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CEC	Cation exchange capacity
DW	Dry weight
LOD	Limit of detection

ABSTRACT

This study was undertaken to determine whether use of recovered sediment as a growth media for garden vegetables promotes the bioaccumulation of undesirable elements in plant tissues. Five plant species, bean, broccoli, carrot, pepper, and tomato, were grown in pots containing either dewatered, aged sediment or a reference soil. Plant growth, development, and yield in the two soils were quantified. Edible and vegetative tissues from the plants were analyzed for 19 elements, including environmentally-important heavy metals and metalloids. Some plants grown in sediment showed a greater biomass and yield as compared to the Ag soil. Elemental analysis of the tissues revealed that only Zn and Mo were elements that were significantly greater in sediment-grown plants on a consistent basis. While significant, Zn concentrations were no more than 3-fold higher than those in plants from the reference soil. The same trend was observed for Mo, except for bean tissues, which showed a >10-fold greater concentration (>20 mg kg^{-1} DW) in sediment-grown plants. The Mo concentrations observed are >3-fold greater than those associated with Mo toxicity to grazing animals, suggesting that use of recovered sediment should be monitored so as to prevent transfer of this element to terrestrial food webs.

1.0 INTRODUCTION

Dredging operations generate large volumes of sediment that must be either disposed of or put to productive use. Once dewatered, recovered sediment could potentially be used in a variety of ways, provided the material has suitable physical and chemical properties. Some potential uses of recovered sediment include use as clean fill, reclamation material, or for landscaping or gardening purposes. Such uses are contingent, however, on the assumption that the use of recovered sediment does not pose additional human or ecological risks.

Sediments from lakes, rivers, or other bodies of water that are used commercially or have contact with commercial enterprises may have elevated concentrations of some contaminants, including heavy metals, metalloids, or organic contaminants. Under aqueous, and often reducing, conditions in the sediment, these contaminants may not be present in soluble form. Rather, these elements may form colloids or precipitates that are retained in sediment rather than being distributed and/or diluted throughout the aqueous system.

When the sediment is dewatered and "aged", these reducing conditions slowly give rise to oxidizing conditions that can change the chemical and physical properties of the media and the speciation of the elements within the media. For example, the Kesterson Reservoir in California's San Joaquin Valley received significant inputs of selenium and other trace elements from agricultural drainage water. This selenium was converted to selenite, where it became largely unavailable to plants but was bioaccumulated in terrestrial food webs via benthic organisms in the wetland sediment (Tokunaga et al., 1991; Wahl et al., 1994). When the wetland was drained and filled as part of efforts to mitigate the accumulation of selenium, the change to

oxidizing conditions began a slow conversion of the selenite to selenate, increasing the bioavailability to and bioaccumulation in plants. Similar changes may occur when sediment is dewatered and land farmed, even for short periods of time. As with the former Kesterson Reservoir, efforts to reclaim sediment and put this material to beneficial use must carefully consider the repercussions of these efforts so as not to create or exacerbate existing problems.

The current study was undertaken to evaluate the potential bioaccumulation of elements from recovered sediment in the vegetative and edible tissues of five common garden plants. This effort is intended to provide managers within the Illinois Department of Natural Resources with the data necessary to evaluate the risks associated with the use of this material in situations where human consumption of edible plant tissues might occur. The plant species were specifically selected to provide an array of different edible tissues, ranging from root material (carrots), to stems (broccoli), fruits (tomato, pepper), and seeds (beans). This will provide an opportunity to evaluate the internal transport of the elements of interest throughout plant tissues, identifying specific elements or plant tissues that may need to be specifically monitored if recovered sediment is to be used in this manner. Analysis of the vegetative tissue will provide additional information, such as the potential ecological impact if specific metals bioaccumulate in leaves. This could pose an ecological risk or a human risk if these tissues were composted and then used as a soil amendment or mulch. The results should also indicate where additional research with this recovered sediment is warranted.

2.0 METHODOLOGY

2.1 Preparation for experiments

The two soils, the recovered sediment and the reference agricultural soil from the University of Illinois (hereafter referred to as Ag soil or reference soil) were received at SIUC in sand bags during the week of April 16, 2001. These sandbags were stored in a garage to protect the material from the elements. Both soils were highly compacted and sieving of the material was difficult, requiring nearly three weeks in total to sieve the material to ~5 mm. The reference soil was the most difficult to sieve as 25-40% of the material (by volume) consisted of tightly compacted aggregates (1-3 cm in diameter) that could not be broken down manually. Since there was ample material for the proposed experiments, it was decided that effort would not be put into reclaiming these aggregates, as it would significantly slow preparation. There was a minimal amount of coarse organic matter in the reference soil but this was easily removed during sieving. The reclaimed sediment showed no aggregate structure. Rather, the entire soil mass in the sandbag had compacted to a single cylindrical shape. In order to sieve the material, significant effort was required to break up the compaction within the sandbag, prior to sieving. The compaction of this material was a factor that was continually monitored throughout this work. After this initial step, the sediment proved relatively easy to handle and was sieved to 5 mm. Pebbles and freshwater mollusk shells were the only significant solid material in the sediment, representing <10% of the total volume.

Soils were stored covered on a plastic tarp during the sieving process. When all the bags of a given soil had been sieved, a cone and quarter technique was used to mix the soil. Briefly, the soil was raked into a cone in the center of the tarp and then quartered such that one-fourth of the

material was spread over a given quadrant. The soil was mixed by folding the respective halves of the soil over the middle. The soil was raked flat followed by another cone and quartering. The soil was mixed again by spreading and folding the soil over itself, but perpendicular to the first mixing step. These steps were repeated twice more, alternating direction 90º each time, so that the soil was coned, quartered and mixed from two separate directions, two times. The tarp was washed and rinsed thoroughly between soils to prevent any cross contamination. In addition, the reference soil was sieved first to insure no transfer of metals from sediment to reference. The texture and color of the two soils were similar after sieving (Fig 1). Both were dark brown with the reference soil showing a slightly lighter color. Particle size of the two soils was also similar (Fig 2). After mixing, each soil was transferred to plastic storage bins and relocated to the greenhouse facility where the plants would be grown.

2.2 Preliminary soil analyses

Soil was prepared for analysis by sieving 1 kg of each mixed soil to <2 mm. Samples (500 g of each soil) were sent to A&L Analytical Laboratories (Memphis, TN). The requested analyses and the results are shown in Table 1. A certified agronomist on staff at A&L Analytical provided fertilizer and liming recommendations (not shown). Particle size analysis confirmed that the two soils were similar in physical structure, as both were classified as silty loam. Nutrient levels in the two soils were similar, with the exception of K and Ca, whose concentrations were juxtaposed in the two soils. The sediment had lower K and higher Ca concentrations, and therefore requires additional K to increase fertility. Based upon these results, a time-release 18-6-12 fertilizer was obtained for use in the pot study, with KCl used to supplement the K levels in the sediment.

Fig 1. Reclaimed sediment after sieving and prior to final mixing. The reference soil was similar in color and appearance.

Fig 2. Texture of the reclaimed sediment after sieving. The penny and metric ruler are added for scale. This particle size is nearly identical to that of the sieved reference soil.

Table 1. Physical and chemical parameters of the reclaimed sediment and reference soils after sieving. Data were obtained from a contract laboratory.

Parameter	Units	Reference soil	Sediment
Particle size	%, sand-silt-clay	36-51-13	30-51-19
Soil classification		silty loam	silty loam
Bulk density	g mL^{-1}	1.20	1.17
Field capacity	g H_2O g^{-1} soil	0.50	0.52
pH		5.2	7.7
CEC	meq/100 g	27.1	27.6
Organic matter	%	1.4	2.1
N	%	0.14[a]	0.13[a]
P	mg kg^{-1} dry soil	81	60
K	mg kg^{-1} dry soil	178	126
Ca	mg kg^{-1} dry soil	3,176	5,772
Mg	mg kg^{-1} dry soil	625	591

[a] Represents total N, inorganic + organic

There was a two unit disparity in the pH between the two soils, with the reference Ag soil showing a more acidic pH. This value was confirmed in our own laboratory with triplicate measurements taken from 1:1 soil:water slurries (Ebbs et al., 1998). The liming recommendation provided by the A&L agronomist was checked by conducting a soil titration of the reference soil. Centrifuge tubes containing 25 g of reference soil were mixed with an equal volume of water containing from 25 to 100 mg of hydrated horticultural lime (1 to 4 mg g^{-1} soil). The centrifuge tubes were incubated at room temperature for five days on an orbital shaker, with triplicate pH measurements taken daily. The pH stabilized within 48 hours (Fig 3). The highest lime treatment achieved the desired pH range (7.5 to 7.8), corresponding to the pH of the sediment. This value is somewhat lower than the recommendation from the agronomist. However, the agronomist's estimate was based upon limestone addition. We used the lower value determined from the soil titration to insure that we would not exceed the desired pH range.

Samples of the 2 mm sieved soil were sent to WMRC for metal analysis in August, 2001 and also in December, 2002. In addition, water extracts of each soil were obtained by mixing the 2 mm sieved soil in a 1:1 ratio with deionized water. This slurry was shaken overnight and the solution recovered by vacuum filtration. These water extracts were also sent for analysis. The elements of interest were Ag, As, B, Ba, Be, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Se, Ti ,Tl, V, and Zn. The data obtained for the two analyses were comparable and are presented in Fig. 4.

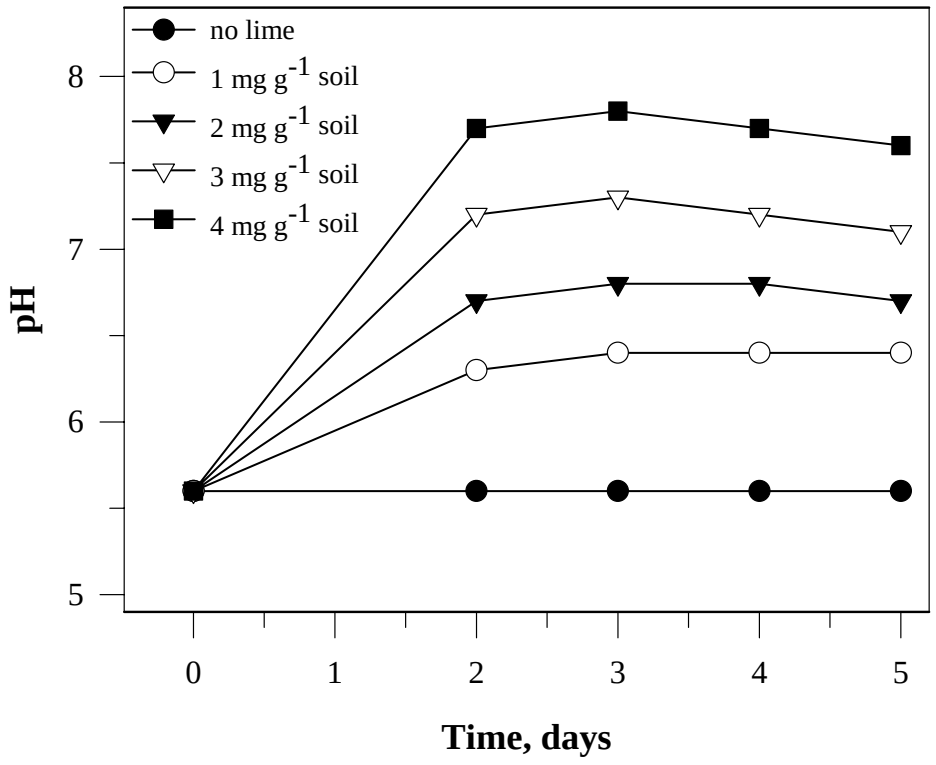

Fig 3. Results from the titration of the reference soil with different quantities of hydrated lime (1-4 mg g^{-1} soil). The pH of the reclaimed sediment is 7.7, so this value represented the desired target value for the soil titration.

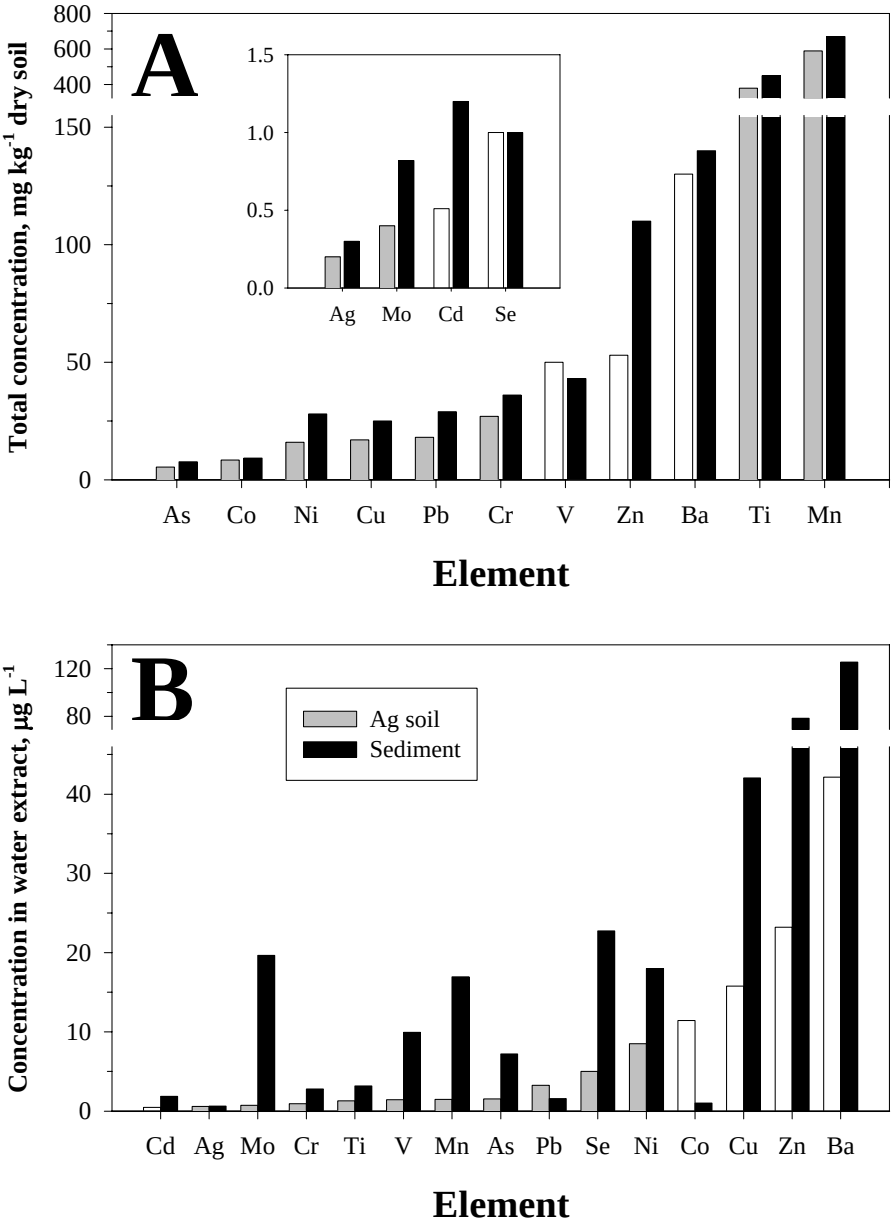

Fig 4. Elemental analysis of the Ag soil and recovered sediment used in these experiments. Data are from a single sample submitted to WMRC in December, 2002. Elements analyzed for but not shown were at or below the limit of detection. **A** Total elemental content for the elements of interest. Axes for the inset correspond to those of the main figure. **B** Elemental concentration in the 1:1 water extract of the two soils.

The analysis of the soil and water extracts of the soil demonstrated that the concentration of several elements was higher for the sediment that the reference soil. With respect to the total elemental content, values were comparable for all elements except Cd, Mo, and Zn. For these three elements, the concentration was no more than 2.5-fold greater than the concentration in the reference soil. However, when the same comparison was made for the water extracts, more dramatic differences emerged. Concentrations of seven elements (As, Ba, Cd, Cu, Se, V, Zn) were from 2.7- to 7-fold higher in the water extracts from the sediment than from the Ag soil. Surprisingly, Mn concentrations were more than 11-fold higher and Mo concentrations 27-fold higher. Possible explanations for the increased solubility of Mo in the recovered sediment appear in the **Discussion**.

Field capacity for each soil was experimentally determined using a gravimetric approach (W. Norvell, USDA-ARS, personal communication). A known mass of oven-dried soil was placed in a polyethylene tube with a small hole cut slightly off-center from the tube bottom. The soil was gradually wetted until breakthrough was observed. When flow through the tube ceased, the mass of water absorbed by the soil was determined, correcting for any soil lost to leaching. Field capacity of the two soils was similar, at ~0.52 g H_2O g^{-1} soil, with 80% of this value selected as the target moisture level for the proposed pot study.

2.3 – Bioaccumulation experiment

Forty pots containing 20 kg of either Ag soil or recovered sediment were established in a total of four replicate blocks (2 soils x 4 blocks x 5 plant species). Pots were randomized within each block to minimize variability. Fertilizer and lime (reference soil only) were top-dressed and

incorporated into the upper 20 cm of the pots during the week of July 9, as a simulation of garden conditions. The amendments were watered in with a sufficient volume of water to reach ~80% of field capacity. A period of 5-7 days was allowed for the lime to react and the fertilizer to begin dispersing into the soil water. Each pot was placed in a nursery tray to allow watering from below and to prevent leaching or loss of soil. Watering from below was also employed during this study to minimize the compaction of the recovered sediment material. Since this material undergoes significant cracking when the soils dries after wetting, it was necessary to maintain the soil at a fairly consistent moisture level and loosen the surface soil frequently to allow the plants in each pot to become established. This compaction and cracking was restricted to the upper 2-3 cm of the soil, with the material below this layer holding its water capacity and texture.

Seeds of bean (*Phaseolus vulgaris*, var. Kentucky Wonder), broccoli (*Brassica oleracea*, var. Calabrese), carrot (*Daucus carota*, var. Chantenay), pepper (*Capsicum annum*, var. California Wonder 300), and tomato (*Lycopersicon esculentum*, large cherry) were obtained from local commercial sources and germinated on filter paper prior to the introduction to the pots. Germination and soil preparations were timed to allow soil nutrient and pH levels to equilibrate prior to introduction of the seeds. After emergence, plants were thinned to five per pot for tomato, pepper, and bean, ten plants per pot for carrot, and one plant per pot for broccoli. Some volunteer plants of each species emerged after thinning and were retained in each pot. Plants were grown in a phytotron under controlled light and temperature conditions (natural lighting + supplemental lighting on a 16 hr photoperiod, 25º C $\pm$ 2º C) and were watered as necessary to maintain adequate hydration of the soil (Fig. 5).

Fig 5. Three of the four replicate blocks of plants from the bioaccumulation study. This picture was taken approximately 45 days after the initiation of the experiment. Pots that appear to have no plants contained small pepper seedlings that are not apparent. The peppers demonstrated slow and inconsistent germination in both soils, so growth of these plants lagged behind the other plants.

The flowering plants (bean, pepper, and tomato) were grown to reproductive maturity, defined here as a point where the first fruits set had reached their full size (Table 2). In addition to fruits, the whole shoots, defined here as the combination of both stem and leaves, of tomato and pepper were harvested. Similar tissues obtained from pots with more than one plant were combined to form a composite sample. Bean shoots were separated into stem and leaves while the bean pods were separated into seeds and hulls. The carrots and broccoli were harvested when each showed substantial development, although these plants had not perhaps reached their maximum size. Carrots were separated into roots and shoots. The roots were scrubbed with a vegetable brush

Table 2. Summary of vegetative and reproductive tissues harvested from the five plant species grown in the bioaccumulation study. Vegetative tissues include stems, leaves, shoots (stem and leaves harvested together), or root (carrot only). Roots could not be harvested from the remaining plants due to the tight compaction that occurred, predominantly in the sediment. Reproductive tissues were either fruits or seeds. These plant species were specifically selected because they provided a wide range of edible tissues

	Tissues Harvested	
Plant Species	**Vegetative**	**Reproductive**
Carrot	Root, Shoot	–
Broccoli	Shoot	–
Pepper	Shoot	Fruits
Tomato	Shoot	Fruits
Bean	Stem, Leaves	Beans, Hulls

and peeled, with the peels and peeled root both initially retained for elemental analysis. Unfortunately, some of the peel samples were discarded rather than reserved. Given the decrease in replicate number this caused, and the fact that there was some confusion in the numbering scheme for these samples, the data from the analysis of the peels is not included in this report. For broccoli, only the whole shoot was harvested. All tissues were rinsed with deionized water to remove any adhering soil particles and blotted dry. Plant tissues were chopped to a coarse consistency to facilitate the drying process (60º C to constant mass). Plants were ground to a fine powder using a Wiley Mill and total dry weight was determined. Subsamples of each tissue were submitted to WMRC for elemental analysis.

2.4 Data analysis

Means and standard errors were calculated, treating individual values within a set of replicates that were at or below the limit of detection (LOD) as the LOD value. If all four replicates were at the LOD, then the data for that element were not included in the data analysis. Concentration ratios were also calculated for each tissue and represent the ratio between the concentration in the tissue and the total concentration in the soil, with both expressed on a dry weight basis. The means obtained for samples from Ag soil- or sediment-grown plants were compared using the Student's T-test (Snedecor and Cochran, 1967).

3.0 RESULTS

3.1 Plant growth, development, and yield

Plants grew equally well in both the soils used in this experiment (Figs 6-7). In fact, total shoot dry mass for pepper and tomato, as well as total hull dry mass for beans, was significantly greater ($P \leq 0.01$) for plants grown in the sediment compared to plants in the Ag soil (Table 3). Likewise, there were no significant differences in the biomass or yield of edible tissues for any of the plants examined (Table 4). As expected, the recovered sediment showed significant compaction and cracking during the experimental period. However, manual disruption of the soil minimized adverse effect on plant growth. Carrots were the notable exception as this root vegetable showed some alteration of growth. Carrots grown in the sediment were generally shorter and had a larger diameter than corresponding plants in the Ag soil (Fig. 8). Beans were the only plant species to show any adverse foliar effects during the experiment (Fig. 9), but plants growing in both soils showed similar symptoms at an equal intensity.

Fig 6. Tomato (foreground) and bean (background) plants growing in recovered sediment (left) and Ag soil (right). The rate and extent of plant growth and development did not differ between the two soils.

Fig 7. Two of the four replicate blocks late in the bioaccumulation experiment just prior to harvest. Fully-developed red peppers growing in a sediment pot are visible in the background.

Table 3. Biomass of vegetative tissues from the plants grown for the bioaccumulation experiment. Peels refer to the scrapings that would normally be obtained when carrots are prepared for human consumption. Values represent the mean and standard error for each plant species and indicated tissue (*n*=4 for all but carrot peels, where *n*=3).

		Total dry mass		
Media	**Plant**	**Leaves or shoots[a], g**	**Stems, g**	**Peels, g**
Ag Soil				
	bean	2.5 (0.6)	6.8 (0.8)	–
	carrot	36.7 (2.4)	–	11.8 (2.1)
	pepper	31.0 (4.6)	–	–
	tomato	108.5 (4.5)	–	–
Sediment				
	bean	2.9 (0.9)	8.3 (1.7)	–
	carrot	38.3 (3.8)	–	18.2 (5.1)
	pepper	61.4 (7.9)	–	–
	tomato	161.5 (10.8)	–	–

[a] For all plants except bean, leaves and stems were harvested together as shoots.

Table 4. Biomass and yield of edible tissues from the plants grown for the bioaccumulation experiment. Values represent the mean and standard error (n=4 for all except carrot, where n=3) for edible tissues for each plant species indicated (bean pods, broccoli stems, carrots, and pepper or tomato fruits). Total dry mass for all plants except broccoli represents the mean dry mass for all edible harvested tissues from a single pot. For broccoli, total dry mass values represent stem biomass. Total yield represents the mean number of fruits (tomato or pepper), pods (beans), or carrot roots produced within a single pot. Yield represents the unit mass of the harvested fruits, pods, or carrot roots from each pot (e.g., g fruit^{-1} or g seed pod^{-1}).

		Biomass measurement		
Media	**Plant**	**Total dry mass, g**	**Total yield, g**	**Yield, g unit^{-1}**
Ag Soil				
	bean, seeds	16.6 (6.6)	25.0 (3.1)	0.6 (0.2)
	bean, hulls	15.3 (3.8)	–	–
	broccoli	126.1 (5.7)	–	–
	carrot	55.4 (6.1)	12.3 (1.0)	4.9 (0.9)
	pepper	22.5 (10.1)	6.0 (1.2)	3.4 (1.1)
	tomato	19.2 (5.5)	43.3 (9.3)	0.4 (0.0)
Sediment				
	bean, seeds	11.1 (1.3)	28.5 (3.5)	0.4 (0.1)
	bean, hulls	28.2 (2.1)	–	–
	broccoli	144.0 (24.1)	–	–
	carrot	26.9 (14.9)	14.3 (1.7)	3.2 (1.3)
	pepper	16.3 (7.9)	9.5 (3.3)	1.7 (0.6)
	tomato	29.1 (3.1)	59.8 (10.2)	0.5 (0.0)

Fig 8. Growth of carrots in the recovered sediment. Note the cracking of the soil (above) and the short, broad structure of carrots harvested from this media.

Fig 9. Growth of beans in sediment (left) and Ag soil (right). Note that the foliar symptoms are present on plants growing in both soils. The most likely explanation for these symptoms are insect damage, natural senescence at fruit (bean) maturity, or a combination of the two.

3.2 Metal uptake and bioaccumulation

For a number of elements, there was no significant difference in elemental content between comparable tissues from plants grown in the sediment and Ag soil. In fact, there were several instances where plant tissue concentrations for some elements were higher in plants grown on the Ag soil that in plants from the sediment pots (Tables 5-10). What makes this trend interesting is the fact the sediment typically had elemental concentrations equal to or higher than the concentrations in the Ag soil, both in terms of total and water-soluble elemental content (Fig. 4).

Table 5. Concentration of selected elements in the shoots (leaves + stems) and fruits of tomato. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection for all replicates from both soils.

	Concentration in shoots, mg kg^{-1}			Concentration in fruits, mg kg^{-1}		
	Ag soil	Sediment	P-value	Ag soil	Sediment	P-value
Cr	<0.3	0.3 (0.1)	NS	0.4 (0.1)	0.3 (0.04)	NS
Pb	0.3 (0.1)	0.6 (0.3)	NS	0.3 (0.1)	0.4 (0.1)	NS
Ni	1.3 (0.3)	0.7 (0.1)	**0.04**	1.0 (0.03)	0.6 (0.04)	**0.001**
Cd	1.1 (0.4)	0.8 (0.1)	NS	0.5 (0.02)	0.5 (0.03)	NS
Mo	0.9 (0.3)	3.1 (0.5)	**0.003**	0.5 (0.02)	1.0 (0.1)	**0.001**
Ti	8.3 (1.4)	7.6 (0.5)	NS	10.0 (1.0)	9.7 (0.2)	NS
Cu	8.3 (1.0)	7.9 (0.8)	NS	7.3 (0.3)	9.7 (1.3)	NS
Mn	46.9 (12.8)	16.2 (4.9)	**0.03**	9.2 (0.3)	7.5 (0.3)	**0.002**
Ba	23.3 (7.6)	20.2 (2.3)	NS	1.4 (0.1)	1.3 (0.1)	NS
Zn	26.1 (3.5)	32.7 (6.1)	NS	16.4 (0.3)	24.3 (7.4)	NS
B	55.4 (18.5)	50.2 (12.8)	NS	10.6 (1.5)	13.6 (1.5)	NS

Table 6. Concentration of selected elements in the shoots (leaves + stems) and fruits of peppers. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection for all replicates from both soils.

	Concentration in shoots, mg kg^{-1}			Concentration in fruits, mg kg^{-1}		
	Ag soil	Sediment	P-value	Ag soil	Sediment	P-value
Cr	0.4 (0.1)	0.5 (0.1)	NS	0.5 (0.1)	0.4 (0.1)	NS
Co	0.5 (0.1)	0.2 (0.01)	**0.003**	0.2 (0.02)	0.2 (0.01)	NS
Pb	0.3 (0.1)	0.2 (0.02)	NS	0.6 (0.3)	0.3 (0.04)	NS
Ni	7.1 (2.1)	3.4 (0.4)	NS	6.1 (2.2)	2.5 (0.6)	NS
Cd	2.3 (0.7)	3.0 (0.4)	NS	0.5 (0.1)	0.8 (0.1)	**0.004**
Mo	0.2 (0.01)	0.3 (0.1)	**0.03**	0.23 (0.02)	0.42 (0.1)	**0.03**
Ti	8.26 (0.9)	8.1 (0.8)	NS	7.8 (0.3)	8.6 (0.5)	NS
Cu	11.3 (1.3)	11.0 (1.9)	NS	11.0 (1.4)	14.6 (2.2)	NS
Mn	47.2 (6.0)	29.3 (4.1)	**0.04**	12.1 (0.7)	12.0 (0.6)	NS
Ba	34.0 (2.7)	14.2 (1.2)	**0.001**	1.6 (0.1)	0.7 (0.1)	**0.001**
Zn	41.0 (8.4)	69.0 (8.5)	**0.02**	16.4 (2.5)	21.3 (1.0)	**0.04**
B	76.3 (6.9)	78.1 (18.7)	NS	19.7 (2.3)	18.3 (1.7)	NS

Table 7. Concentration of selected elements in the vegetative tissues (leaves or stems) from beans. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection (LOD) for all replicates from both soils.

	Concentration in stems, mg kg^{-1}			Concentration in leaves, mg kg^{-1}		
	Ag soil	Sediment	P-value	Ag soil	Sediment	P-value
As	0.2 (0.04)	0.5 (0.1)	**0.002**	0.3 (0.1)	0.4 (0.2)	NS
Be	LOD	LOD	NS	0.2 (0.04)	0.5 (0.1)	**0.002**
Co	0.2 (0.03)	LOD	NS	0.5 (0.3)	0.3 (0.1)	NS
Cr	0.7 (0.4)	0.4 (0.04)	NS	2.2 (0.7)	1.2 (0.6)	NS
Pb	0.6 (0.2)	0.5 (0.1)	NS	0.9 (0.6)	0.9 (0.5)	NS
Ni	1.4 (0.3)	0.8 (0.1)	**0.03**	3.0 (1.2)	2.4 (0.6)	NS
Cd	0.3 (0.1)	0.4 (0.03)	NS	LOD	LOD	NS
Se	LOD	LOD	NS	LOD	1.2 (0.2)	NS
Mo	2.1 (0.2)	28.3 (1.6)	**0.001**	3.8 (1.2)	31.4 (6.1)	**0.003**
Ti	8.8 (3.6)	5.9 (0.6)	NS	19.6 (11.3)	16.1 (6.2)	NS
Cu	7.1 (1.9)	7.8 (1.5)	NS	8.9 (1.0)	8.2 (0.5)	NS
Mn	19.1 (1.1)	10.7 (0.8)	**0.001**	122.5 (11.9)	46.7 (7.3)	**0.001**
Ba	33.3 (2.3)	20.4 (2.6)	**0.003**	86.9 (7.5)	51.6 (11.7)	**0.02**
Zn	16.7 (2.4)	35.6 (1.6)	**0.001**	21.9 (4.1)	33.3 (3.7)	**0.03**
B	10.9 (0.9)	25.6 (4.3)	**0.01**	95.9 (6.5)	100.1 (14.2)	NS

Table 8. Concentration of selected elements in the edible tissues (seeds or hulls) from beans. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection for all replicates from both soils.

	Concentration in seeds, mg kg^{-1}			Concentration in hulls, mg kg^{-1}		
	Ag soil	Sediment	P-value	Ag soil	Sediment	P-value
Cr	0.5 (0.3)	1.4 (1.4)	NS	1.0 (0.1)	0.3 (0.1)	**0.001**
Pb	0.5 (0.3)	2.4 (1.2)	NS	1.3 (0.6)	0.9 (0.2)	NS
Ni	5.1 (0.2)	8.9 (1.9)	**0.05**	3.5 (1.3)	3.5 (0.8)	NS
Mo	5.3 (0.3)	34.8 (1.9)	**0.001**	1.6 (0.3)	24.9 (2.0)	**0.001**
Ti	8.8 (0.6)	7.7 (0.5)	NS	5.11 (0.9)	8.2 (1.8)	**0.001**
Cu	9.6 (0.4)	9.7 (0.4)	NS	7.1 (0.8)	7.8 (0.4)	NS
Mn	14.5 (0.7)	11.0 (0.2)	**0.002**	17.0 (1.7)	13.8 (1.8)	NS
Ba	2.5 (0.3)	1.5 (0.3)	**0.02**	15.4 (1.2)	8.8 (1.2)	**0.003**
Zn	27.2 (0.5)	34.3 (1.5)	**0.001**	18.9 (4.6)	26.6 (2.5)	NS
B	12.6 (3.0)	LOD	NS	59.7 (5.5)	31.4 (4.2)	**0.002**

Table 9. Concentration of selected elements in tissues from carrot. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection (LOD) for all replicates from both soils.

	Concentration in peeled roots, mg kg^{-1}			Concentration in shoots, mg kg^{-1}		
	Ag soil	Sediment	P-value	Ag soil	Sediment	P-value
Cr	0.5 (0.1)	0.7 (0.1)	NS	2.1 (0.9)	1.6 (0.7)	NS
As	LOD	LOD	–	0.3 (0.1)	0.3 (0.2)	NS
Pb	0.5 (0.1)	0.4 (0.1)	NS	0.9 (0.7)	0.9 (0.5)	NS
Ni	4.1 (2.7)	2.7 (1.1)	NS	2.8 (0.9)	2.5 (1.1)	NS
Co	LOD	LOD	–	0.4 (0.2)	0.4 (0.3)	NS
Cd	0.9 (0.2)	1.2 (0.2)	NS	1.5 (0.4)	1.5 (0.4)	NS
Mo	0.3 (0.1)	0.2 (<0.01)	NS	1.4 (0.4)	1.8 (0.4)	NS
Ti	5.0 (0.4)	12.5 (1.0)	**0.001**	17.3 (7.7)	16.4 (8.5)	NS
Cu	6.1 (0.6)	8.5 (0.6)	**0.008**	7.7 (1.5)	8.3 (1.4)	NS
Mn	7.1 (1.4)	10.4 (1.3)	**0.05**	52.8 (3.9)	37.8 (10.1)	NS
Ba	37.0 (3.8)	53.3 (4.6)	**0.01**	104.3 (27.7)	94.0 (18.2)	NS
Zn	19.5 (2.0)	28.0 (3.5)	**0.03**	31.5 (6.3)	35.8 (5.1)	NS
B	25.2 (2.1)	36.8 (2.2)	**0.003**	72.8 (13.8)	83.8 (16.9)	NS

Table 10. Concentration of selected elements in broccoli shoots. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection (LOD) for all replicates from both soils.

	Concentration in shoots, mg kg^{-1}						
	Ag soil	Sediment	P-value		Ag soil	Sediment	P-value
Cr	0.2 (0.02)	0.7 (0.3)	**0.03**	**Ti**	5.9 (0.6)	6.2 (0.7)	NS
As	0.4 (0.1)	LOD	–	**Cu**	2.1 (0.3)	2.5 (0.3)	NS
Pb	0.3 (0.1)	0.2 (0.02)	NS	**Mn**	19.9 (2.9)	11.5 (0.9)	**0.005**
Ni	1.2 (0.4)	1.7 (0.8)	NS	**Ba**	37.2 (6.7)	35.3 (6.7)	NS
Cd	0.2 (0.01)	0.3 (0.1)	NS	**Zn**	9.7 (1.7)	20.9 (2.5)	**0.03**
Mo	1.8 (0.5)	4.8 (1.0)	**0.02**	**B**	37.1 (6.4)	54.2 (3.6)	**0.02**

This is particularly evident when the data are expressed in terms of the concentration ratio, defined here as the ratio of the concentration in the plant tissue (dry weight basis) to the total elemental concentration in the dry soil. Nearly all differences that were statistically significant were instances where the concentration ratio, which for most elements was 5.0 or less, was greater for plants in the Ag soil than for plants in the sediment (Tables 11-16). There were few exceptions to this trend and almost all of these involved a limited number of elements.

For sediment-grown plants, Mo and Zn were the only two elements that were, with any consistency, present at significantly higher concentrations than plants grown in Ag soil. While significant, the differences in Zn content were no more than 2-fold, regardless of the plant species examined. There was no significant difference in the Zn content of tomato shoots or fruits between the two soils (Table 5). Ironically, Zn concentration ratios for the various plant species were either not significantly different between soils or were significantly greater in the Ag soil. This implies that the difference in Zn concentration is primarily due to the higher concentration of soil Zn but that Zn uptake is somewhat consistent between plants grown in the two soils.

More surprising were the results for Mo. For all species except carrot (Table 9), the Mo concentration was significantly higher in sediment-grown plants than in those grown in Ag soil. For tomato, pepper, and broccoli, the values were, like Zn, no more than 3-fold higher in the sediment-grown plants. However, Mo concentrations in all bean tissues from sediment-grown plants were up to 16-fold higher, reaching concentrations in excess of 30 mg kg^{-1} DW (Tables 7-8). The Mo concentration ratios were also significantly greater in tomato (Table 11) and bean

(Tables 13-14). The Mo concentration ratio varied from less than 1.0 for some species to greater than 20.0 for beans. While the total and soluble Mo concentrations in the sediment were higher than in the Ag soil, Mo transport by these plant species clearly differed and lead to the patterns of accumulation observed here. Although beans were the only species to show overt foliar damage during this experiment, it should be reiterated that these symptoms were equally evident in plants from Ag soil and sediment pots, despite differences in concentration of greater than one order of magnitude. Thus, Mo accumulation does not appear to be the proximate cause of these effects.

There were other instances in which the content of one or more elements was significantly greater in sediment-grown plants than in those grown in Ag soil, but this was typically limited to only a single plant species. For example, the Ni content of some bean tissues was significantly greater in sediment grown plants, although the magnitude of the difference was small. Boron and beryllium concentrations were also significantly greater in vegetative tissues of bean and broccoli from sediment-grown plants. Nevertheless, for these and other elements, the instances where differences are significant are generally not those where the elemental concentrations differ substantially in magnitude.

4.0 DISCUSSION

The primary objective of the study conducted here was to evaluate the extent to which elements in recovered sediment bioaccumulated in the edible tissues of common garden plants. This will provide the information necessary to evaluate how usage of this material might impact human health. A secondary objective was to evaluate bioaccumulation in vegetative tissues to provide

Table 11. Concentration ratios for elements in tissues of tomato. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection (LOD) for all replicates from both soils.

	Concentration Ratio in shoots			Concentration Ratio in fruits		
	Ag soil	Sediment	P-value	Ag soil	Sediment	P-value
Cr	0.01 (<0.01)	0.01 (<0.01)	NS	0.01 (<0.01)	0.01 (<0.01)	NS
Pb	0.02 (<0.01)	0.02 (0.01)	NS	0.02 (<0.01)	0.01 (<0.01)	NS
As	0.04 (<0.01)	0.03 (<0.01)	NS	0.04 (<0.01)	0.03 (<0.01)	NS
Ni	0.08 (0.02)	0.03 (<0.01)	**0.02**	0.1 (<0.01)	0.02 (<0.01)	**0.001**
Cd	2.2 (0.7)	0.7 (0.1)	**0.05**	0.9 (0.04)	0.4 (0.03)	**0.001**
Mo	2.1 (0.6)	3.8 (0.7)	**0.04**	1.1 (0.1)	1.2 (0.1)	**0.03**
Ti	0.02 (<0.01)	0.02 (<0.01)	NS	0.03 (<0.01)	0.02 (<0.01)	NS
Cu	0.5 (0.1)	0.3 (0.03)	**0.02**	0.4 (0.02)	0.4 (0.1)	NS
Mn	0.08 (0.02)	0.02 (0.01)	**0.02**	0.02 (<0.01)	0.01 (<0.01)	NS
Ba	0.2 (0.1)	0.1 (0.02)	NS	0.01 (<0.01)	0.01 (<0.01)	NS
Zn	0.5 (0.1)	0.3 (0.1)	**0.02**	0.3 (0.01)	0.2 (0.1)	NS
B	5.5 (1.9)	2.5 (0.6)	NS	1.1 (0.1)	0.7 (0.1)	**0.003**

Table 12. Concentration ratios for elements in tissues of pepper. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection (LOD) for all replicates from both soils.

	Concentration Ratio in shoots			Concentration Ratio in fruits		
	Ag soil	Sediment	P-value	Ag soil	Sediment	P-value
Cr	0.02 (<0.01)	0.01 (<0.01)	NS	0.02 (<0.01)	0.01 (<0.01)	NS
Co	0.1 (0.01)	0.02 (<0.01)	**0.02**	0.03 (<0.01)	0.02 (<0.01)	**0.05**
Pb	0.01 (<0.01)	0.01 (<0.01)	NS	0.03 (0.01)	0.01 (<0.01)	NS
As	0.04 (<0.01)	0.03 (<0.01)	**0.001**	0.04 (<0.01)	0.03 (<0.01)	**0.05**
Ni	0.4 (0.1)	0.1 (0.01)	**0.04**	0.4 (0.1)	0.1 (0.02)	**0.05**
Cd	4.6 (1.5)	2.5 (0.3)	NS	1.0 (0.1)	0.7 (0.1)	**0.03**
Mo	0.5 (0.03)	0.4 (0.1)	NS	0.5 (0.1)	0.5 (0.1)	NS
Ti	0.02 (<0.01)	0.02 (<0.01)	NS	0.02 (<0.01)	0.02 (<0.01)	NS
Cu	0.7 (0.1)	0.4 (0.1)	**0.03**	0.7 (0.1)	0.6 (0.1)	NS
Mn	0.1 (0.01)	0.04 (0.01)	**0.01**	0.02 (<0.01)	0.02 (<0.01)	NS
Ba	0.3 (0.02)	0.1 (0.02)	**0.001**	0.01 (<0.01)	<0.01 (<0.01)	NS
Zn	0.8 (0.2)	0.6 (0.1)	NS	0.3 (0.1)	0.2 (0.01)	**0.04**
B	7.6 (0.7)	3.9 (1.0)	**0.001**	2.0 (0.2)	1.0 (0.1)	**0.01**

Table 13. Concentration ratios for selected elements in the vegetative tissues (leaves or stems) from beans. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection (LOD) for all replicates from both soils.

	Concentration Ratio in stems			Concentration Ratio in leaves		
	Ag soil	Sediment	P-value	Ag soil	Sediment	P-value
As	0.1 (0.01)	0.1 (0.01)	NS	0.1 (0.02)	0.1 (0.02)	NS
Hg	0.02 (<0.01)	<0.01 (<0.01)	**0.01**	0.05 (0.01)	0.04 (0.02)	NS
Co	0.03 (<0.01)	0.02 (<0.01)	NS	0.1 0.03)	0.03 (0.01)	NS
Cr	0.03 (0.01)	0.01 (<0.01)	NS	0.1 (0.03)	0.03 (0.02)	NS
Pb	0.03 (0.01)	0.02 (<0.01)	NS	0.1 (0.03)	0.03 (0.02)	NS
Ni	0.1 (0.02)	0.03 (<0.01)	**0.02**	0.2 (0.1)	0.1 (0.02)	NS
Cd	0.6 (0.1)	0.3 (0.03)	NS	0.4 (<0.01)	0.2 (<0.01)	NS
Mo	4.9 (0.6)	34.5 (2.0)	**0.001**	8.6 (2.7)	38.3 (7.4)	**0.003**
Ti	0.02 (0.01)	0.01 (<0.01)	NS	0.1 (0.03)	0.04 (0.01)	NS
Cu	0.4 (0.1)	0.3 (0.1)	NS	0.5 (0.1)	0.3 (0.02)	**0.007**
Mn	0.03 (<0.01)	0.02 (<0.01)	**0.001**	0.2 (0.02)	0.1 (0.01)	**0.001**
Ba	0.3 (0.02)	0.2 (0.02)	**0.002**	0.7 (0.1)	0.4 (0.1)	**0.008**
Zn	0.3 (0.1)	0.3 (0.01)	NS	0.4 (0.1)	0.3 (0.03)	NS
B	1.1 (0.1)	1.3 (0.2)	NS	9.6 (0.7)	5.0 (0.7)	**0.001**

Table 14. Concentration ratios for selected elements in the edible tissues (seeds or hulls) from beans. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection (LOD) for all replicates from both soils.

	Concentration Ratio in seeds			Concentration Ratio in hulls		
	Ag soil	Sediment	P-value	Ag soil	Sediment	P-value
Cr	0.02 (0.01)	0.04 (<0.04)	**0.001**	0.04 (<0.01)	0.01 (<0.01)	NS
Pb	0.03 (0.01	0.1 (0.04)	NS	0.1 (0.04)	0.03 (0.01)	NS
Ni	0.3 (0.1)	0.3 (0.1)	NS	0.2 (0.1)	0.1 (0.03)	NS
Mo	12.1 (0.7)	42.4 (2.3)	**0.001**	3.7 (0.7)	30.4 (2.5)	**0.001**
Ti	0.02 (<0.01)	0.02 (<0.01)	NS	0.01 (<0.01)	0.02 (<0.01)	NS
Cu	0.6 (0.02)	0.4 (0.02)	**0.02**	0.4 (0.1)	0.3 (0.02)	**0.03**
Mn	0.02 (<0.01)	0.02 (<0.01)	NS	0.03 (<0.01)	0.02 (<0.01)	NS
Ba	0.02 (0.01)	0.01 (0.01)	**0.2**	0.1 (0.01)	0.1 (0.01)	**0.002**
Zn	0.5 (0.1)	0.3 (0.01)	**0.001**	0.4 (1.0)	0.2 (0.02)	NS
B	–	–	–	6.0 (0.6)	1.6 (0.2)	**0.001**

Table 15. Concentration ratios for selected elements in tissues from carrot. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection (LOD) for all replicates from both soils.

	Concentration Ratio in peeled roots			Concentration Ratio in shoots		
	Ag soil	Sediment	P-value	Ag soil	Sediment	P-value
Cr	0.02 (<0.01)	0.02 (<0.01)	NS	0.03 (0.02)	0.04 (0.03)	NS
As	–	–	–	0.1 (0.03)	0.04 (0.02)	NS
Pb	0.03 (0.01)	0.01 (<0.01)	NS	0.1 (0.04)	0.03 (0.02)	NS
Ni	0.3 (0.2)	0.1 (0.04)	NS	0.2 (0.1)	0.1 (0.04)	NS
Cd	1.8 (0.4)	1.0 (0.2)	**0.04**	2.9 (0.8)	0.7 (0.1)	**0.04**
Mo	0.6 (0.1)	0.3 (<0.02)	NS	3.3 (0.8)	2.1 (0.5)	NS
Ti	0.01 (<0.01)	0.03 (<0.01)	**0.001**	0.1 (0.02)	0.04 (0.02)	NS
Cu	0.4 (0.03)	0.3 (0.02)	NS	0.5 (0.1)	0.3 (0.1)	NS
Mn	0.01 (<0.01)	0.02 (<0.01)	NS	0.1 (0.01)	0.1 (0.02)	NS
Ba	0.3 (0.03)	0.4 (0.03)	NS	0.8 (0.2)	0.7 (0.1)	NS
Zn	0.4 (0.04)	0.3 (0.03)	**0.02**	0.6 (0.1)	0.3 (0.1)	**0.03**
B	2.5 (0.2)	1.8 (0.1)	**0.008**	7.3 (1.4)	4.2 (0.9)	**0.04**

Table 16. Concentration ratios for selected elements in broccoli shoots. Data represent the mean and standard error for each sample (n = 4). P-values indicate significant differences between the mean values for a given element between the two soils, as determined from a one-tailed t-test. Elements analyzed for but not shown here were at or below the limit of detection (LOD) for all replicates from both soils.

	Concentration Ratio in shoots						
	Ag soil	Sediment	P-value		Ag soil	Sediment	P-value
As	0.1 (0.02)	0.03 (<0.01)	**0.02**	**Ti**	0.02 (<0.01)	0.01 (<0.01)	NS
Cr	0.01 (<0.01)	0.02 (<0.01)	NS	**Cu**	0.1 (0.01)	0.1 (0.01)	NS
Pb	0.01 (<0.01)	0.01 (<0.01)	NS	**Mn**	0.03 (<0.01)	0.02 (<0.01)	NS
Ni	0.1 (0.02)	0.1 (0.03)	NS	**Ba**	0.3 (0.1)	0.2 (0.1)	NS
Cd	0.4 (0.02)	0.2 (0.04)	**0.03**	**Zn**	0.2 (0.03)	0.2 (0.02)	NS
Mo	4.2 (1.2)	5.9 (1.2)	NS	**B**	3.7 (0.7)	2.7 (0.2)	NS

data useful in evaluating the ecological risks associated with usage of this material, or additional risks to human health that might arise from the disposition of harvested plant tissues (e.g., composting of harvested tissues and use on garden plots). Such information will assist the Illinois Department of Natural Resources and other agencies in their efforts to develop specific plans for the use of the large volumes of sediment recovered from the dredging operations underway in the state of Illinois. The results should also indicate where additional study of this sediment material is required.

Elemental analysis of the recovered sediment and the reference Ag soil confirmed that elemental concentrations were higher for the sediment than for the Ag soil. This difference was evident for both total elemental concentration in the soils and the concentration of elements in 1:1 water extracts. In general, the difference in content of a given element between the two soils was no more than two- to five-fold (Fig. 4). Given that the physicochemical properties for the two soils were similar (Table 1) (with the exception of pH, Ca content, and K content) this might imply that plants grown in sediment would consistently display greater bioaccumulation than those grown in the Ag soil. However, this appears only to be true for a limited number of elements.

While there were some significant differences in elemental content and elemental concentration ratios between the two soils, there were as many instances where the value was significantly greater in the Ag soil. Even in those situations where the accumulation from sediment was greater than that from the Ag soil, the differences were generally only 2- to 3-fold in magnitude. Zinc is the best example of this situation, showing higher concentrations in sediment-grown plants than Ag soil grown plants for all five species, although the difference for tomato was not statistically significant. The Zn concentrations observed in the tissues of sediment-grown plants were generally >20-30 mg kg^{-1} DW. Concentrations in that range have been observed for similar plants grown in Zn contaminated soils (Kabata-Pendias and Pendias, 2001). However, the concentrations observed here fall at the lower end of that range. Even so, the background concentration of some plants, such as clover, range from 25 to 45 mg kg^{-1} DW. Thus it is perhaps not surprising to see that Zn concentrations in plants from the Ag soil show Zn concentrations in the same range. Concentrations must well exceed 0.1% (dry weight basis) before a health risk is perceived (Kabata-Pendias and Pendias, 2001). There were significant

differences for other elements but these differences were not consistent across species and were often contradicted when the data was expressed in terms of the concentration ratios. When compared to published data (Kabata-Pendias and Pendias, 2001), none of these elements were present at concentrations that immediately indicate a potential hazard to human or animal consumers.

The notable exception to this trend was Mo, which showed a >10-fold increase in accumulation in bean tissues. The bioaccumulation in the tissues of some other plant species was also significant, but not to the extent observed in beans and certainly not to concentrations >10 mg kg^{-1} DW. The concentrations observed in bean tissues were >30 mg kg^{-1} DW while comparable tissues from the Ag soil were < 5 mg kg^{-1} DW. This Mo concentration in the sediment-grown tissue is much higher than those typically associated with Mo toxicity in grazing animals (<5 mg kg^{-1} DW). Tissue concentrations of molybdenum >10 mg kg^{-1} DW reportedly pose a serious risk to grazing animals (Kabata-Pendias and Pendias, 2001).

Three factors likely contributed to this greater accumulation of Mo in plants, and beans in particular. The first is the aforementioned difference in Mo content between the two soils, with the sediment showing a 2-fold greater concentration on a total basis (Fig. 4). Perhaps more importantly, the water-soluble Mo in the sediment was 10-fold greater than in the Ag soil. The factor that contributed most to this difference was most likely the two unit pH difference between the soils. The water extracts analyzed here were obtained using Ag soil that had not been limed as the pots were. Soil pH has been shown to have a significant effect on Mo solubility in soils, with neutral to alkaline pH values increasing solubility and values <5.5

decreasing solubility (Liu et al., 1996; Frank and Galgan, 1997; McBride et al., 2000; Kabata-Pendias and Pendias, 2001). The Eh (redox potential) is a second factor that exerts a significant influence on solubility (Kabata-Pendias and Pendias, 2001), but this value was not measured here. These two factors control Mo speciation in soils, contributing to the formation of MoO_4^{2-} in soils of neutral to alkaline pH and $HMoO_4^-$ in acidic soils.

Since the Ag soil was limed, the pH values should have been more comparable between the two soils. Unfortunately, the soil pH in the Ag soil and sediment pots was not measured at the termination of the experiment so it is unclear whether the liming achieved the desired pH throughout the pots of Ag soil. The liming was specifically top-dressed and incorporated into the soil to mimic activities that would take place during gardening. While a more thorough mixing would perhaps have been used for an agronomic study, the objective here required the more precise simulation of one intended use. It is possible that the liming altered the pH only in the upper portion of the Ag soil, with the pH in the lower part of the pot remaining close to the initial value of 5.0. Since the pots were watered from below rather than above (to prevent compaction), penetration of the lime into the depth of the soil may have been limited. Nevertheless, as the pH plays a significant role in controlling Mo solubility, excess liming of sediment-derived material in the field may further increase Mo solubility and subsequent uptake.

Finally, there is at least one plant-specific factor of importance here. Molybdenum is a cofactor in several enzymes, most notably the nitrogenase enzyme associated with nitrogen fixation. Perhaps not surprisingly, studies have shown that legumes tend to accumulate Mo to a greater extent than non-leguminous plants, even under comparable conditions (McBride et al., 2000;

Kabata-Pendias and Pendias, 2001). The same pattern was observed here, with bean tissues showing a greater accumulation of Mo than the other four plant species. The combination of these three factors – soil concentration, soil pH, and a leguminous plant species – is the most likely explanation for the greater accumulation in beans observed here.

From a practical standpoint, these results imply that leguminous forages growing on recovered sediment with similar pH and Mo concentrations may accumulate Mo to an extent potentially harmful to grazing animals. This potential outcome has driven most of the research involving Mo uptake and accumulation by plants. In addition to establishing a relative index (a tissue concentration 10 mg kg^{-1} DW) for potential toxicity, these studies have also demonstrated that there are seasonal differences in Mo accumulation in plant tissues as well as annual differences (Kabata-Pendias and Pendias, 2001). The cause of these fluctuations may be related to leaching of salts that complex Mo or changes in pH due to fertilizer regimes. Use of this recovered sediment may therefore have to be accompanied by monitoring of soil conditions (principally pH and Eh) if Mo bioaccumulation in leguminous forages is to be avoided.

5.0 CONCLUSIONS

Although compaction was a concern for the sediment, plants grew equally well in the two soils, with some sediment-grown plants showing significantly greater biomass and yield. The only two elements that were consistently higher in the tissues of sediment-grown plants were Zn and Mo. For Zn, the differences were statistically significant but only 2- to 3-fold in magnitude. However the differences in the Zn concentration ratio between plants grown in sediment and Ag soil was either not significant or significantly greater in the Ag soil, suggesting that these difference in Zn

concentration are not representative of excessive Zn bioaccumulation. In contrast, Mo bioaccumulation in tissues of bean was substantially greater (10-fold or more) for sediment-grown plants than those from the Ag soil. The other four plant species grown in sediment also displayed significantly greater Mo concentrations, but the magnitude was no more than 2- to 3-fold. The greater accumulation of Mo in these five species is likely due to the higher Mo concentration in sediment and the greater solubility of Mo at the higher sediment pH. The 10-fold greater bioaccumulation in sediment-grown bean tissues as compared to the plants from the Ag soil is likewise due to the fact that legumes tend to accumulate more Mo from soils than non-leguminous plants. This level of Mo in beans would not likely be detrimental to human health as typical consumption of this plant food would not provide dietary intakes that exceed the lowest observable adverse effect level (LOAEL) of 140 μg Mo kg^{-1} d^{-1} indicated in the U.S. Environmental Protection Agency's IRIS database (http://www.epa.gov/iris/subst/0425.htm).

6.0 RECOMMENDATIONS

This data here suggest that in principle the reclaimed sediment from the Peoria Lake-Illinois River system could potentially be used safely for the production of garden vegetables. This conclusion applies to the specific sediment material used here. Whether this holds true for plants grown in Peoria Pool sediments with different physicochemical properties is a question that warrants additional study. If, however, this reclaimed sediment is typical of the material recovered from the Peoria Pool, both in terms of its physicochemical properties and the concentrations of inorganic and organic constituents, then the results here suggest that the sediment would likely be a suitable and safe medium for vegetable production. Additional study is recommended to validate this conclusion and to provide adequate protection for human health.

7.0 REFERENCES

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