# PATTERNS OF ACCUMULATION OF HEAVY METALS IN NON-WOODY VEGETATION ESTABLISHED ON ZINC-LEAD SMELTER CONTAMINATED SOILS

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## ABSTRACT

Soil columns for two soil types obtained from an abandoned lead and zinc smelter at Dearing in Montgomery County, Kansas, were vegetated by means of a grass/legume seeding mixture. Herbaceous shoot and root material was analyzed for zinc, lead, and cadmium by ICP spectrometry. Results indicate that for both types of substrate there was significant accumulation of all three metals by root systems with relatively low concentrations of any of these metals being partitioned to the shoots. Partitioning between shoots and roots for all three metals on both soil types averaged 1:5 (shoot:root). There was little correlation between root and shoot concentrations of any of these metals. Implications of these observations for phytoremediation of smelter sites are considered.

***Key words:*** *shoot-root partitioning, zinc, lead, cadmium, phytoremediation*

## INTRODUCTION

This study is part of a series of studies that attempt to evaluate the potential of vegetational remediation of sites contaminated by heavy-metal mining and smelting in southeast Kansas (Abdel-Saheb et al., 1994; Hetrick et al., 1994; Norland, 1994; Pierzynski et al., 1994; Youngman et al., 1998). Of particular concern is control of leaching of heavy metals into shallow aquifers, runoff to surface water, and prevention of contamination of water consumed by humans and livestock in the vicinity of these sites. Revegetation of smelter sites as a means to remediate them by phytoextraction, phytostabilization, or a combination of both processes is supported by recent literature (Cunningham et al., 1995 1996; Raskin et al., 1994; Salt et al., 1995).

The site chosen for this study was the abandoned Dearing Smelter in Montgomery County near the town of Dearing, Kansas. The 48 acres of land on which the smelter was located was purchased by the American Zinc and Lead Smelting Company in 1907 and sold in 1919 after operations at the smelter ceased. Soil columns of either Lanton clay loam (bog soil) or accumulated smelter waste (slag fines) were either left untreated, amended with the incorporation of composted cattle manure, or amended and seeded to grass and legumes. Leachate from the columns was monitored by means of duckweed bioassays (Youngman et al., 1998). Plant material established on vegetated columns was analyzed for Cd, Pb, and Zn to determine the degree of accumulation of these metals in shoots and roots. Patterns of accumulation were analyzed and implications of shoot-root allocation were evaluated.

## METHODOLOGY

Three columns for each of the two substrates described in the introduction were obtained by driving 38 cm sections of thick-walled PVC pipe (5 mm wall X 155 mm ID) sections approximately 30 cm into the ground. Cores were placed in a framework located in a Sherer Growth Room (Model CEL 512-37, Sherer-Gillett Co., Marshall, Michigan). Simulated rainwater was drawn through the columns using a vacuum pump to create continuous negative pressure (Youngman et al.,, 1998). Vegetation was allowed to develop for approximately three months. Columns were examined and plant material was harvested by sawing columns in half lengthwise with a table saw. After recording rooting depth, all plant material was carefully removed from each column, substrate was removed by washing roots in tap water followed by several distilled-water rinses. Plant material was dried at room temperature for one week, roots and shoots were separated, and dry weights were determined to the nearest 0.01g. Roots and shoots were prepared for elemental analysis by pulverizing to approximately 20 mesh particle size using a 250 ml stainless steel pulverizing container with a one-liter Waring commercial two-speed blender (Model 5011, Dynamics Corporation of America, New Hartford, Connecticut). Three one-gram samples of shoot and root from each column were wet ashed in 10 ml concentrated nitric acid (Reagent ACS, Fisher Chemical) according to procedures outlined in Jones et al., (1990). Ashing was carried out in 250 ml beakers covered by 90 mm watch glasses on hot plates adjusted to 125°C for 4 h. A reagent blank was run for each set of six samples. After cooling, digestate was filtered through Whatman #1 filter paper and volume was brought to 20 ml. Determination of Cd, Pb, and Zn was by ICP spectrometry (Perkin-Elmer, Model 400) at 228.80 nm, 220.35 nm, and 213.85 nm, respectively. Heavy metal analysis of substrates and their elutriates were performed by ICP and reported previously (Youngman et al., 1998). Data analysis was performed using Statistical Analysis System (SAS, 1995). This experiment was designed to be analyzed as a hierarchical, or nested, analysis of variance (ANOVA). Soil type (bog or slag) was the highest design level; columns were nested within soil type and three replicate measures were taken for each column. The nested ANOVA presents variance components, which indicate the relative contribution of each hierarchical level to the total variance. Additionally, rank correlation analysis was performed to examine associations between concentration ratios in shoots and roots. Significance was determined at the probability level of $p <$ or $= 0.05$.

## RESULTS

Descriptive statistics are presented in Figures 1-3. Heavy-metal concentration in slag and bog substrates is summarized in Figure 1. Zinc concentrations were higher for both substrates than either cadmium or lead with cadmium having the lowest concentrations in both. Concentration of all three heavy metals in elutriates produced from each substrate was much higher for zinc than either of the other two metals, with concentrations of zinc being greater in slag than in bog substrate. Soil columns containing either of the two substrates supported extensive herbaceous biomass. Root biomass extended one-third to two-thirds of the length of the column in either substrate. Biomass production (Figure 2) and shoot-root biomass ratios were similar for both substrates with mean biomass ratios ranging from 0.52 for bog to 0.64 for slag substrates. Each of the heavy metals examined produced a different pattern of shoot-root concentration ratios (Figure 3). Concentration of cadmium in shoots and roots was higher with bog substrate. Shoot-root concentration ratios were similar for both substrates with much higher concentrations in roots than in shoots. Concentration of lead in plant biomass, conversely, was higher and more variable in slag than in bog substrate, and shoot-root concentration ratios were also higher for slag substrate. Zinc concentrations and shoot-root biomass ratios were similar for the two substrates, with higher concentration in roots than in shoots.

Variance components derived from nested ANOVA are depicted in Figure 4 only for those analyses that indicated a significant variance contribution by either soil type or column. Variance components indicated that most of the variability in heavy metal concentrations was attributed to differences among columns for zinc in shoots and to differences between soils for cadmium in shoots and in roots and for lead in roots. The only significant correlation between shoot and root concentration for a particular element was for lead from slag substrate ($r=-0.783$, $p = 0.0125$).

Even though most of the heavy metal was partitioned to the roots for either substrate, shoot concentrations of these metals were significantly higher than maximum tolerable dietary levels for cattle (National Research Council, 1980). This site would therefore not be suitable for grazing by livestock following phytoremediation. High concentrations of these metals in shoot and root biomass suggest that herbaceous vegetation would be a suitable sink for these heavy metals and that phytoextraction and phytostabilization might play significant roles in the remediation of smelter sites.

## CONCLUSIONS

1. High concentrations of zinc and lesser concentrations of cadmium and lead were present in slag and bog substrates. Soil elutriates had low detectable concentrations of cadmium and lead but relatively high concentrations of zinc with significantly higher concentration in slag elutriate.
2. Both organically amended substrates supported extensive herbaceous plant biomass with roots extending to the lower levels of each column.
3. Concentrations of all three heavy metals were five times greater in the roots than in the shoots for both substrate types. Concentration of cadmium in biomass was higher for bog substrate, concentration of lead in biomass was higher for slag substrate, and concentration of zinc in biomass was about equal for the two substrates.
4. Significant shoot-root concentrations of a particular metal were found only for lead for biomass for slag substrate.
5. The main source of variability of metal data is among columns for shoot zinc and between substrate types for shoot lead, shoot and root cadmium, and root lead.

6. Remediation of this smelter site could be accomplished by phytoextraction and phytostabilization. The use of herbaceous vegetation for grazing would appear to be precluded by shoot concentrations of all three metals in excess of maximum tolerable dietary levels for cattle.

## ACKNOWLEDGEMENT

This study was funded by Kansas EPSCoR: Enhancement of Bioremediation Research in Kansas, R82-1829-010. We acknowledge also the assistance of Dale and Nick Roark at Arrow Laboratory, Inc. (Wichita) for ICP spectrometric analysis of soil, water and plant samples and Karen Brown-Siullivan (Biological Sciences Department, WSU) for her assistance with statistical analysis and data interpretation.

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**Figure 1.** Cadmium, lead and zinc concentrations of substrates used for columns and for elutriates of these substrates. Values are means and +/-1SD based on three replicates.

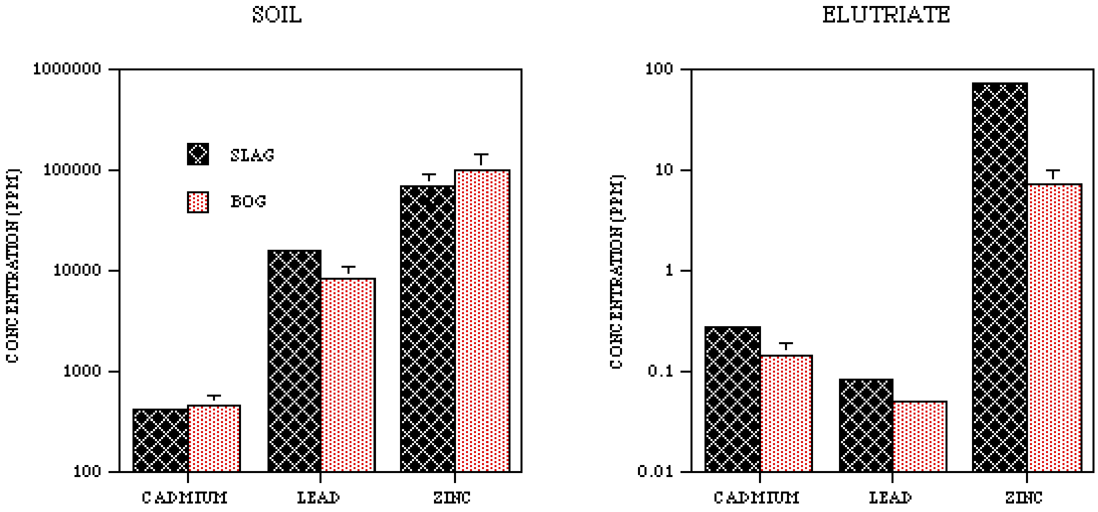

**Figure 2.** Total shoot and root biomass based on three columns for each substrate type. Values are means and +/-1SD based on three replicates.

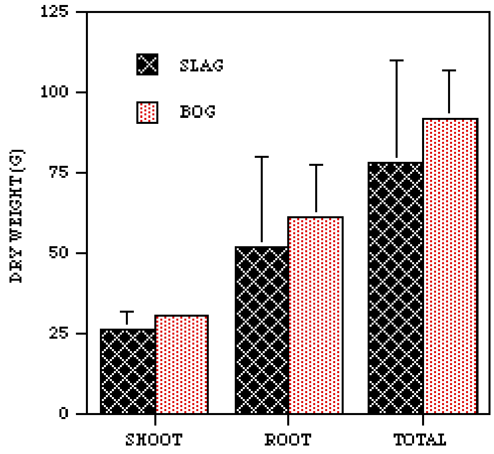

**Figure 3.** Concentration of cadmium, lead , and zinc for shoots and roots based on dry weight and shoot-root concentration ratios. Values are means and +/-1SD based on three samples from each of three columns for each substrate type. Maximum tolerable dietary levels for cadmium, lead, and zinc of 0.5, 30, and 500 ppm, respectively, are indicated with horizontal lines (National Research Council, 1980).

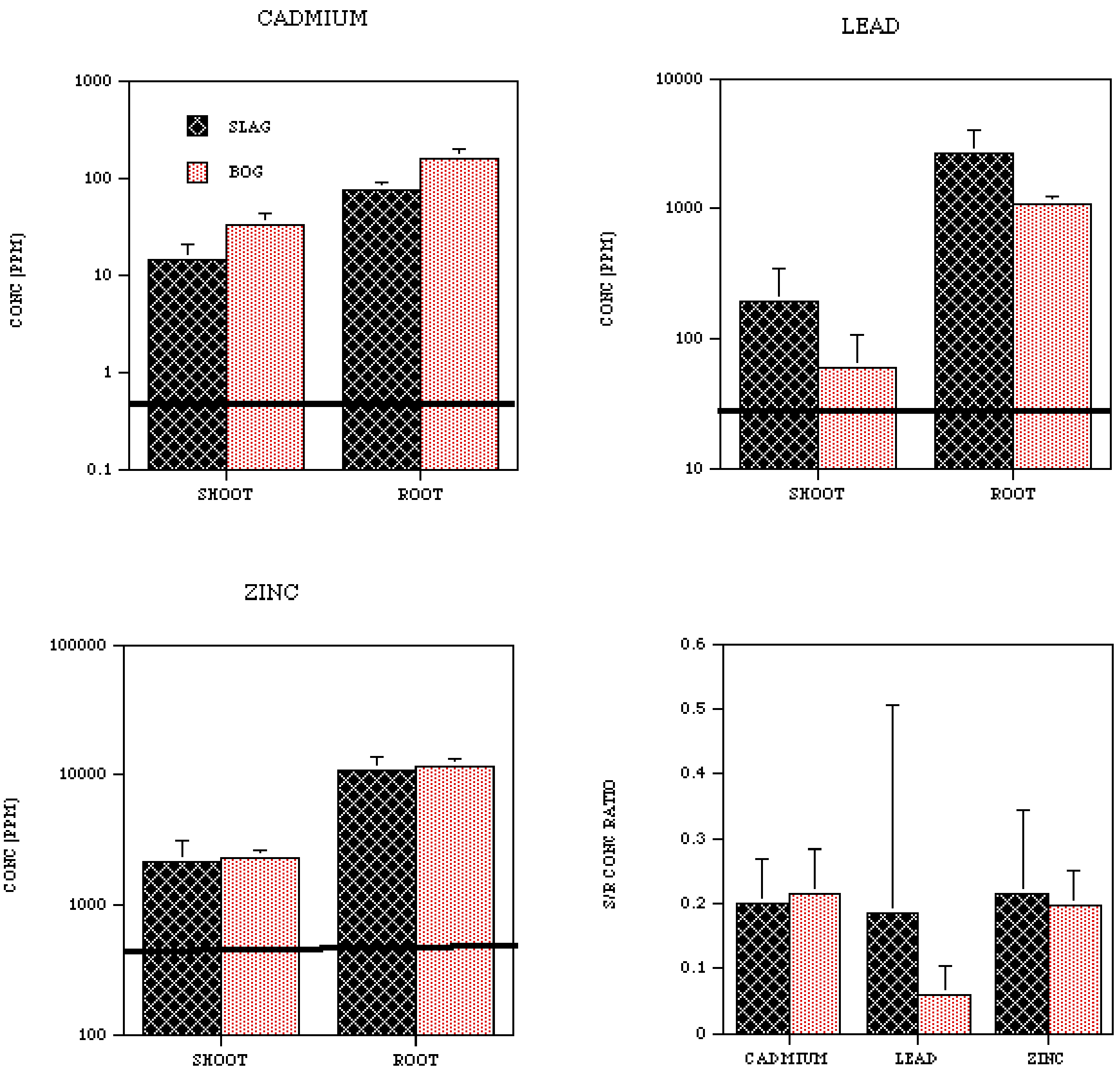

**Figure 4.** Source of variability of metal concentration data. Portion of total variance due to soil, column, or error are based on percentages. Although all combinations of shoots and roots for the three metals were evaluated, only those shown produced significant F-ratios based on nested analysis of variance.