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Using phosphate rock to immobilize metals in soil and increase arsenic uptake by hyperaccumulator *Pteris vittata*

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Abstract

This greenhouse experiment evaluated the effects of phosphate rock (PR) on arsenic and metal uptake by the arsenic hyperaccumulator *Pteris vittata* in a soil spiked with arsenic and heavy metals Cd, Pb and Zn. Five soil treatments were used, 1) control with no arsenic, 2) spiked with 50 mg kg^{-1} As (As) as $Na_2H\ AsO_4$, 3) spiked with 50 mg kg^{-1} As and P as PR (AsP), 4) spiked with 50 mg kg^{-1} As, Pb, Cd, and Zn (AsM), and 5) spiked with 50 mg kg^{-1} As, Pb, Cd, Zn and P (AsMP). The plants were harvested after growing in the soil for five weeks. Compared to the As treatment, the presence of heavy metals (AsM) reduced arsenic concentrations in the fronds from 1631 to 608 mg kg^{-1}. However, this effect was mitigated by PR (AsMP), with arsenic concentrations in the fronds increased from 608 to 1046 mg kg^{-1}. Phosphate rock also significantly reduced Pb (13.5 to 4.10 mg kg^{-1}) and Cd (13.0 to 3.45 mg kg^{-1}) concentrations in the fronds. Most of the arsenic in *P. vittata* was accumulated in the fronds (89–93%). Compared to the control, P was more concentrated in the roots along with less P being translocated to the fronds in the treatments with arsenic. While in those same treatments higher Ca concentrations in both the fronds and roots were observed. This research shows that PR was effective in increasing arsenic uptake and decreasing metal uptake by *P. vittata* and thus can be used as a cost-effective amendment for phytoremediation of arsenic and metal polluted soils.

Keywords: Phosphate rock; Arsenic; Lead; Cadmium; Zinc; Phytoremediation

1. Introduction

Arsenic contamination in the environment is widespread due to both natural and anthropogenic activities. It is of great environmental concern because arsenic is a known carcinogen and mutagen. Arsenic contamination, however, often coexists with other heavy metals because it is released to the environment primarily as a by-product of copper (Cu) and lead (Pb) smelters (Bagga and Peterson, 2001). Smelting and mining sites are often significant sources of contamination because pyrometallurgical production processes lead to large emissions of Pb, Zn, Cu, Cd and As (Boisson et al., 1999).

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Phytoextraction is an emerging technology utilizing hyperaccumulating plants to clean up metal-contaminated soils. It reduces the amount of hazardous wastes to be landfilled, is aesthetically pleasing and is acceptable to the general public as a cost-effective and environment-friendly technique. The arsenic hyperaccumulator *Pteris vittata* (Chinese Brake fern) was found growing on a site in Central Florida contaminated with chromated copper arsenate (CCA; Ma et al., 2001). The fact that the plant accumulates most of the arsenic in its aboveground biomass coupled with its large biomass makes it ideal for phytoremediation.

Our previous research has shown that the plant was able to accumulate arsenic in the presence of other metals albeit at a reduced rate (Fayiga et al., 2004). Phosphate rock has been shown to immobilize metals in contaminated soils (Ma et al., 1995), and reduce metal uptake in sudax (*Sorghum bicolor L.*) (Laperche et al., 1997). On the other hand, phosphate has also been shown to increase arsenic availability in the soil leading to increased plant uptake (Peryea, 1998). Therefore, P-induced metal stabilization and arsenic solubilization expected from the addition of phosphate fertilizers in soils should enhance arsenic uptake by *P. vittata* in the presence of other metals. Phosphate rock also supplies calcium in addition to increasing soil pH, thereby providing better growth condition for the fern, which prefers to grow in a lime-rich environment (Jones, 1987).

Therefore, we hypothesized that the addition of phosphate rock reduces metal uptake while it also increases arsenic uptake by *P. vittata*. The main objective of this study was to evaluate the effectiveness of phosphate rock in increasing arsenic uptake and reducing metal uptake by *P. vittata* using a greenhouse experiment. The results from this study should shed light on the feasibility of using phosphate rock as an amendment for phytoremediating soils that are contaminated with both arsenic and heavy metals.

2. Materials and method

2.1. Soil and phosphate rock characterization

A sandy soil collected from a garden in Gainesville, FL was used in this experiment. The soil was air-dried, passed through 2 mm sieve and analyzed for total concentrations of Pb, Cd, Zn and As. Soil pH was measured using a pH meter in a 1 : 2 soil to solution ratio. Cation exchange capacity was determined by the ammonium acetate method (Thomas, 1982). Organic matter was determined by the Walkley Black method (Nelson and Sommers, 1982) and particle size by the pipette method (Day, 1965). The phosphate rock sample (PR, <60 μm), which is classified as ground concentrate, was obtained from PCS Phosphate, White Springs, FL. Phosphate rock and soil samples were digested using EPA Method 3050A with the Hot Block digestion system (Environmental Express, Mt. Pleasant, SC). Total Ca, Al, Mg, and Fe concentrations in the samples were analyzed using a flame atomic absorption spectrometer (Varian 220 FS with SIPS, Varian, Walnut Creek, CA). The selected physico-chemical properties of the soil and phosphate rock used in this experiment are listed in Table 1.

Table 1
Selected properties of soil and phosphate rock used in this experiment

	Concentration
Soil	
Sand (%)	89.2
Silt (%)	7.5
Clay (%)	3.3
CEC ($cmol_c\ kg^{-1}$)[a]	17
Organic matter ($g\ kg^{-1}$)	31.5
Soil pH	6.89
Total As ($mg\ kg^{-1}$)	0.41
Mehlich-3 As ($mg\ kg^{-1}$)	0.003
Total P ($mg\ kg^{-1}$)	277
Mehlich-3 P ($mg\ kg^{-1}$)	87.2
Total Ca ($mg\ kg^{-1}$)	4769
Total Cd ($mg\ kg^{-1}$)	0.13
Total Pb ($mg\ kg^{-1}$)	9.52
Total Zn ($mg\ kg^{-1}$)	105
Phosphate rock	
pH	7.1
P (%)	14.3
Fe (%)	0.63
Al (%)	0.66
Ca (%)	34.3
Mg (%)	0.22

[a] CEC-cation exchange capacity.