenic removal from soil

Soil treatment	Initial As concentration in soil (mg kg^{-1})	Average biomass yield at H1 (g $plant^{-1}$)	Arsenic uptake at H1 (mg $plant^{-1}$)	Total As removed (kg ha^{-1} y^{-1})	Estimated years to remediate our study site
Control	85.5±8.8	23.95	46.6	7.8	41
Compost		36.77	47.5	7.9	40
Blood Meal		24.45	16.4	2.7	117
Ammonium Sulfate		26.93	17.3	2.9	109
Bone Meal		19.70	13.4	2.2	144
Phosphate Rock		28.38	14.2	2.4	136

Table 2. Efficiency of different treatments for arsenic removal and estimated years for remediation to an assumed regulatory standard of 10 mg kg^{-1}. H1 refers to first harvest (8 months of fern growth).

Study	Experiment type	Soil treatment	As uptake (mg $plant^{-1}$ y^{-1})	Estimated years to remediate our site
Our results	field	Compost	71	40
		Phosphate rock	21	136
Gonzaga et al. (2008) [3]	greenhouse	N:P:K fertilizer	32	89
Kertulis-Tartar et al. (2006) [4]	field	none	40	71
Lessl and Ma (2013) [5]	raised bed	P fertilizer	93	31
		Phosphate rock	172	17
Shelmerdine et al. (2009) [6]	greenhouse	none	1	2854

Table 3. Comparison of arsenic uptake efficiency by *P. vittata* in different studies of moderately contaminated soils (As < 360 mg kg^{-1}).

IMPLICATIONS AND FUTURE RESEARCH

Implications:

- Senesced fronds lost arsenic, possibly due to leaching back into soil at fern base. Timing harvesting to avoid senescence could improve arsenic removal by 12%.
- Compost showed the best ability to enhance both frond arsenic concentration and biomass.
- In phosphate-treated plots, ferns may have taken up phosphate preferentially over arsenate.
- The arsenic uptake rates we report for compost-treated ferns compare favorably with published uptake rates. Additional improvements in uptake and biomass production are needed to shorten remediation timescales.

Future work:

- Analysis of arsenic concentration in soil samples
- Conduct batch experiments to elucidate effects of fertilizers on arsenic phytoavailability
- Examine effects of fern planting density and harvest method on arsenic removal
- Determine the effects of multiple contaminants on the fern's ability to remove arsenic

REFERENCES

[1] M.P. Elless et al. (2008) *Env. Poll.* 156:20; [2] L.Q. Ma *et al.* (2001) *Nature* 409, 579; [3] M.I.S. Gonzaga et al. (2008) *Env. Poll.* 154:212; [4] G.M. Kertulis-Tartar et al. (2006) *Int. J. Phytorem.* 8:311; [5] J.T. Lessl and L.Q. Ma (2013) *Env. Sci. Tech.* 47:5311; [6] P.A. Shelmerdine et al. (2009) *Env. Poll.* 157:1589

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