Urban Gardening and Soil Lead Assessment and Solutions

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Today’s Presentation

Assessment of soil Pb and human exposure (bioavailability) in urban soils

Solutions to soils with Pb issues
In situ soil remediation: Use of inexpensive soil amendments to remediate soils (reduce contaminant exposure / risk)

Management practices to reduce exposure to soil Pb
Vacant Land in Cleveland is 3,000 acres and expected to increase greatly as new initiatives (i.e., American Recovery and Reinvestment Act) provide funding for demolition of substandard housing.

16,500 properties in Cuyahoga County land bank

Vacant Land reduces value from city neighborhoods
Nationwide Creation of Vacant Urban Land
Urban agriculture/gardening
improve the availability of healthy, fresh foods,
improve nutrition and health of residents
Community gardens improve the quality of life and
social fabric of city neighborhoods

Creation of parks, playgrounds and other commons
Soil Pb Pollution

Pb in paint until 1978

Leaded gasoline

Phased out in 1970s

50% deposited within 100 m of road

other 50% dispersed
# Excessive Blood Pb (EBL) in Cuyahoga County

<table>
<thead>
<tr>
<th></th>
<th>EBL &gt; 10 μg/dL</th>
<th>EBL &gt; 5 μg/dL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuyahoga county</td>
<td>8.5 %</td>
<td>34.6 %</td>
</tr>
<tr>
<td>Cleveland</td>
<td>11.0 %</td>
<td>42.2 %</td>
</tr>
</tbody>
</table>

Cuyahoga County Board of Health
Epidemiology and Surveillance Services. Feb 2008

Significant Pb exposure -- indoor (house dust) and outdoor (soil)
Many urban soils have Pb contamination

Effect of distance from the center of Baltimore on Pb concentration in garden soils (1983)

<table>
<thead>
<tr>
<th>Distance</th>
<th>N</th>
<th>Mean</th>
<th>Med.</th>
<th>90%-ile</th>
<th>Max.</th>
<th>%&gt;500</th>
</tr>
</thead>
<tbody>
<tr>
<td>km</td>
<td></td>
<td>------</td>
<td>------</td>
<td>---------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>1-50</td>
<td>549</td>
<td>424</td>
<td>124</td>
<td>992</td>
<td>10900</td>
<td>20.9</td>
</tr>
<tr>
<td>1-4</td>
<td>90</td>
<td>1020</td>
<td>664</td>
<td>1810</td>
<td>10900</td>
<td>61.1</td>
</tr>
</tbody>
</table>

Similar soil Pb historical legacy in many cities
Two possible urban garden sites
Soil Pb Assessment

Can these be used for gardening?
Determine contaminant transmission (mobility, bioavailability) to calculate risk from soil Pb
Soil / contaminant chemistry affects availability, contaminant transmission, and human and ecological risk.
Critical Human Exposure Pathways

Soil Contaminant

- Soluble
  - Released In Gut
    - Taken Up By Plant
      - Drinking Water (Pathway 1)
      - Ingestion of Soil (Pathway 2)
      - Food Chain (Pathway 3)

Soil Pb is insoluble / little phytoavailability

Risk driver for soil Pb in urban gardens is soil ingestion, not Pb in the food chain or drinking water.
Using Oral Bioavailability to Assess Human Health Risk of the Soil Ingestion Pathway

\[
\text{CDI} = \frac{[\text{Soil Pb}] \times (\text{EF}) \times (\text{ED}) \times (\text{IR}) \times (\text{BIO})}{(\text{BW}) \times (\text{AT})}
\]

CDI = chronic daily intake of Pb
= Pb absorbed into blood
[Soil Pb] = total soil Pb

EF, ED = exposure frequency / duration
IR = ingestion rate
BIO = Bioavailability of Pb in soil which ranges from 0.0 to 1.0

How do we assess the CDI (risk)?
Measuring Bioavailability Using *In Vivo* Models

- accurate bioavailability
- unlikely model
- acceptable model for Pb, As, other bioavailability
- expensive ethical issues
In Vitro Gastrointestinal Methods
An Inexpensive, Fast, Accessible Alternative

Simulated human gastrointestinal extraction

Bioaccessible metal = dissolved in gastric and/or intestinal solution; bioaccessible is a conservative measure of bioavailable metal

IVG extraction

% IVBA = \( \frac{\text{In vitro dissolved metal}}{\text{Total soil metal}} \)

OSU IVG

metal analysis by ICP
OSU Soil Chemistry

Metal Bioaccessibility Testing of Soil

We have a very active research program and we offer a variety of IVG soil tests to the public.
RBALP *in vitro* gastrointestinal method correlated with swine bioavailable Pb


U.S. EPA, Guidance for Evaluating the Oral Bioavailability of Metals in Soils for Use in Human Health Risk Assessment OSWER 9285.7-80, May 2007; RBALP IVG accepted for Pb, others under consideration for Pb and As.
OSU IVG Research
more active than ever after 10+ yr

the soil isn’t contaminated
Assessment of Soil Pb in Urban Soil

Risk-Based Pathway Analysis

If risk is unacceptable → cleanup/remedial action required

First, use Soil-Screening levels to evaluate contamination and determine if detailed risk assessment is needed
Soil Assessment of Pb
First -- Measure Total Soil Pb

Strong acid digestion used to dissolve soil and release Pb

USEPA Method 3051, 3051A, 3052

USEPA Method 3050

Analysis of dissolved “soil” by inductively coupled plasma atomic emission spectroscopy
Compare your soil Pb to Soil Screening Levels (SSL)

- If Total Soil Pb > SSL, then:
  - Yes: Further Investigation for Contaminant
  - No: No further investigation

USEPA SSL for Pb is 400 mg/kg (with default assumptions)

200 mg soil ingested/day; 60% relative bioavailability
Ohio EPA Voluntary Action Program

“This Program was created to give individuals a way to investigate possible environmental contamination, clean it up if necessary and receive a promise from the State of Ohio that no more cleanup is needed.”

http://www.epa.ohio.gov/derr/volunt/volunt.aspx

Generic direct-contact soil standards: residential land use category considers soil ingestion, dermal absorption, inhalation of particulate emissions

Pb VAP soil standard: 400 mg/kg
Two possible urban garden sites

Soil Pb
221 to 391 mg/kg Pb, mean 313

Soil Pb
770 to 900 mg/kg Pb, mean 800

Can these be used for gardening?
How do you reduce risk from exposure to soils > 400 mg/kg Pb?

Soil Ingestion Pathway

\[
CDI = \frac{[\text{Soil Pb}]}{(\text{EF}) (\text{ED}) (\text{IR}) (\text{BIO})} (\text{BW}) (\text{AT})
\]

1. Reduce [soil Pb] term - reduce soil Pb
2. Reduce exposure / ingestion of soil, EF, ED, IR
3. Reduce exposure / Pb bioavailability, (bio)
Reducing Soil Pb
Soil Excavation/Landfilling

Excavate top 6”
Fill with new soil “borrowed soil”

Soil Pb, 800 mg/kg

Very Expensive but Contaminant “Gone”
--at least gone from earth surface

$100 to $300/ton
$20,000 to $60,000 / property

Thousands of properties in one city?
$200M?
In-situ Soil Pb Remediation

Phytoremediation
Chemical Immobilization
Remove Soil Pb by Phytoremediation

solar-driven metal pumps  green remediation

Hyperaccumulator plant- more than 1% metal in plant
Phytoextraction

Harvest → Beneficial Use

Biomining: ash plant as ore (Ni)
Mineral feed supplement (Se)

Soil metal contaminant MUST be bioavailable for metal uptake to occur

Limited to contaminants that have some solubility in soil
Pb is very insoluble in soil
**Known Metal(loid) hyperaccumulating plants**

Table 1. Example plant species which hyperaccumulate elements to over 1% of their shoot dry matter, usually at least 100-fold levels tolerated by crop species.

<table>
<thead>
<tr>
<th>Element</th>
<th>Plant species</th>
<th>Maximum metal concentration</th>
<th>Location collected</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td><em>Thlaspi caerulescens</em>†</td>
<td>39 600 mg kg⁻¹ dry wt.</td>
<td>Germany</td>
<td>Reeves and Brooks, 1983b</td>
</tr>
<tr>
<td>Cd</td>
<td><em>Thlaspi caerulescens</em></td>
<td>2 908 mg kg⁻¹ dry wt.</td>
<td>France</td>
<td>Reeves et al., 2001</td>
</tr>
<tr>
<td>Cu‡</td>
<td><em>Aeolanthus bifurcatus</em></td>
<td>13 700 mg kg⁻¹ dry wt.</td>
<td>Zaire</td>
<td>Brooks et al., 1978</td>
</tr>
<tr>
<td>Ni</td>
<td><em>Phyllanthus serpentinus</em></td>
<td>38 100 mg kg⁻¹ dry wt.</td>
<td>New Caledonia</td>
<td>Kersten et al., 1979</td>
</tr>
<tr>
<td>Co‡</td>
<td><em>Haumaniastrum robertii</em></td>
<td>10 200 mg kg⁻¹ dry wt.</td>
<td>Zaire</td>
<td>Brooks et al., 1978</td>
</tr>
<tr>
<td>Se</td>
<td><em>Astragalus racemosus</em></td>
<td>14 900 mg kg⁻¹ dry wt.</td>
<td>Wyoming</td>
<td>Beath et al., 1937</td>
</tr>
<tr>
<td>Mn</td>
<td><em>Alyxia rubricaulis</em></td>
<td>11 500 mg kg⁻¹ dry wt.</td>
<td>New Caledonia</td>
<td>Brooks et al., 1981</td>
</tr>
<tr>
<td>As</td>
<td><em>Pteris vittata</em></td>
<td>22 300 mg kg⁻¹ dry wt.</td>
<td>Florida</td>
<td>Ma et al., 2001</td>
</tr>
<tr>
<td>Tl</td>
<td><em>Biscutella laevigata</em></td>
<td>15 200 mg kg⁻¹ dry wt.</td>
<td>France</td>
<td>Anderson et al., 1999</td>
</tr>
</tbody>
</table>

† Ingrouille and Smirnoff (1986) summarize consideration of names for *Thlaspi* species; many species and subspecies were named by collectors over many years (Reeves and Brooks, 1983a, 1983b; Reeves, 1988).

‡ Although Cu and Co hyperaccumulation were confirmed in field collected samples, similar concentrations have not been attained in controlled studies.

**Chaney et al. 2007. J. Environ. Quality 36:1429-1443.**
Alleged phytoremediation of Pb contaminated soils

There isn’t a Pb hyperaccumulator plant

Most lead contamination is very insoluble in soil and not available for plant uptake (i.e., phytoextraction)

In 1997, lead contaminated soil was reported to be phytoremediated by Indian mustard (*Brassica juncea*)

Indian mustard Pb content of >1%, approaching 3%!

News spread around the world!
Chelate-assisted phytoextraction of Pb from soil

Soil-Pb + EDTA$^{4-}$ = Clean soil + PbEDTA$^{2-}$

add chelate solution to soil

PbEDTA$^{2-}$ = Pb$^{2+}$ + EDTA$^{4-}$

Greatly increased Pb$^{2+}$ dissolved in soil solution

Subsequent studies report large uptake of Pb was due to root membrane injury by EDTA
Chelate-assisted phytoextraction of Pb from soil

very serious problems

Several studies in 2001-2005 period found very little of soil Pb was recovered in the Indian mustard

Mass balance showed >90% of the Pb was unaccounted for -- where did the Pb go?

Hint: EDTA solubilized Pb?

Groundwater contamination of Pb -- lysimeters found Large amounts of Pb in water table -- little in plants
Reduce Pb Bioavailability and Exposure
Soil Remediation by *in situ* Soil Amendments

Treat soil to reduce contaminant solubility/availability to ecological and human receptors

Objective is to reduce Pb Oral bioavailability
Reduce Pb Bioavailability and Exposure
Soil Remediation by *in situ* Soil Amendments

**Phosphates / P Fertilizer**

\[ \text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2 + x\text{Pb}^{2+} \rightarrow \text{Ca}_{10-x}\text{Pb}_x(\text{PO}_4)_6(\text{OH})_2 + x\text{Ca}^{2+} \]

Hydroxyapatite + available Pb  
Lead pyromorphite  
Low bioavailability
Pb immobilization using phosphorus fertilizer calcium or ammonium phosphates
Remediation of Soil Pb at Joplin, Missouri

In-place Inactivation & Natural Ecological Restoration Technologies (IINERT)

Urban soil contaminated with Pb smelter waste
Field Amendments at Joplin

Control

P Only
- 1.0 % P-TSP
- 3.2 % P-TSP
- 1.0 % PRock
- 0.5 % H$_3$PO$_4$
- 1.0 % H$_3$PO$_4$

P & Fe
- 1.0 % IRR + 1.0 % P-TSP
- 2.5 % IRR + 0.32 % P-TSP
- 2.5 % IRR + 1.0 % P-TSP

P & Biosolids
- 10 % Biosolids Compost
- 10 % BC + 0.32 % P-TSP
- 10 % BC + 1.0 % P-TSP
Joplin Soil Feeding Test
Clinical Protocol

- Human volunteers with Pb isotope ratio different from that of the test soils.
- Screening and physical exam.
- Obtain informed consent.
- Three day clinic admission.
- Subject dosed at 250 μg Pb/70 kg BW using soil <250 μm in gelatin capsules.
- Collect blood and urine samples
Phosphate Amendment Reduced Soil Pb Bioavailability to Humans

Joplin Soils -- Results

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (yr)</th>
<th>Weight (kg)</th>
<th>Pb Dose (µg)</th>
<th>Soil Dose (mg)</th>
<th>Bioavailability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>29.6</td>
<td>62.2</td>
<td>238</td>
<td>45.7</td>
<td>42.2 (26.3-51.7)</td>
</tr>
<tr>
<td>P-Treated</td>
<td>34.5</td>
<td>72.2</td>
<td>261</td>
<td>61.5</td>
<td>13.1 (10.5-15.8)</td>
</tr>
</tbody>
</table>

70% reduction in Pb bioavailability!
Summary Soil Pb
Assessment / Solutions

VERY HIGH (> 1,500?)
consider another use for soil

HIGH, MEDIUM
1. assess Pb bioavailability to adjust Pb exposure!
2. May need to take action to reduce Pb exposure, cut off exposure / treat to reduce Pb bioavailability, or both

LOW (400 mg/kg) -- don't worry, be happy
Thank you for your attention
More information? Please contact:

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