Managing Contaminants in Urban Vegetable Gardens to Minimize Human Exposure

Ganga Hettiarachchi
Department of Agronomy

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CLU-IN Webinar
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Common Contaminants and Human Exposure Risks of Urban Gardening

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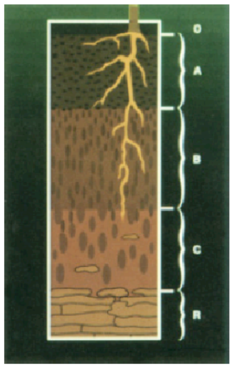
Urban Soils

Natural soil profile
with major horizons



Urban Soil Profile

A horizon

B horizon

C horizon
(human
artifact)

SOURCE: URBAN SOIL PRIMER, 2005. USDA, NRCS PUBLICATION. HTTP://SOILS.USDA.GOV/USE/URBAN/DOWNLOADS/PRIMER(SCREEN).PDF

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Common Soil Quality Issues: Urban Soils
Soil compaction
Shallow soil, stones and other debris
Poor Drainage
Low organic matter, low nutrient concentrations
Interrupted nutrient cycling, modified soil organism activity, poor nutrient availability
Soil contamination: Road side soils, previous buildings, affected by industrial fallout, etc.

Contaminants in Urban Soil

One of the major challenges of growing vegetables in an urban environment is the possibility of soil contamination.

Examples: lead from paint and leaded gasoline; arsenic, DDT, and chlordane as pesticides; polycyclic aromatic hydrocarbons from incomplete burning of C-containing materials

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Potential Exposure Pathways

Direct exposure (Ingestion of soil and dust)

Soil → Human

Direct exposure (Inhalation, Dermal)

Soil → Human

Indirect Exposure

Soil → Plant → Human

The concentrations of these contaminants in the above-ground portions of the plants would be very low

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Bioavailability

A measure of the fraction of the chemical(s) of concern in environmental media that is accessible to an organism for absorption

American Society for Testing and Materials, 1998

An essential or toxic element is bioavailable if it is present as, or can be transformed readily to, the free ion species, if it can move to plant roots on a time scale that is relevant to plant growth and development, and if, once absorbed, it affects the life cycle of the plants

Sposito, 1989

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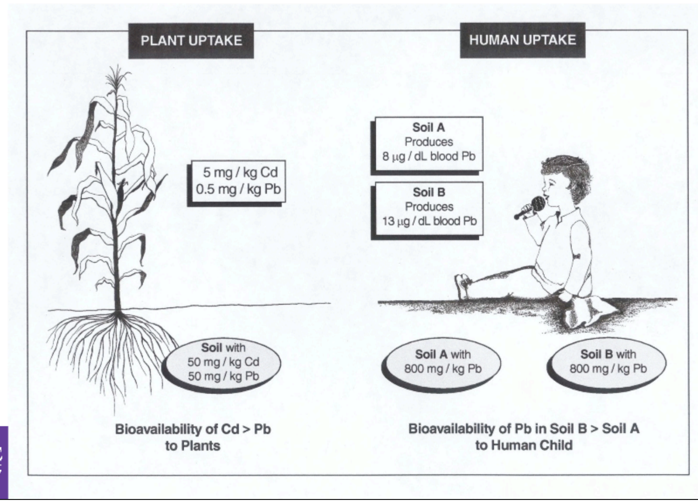
Bioavailability

- Describes the fraction of the chemical(s) of concern in soil that is accessible to an organism (human or plants) for absorption.



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Bioavailability of soil contaminants depends on

- The solubility and/or availability of different pools of contaminant in soil
- Soil properties

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What are these pools? Speciation

Form	Example
A. Free metal	Pb^{2+} (lead ion)
B. Soluble complexes	$Pb(OH)^{1+}$; $Pb(OH)_2^0$; $PbCO_3^0$, $PbCl^+$ Pb-citrate
C. Polymeric organic complexes	Pb – humic acid
D. Adsorbed or incorporated metal onto soil minerals	Pb bound on, or in, microparticulate oxides or aluminosilicates
F. Precipitated metal form	Pb phosphate, Pb carbonate, Pb sulphate, Pb sulfide

High

Low Availability

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Soil properties: pH

Concentrations (mg/kg) of selected elements in Alfalfa tissue as influenced by soil pH

pH	Cd	Cu	Ni	Mo
6.0	0.8	17.7	1.9	193
7.0	0.6	16.8	0.8	342
7.7	0.4	16.0	0.8	370

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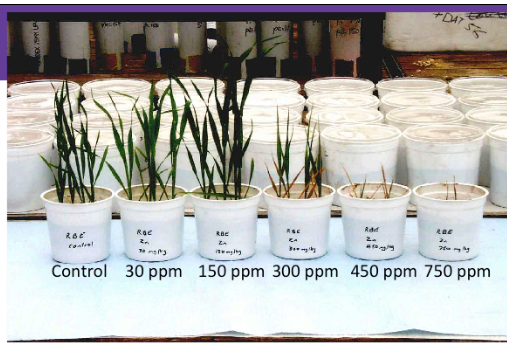
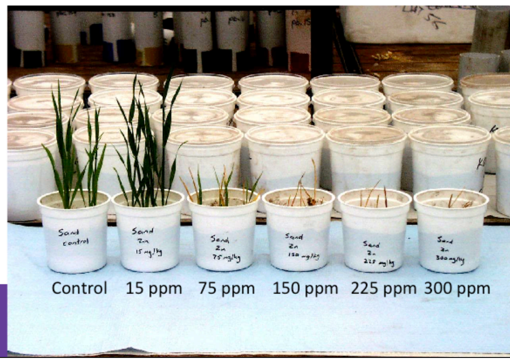
Source: Pierzynski et al., 2005

Soil Type



Clayey Soil



Sand

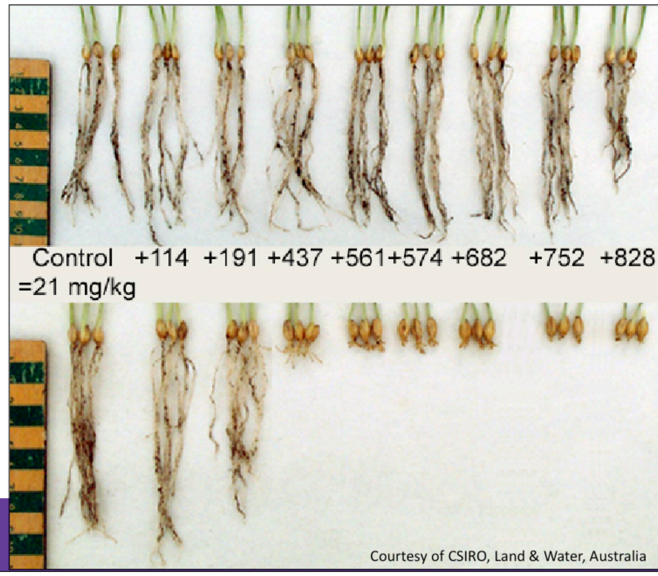
Courtesy of CSIRO, Land & Water, Australia

Natural attenuation (ageing) in soil

Example: root elongation on soil contaminated by Cu

Field transect

Fresh spike



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Species difference in tolerance/uptake

Rice

Barley

Mustard

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Courtesy of CSIRO, Land & Water, Australia

Addition of Soil Amendments Can Reduce Contaminant Bioavailability

Bioavailability: the fraction of the chemical(s) of concern in soil that is accessible to an organism (human or plants) for absorption

Metal contaminated soils- unamended	With Lime	With Beringite-modified aluminosilicate	With Red Mud Fe oxide rich residue

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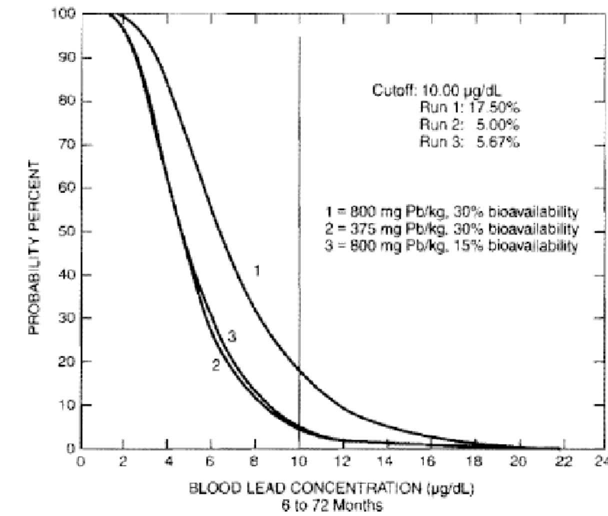
Courtesy of CSIRO, Land & Water, Australia



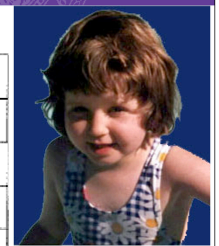


Figure 13.6 IEUBK model output showing the influence of soil Pb bioavailability on the proportion of children 6 to 72 months of age who have >10 µg/dL blood Pb concentration. Curve 1 assumes 800 mg Pb/kg soil and 30% bioavailability while curve 3 uses 800 mg Pb/kg and 15% bioavailability. Curve 2 uses 30% bioavailability and shows that soil Pb cannot exceed 375 mg/kg to have no more than 5% of the children with >10 µg/dL blood Pb concentration.

Using Soil Amendments to Reduce Human Exposure to Contaminants

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Questions

- Is there contamination?
- If so, what is it and how much?
- Does the site require environmental cleanup?
- Growing in-ground or above ground?
- Who will work in the garden (adults, kids, ADA)?
- What are the general soil conditions?
- What crops will be grown?

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Growing In-Ground vs Above Ground

Decision-making drivers

- Liability
- Comfort level of gardeners re. residual contamination
- Soil conditions
- Accessibility
- Cost
- Space

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Growing In-Situ

- May need to take some precautions
- Add amendments

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Raised Beds

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Container Gardening

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Source: www.google.com

Soil Quality Issues in Urban Soils

- Nutrient Status   inadequate in urban soils
- Soil pH
- Organic matter content low in urban soils
- Soil type (clayey vs sandy soils)
- Soil Compaction   yes
- Soil Chemistry   an issue in urban soils
  - Toxicity of soil contaminants (some metals)
  - Excess Na (phyotoxic)
  - Excess salts (phytotoxic)

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3/29/2010 15:39

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Compaction

- Reduces soil porosity
- Air movement and root penetration are restricted
- Water runs off or ponds instead of infiltrating
- Roots grow sideways instead of downward
- Remedies: Tilling and addition of compost (Improving soil organic matter content will help binding contaminants (reduces their bioavailability))

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Nutrient Status

- Nutrient status: N, P, K
- Nitrogen: healthy leaf and stem growth
- Phosphorus: important for root growth, flower production, binds metals (reduces bioavailability)
- Potassium: overall plant health

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pH

- Measure of soil acidity or basicity/alkalinity
- Has a great impact on numerous soil chemical reactions

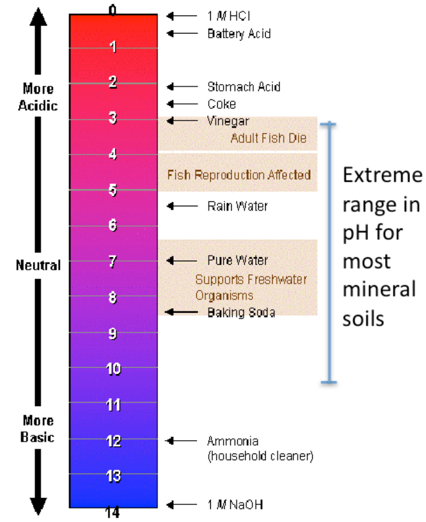
Examples: adsorption

Low soil pH means:

higher mobility of cationic metals

lower mobility of anions

Typical pH values



pH Adjustment

- Adding lime to increase alkalinity
- Select fertilizer to increase acidity: ammonium sulfate, sulfur-coated urea

$$2NH_4^+ + 3O_2 \xrightarrow{\text{bacteria}} 2NO_2^- + 2H_2O + 4H^+$$

ammonium + oxygen → nitrite + water + acid

- Add elemental sulfur or aluminum sulfate to acidify soils

$$2S + 3O_2 + 2H_2O \xrightarrow{\text{bacteria}} 2H_2SO_4$$

sulfur + oxygen + water → sulfuric acid

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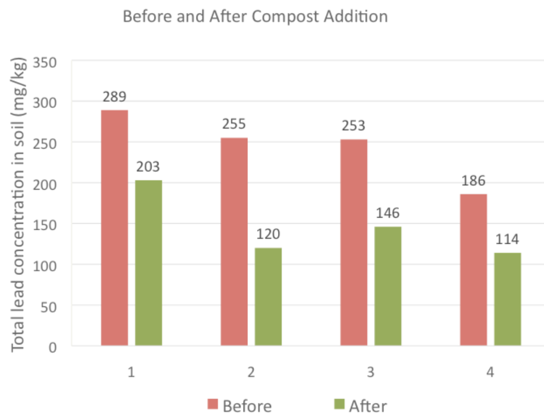
Organic Matter

- Enhances soil color
- Improves soil structure
- Improves soil drainage and aeration (clayey soils)
- Retains Water (sandy soils)
- Provides soil nutrients
- Encourages microbial activity
- Binds contaminants, reduces bioavailability
- Ideal OM content depends on soil type

  Below 1-3 % OM can be considered as low

Contaminant Dilution through Compost Addition

Washington Wheatley Site, Kansas City, MO



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Differences in growth between amended and non-amended plots

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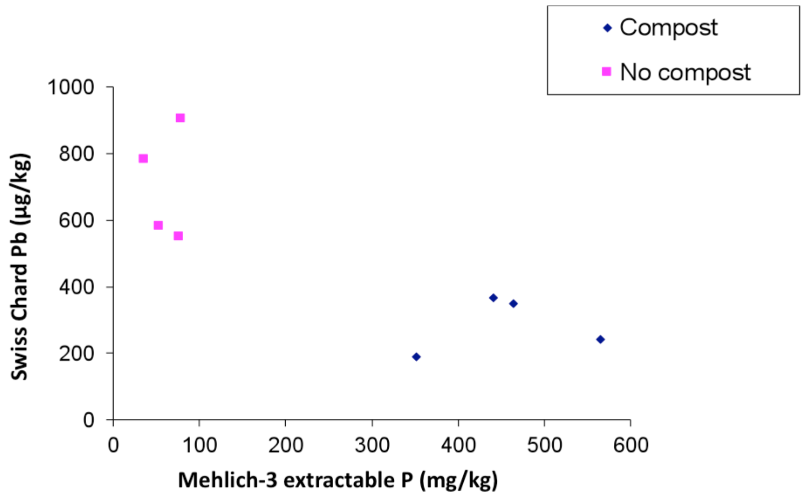
Further dilution of contaminants through enhanced growth

Swiss Chard Pb versus available P in Soils

(Wash. Wheatley, Kansas City, MO)



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Biosolids

- Nutrient rich organic material resulting from the treatment of domestic sewage in treatment facility
- Tested (federal biosolids rule: 40CFR Part 503)
- Biosolids can be applied as fertilizer and will improve soil structure
- Very efficient use of organic N,P by crops because of slow release throughout the growing season

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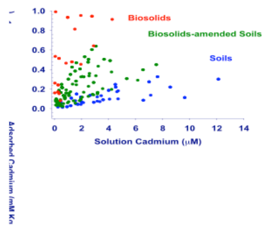
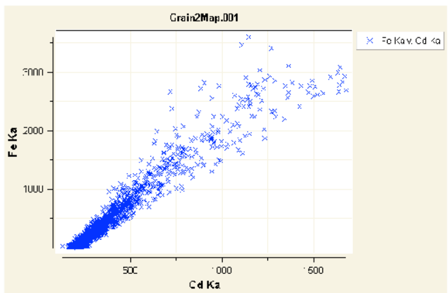
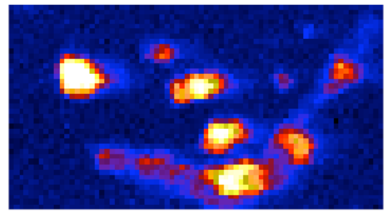
Cadmium Adsorption in amended soils



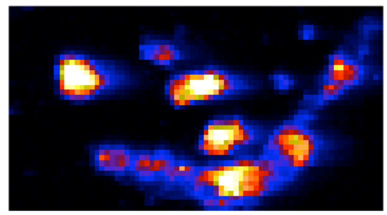
Ryan et al. (2003)

Biosolids μ-XRF Maps





Cd



Fe

Key point: Tight correlation between iron and metals

Hettiarachchi et al., 2005

Use of Soil Amendments

Table 1: Types of Problems Addressed by Soil Amendments

	Exposure Pathways and Adverse Effects	Interactions	Solutions
Contaminant Bioavailability/Phytoavailability Problems			
Toxicity (inorganic)			
Aluminum (Al)	Phytotoxicity Runoff Leaching	Low pH [2] = more toxic; Low P = more toxic; High calcium (Ca) = less toxic	Raise pH greater than 6.0, add OM and P; add gypsum or other high soluble Ca source
Arsenic (As)	Soil Ingestion Runoff Leaching	High pH [2] = more toxic; High P = more soluble	Add organic matter (OM) and adjust pH to between 5.5-6.5
Borate (BO_3^{3-})	Phytotoxicity	Low and High pH [2] = more toxic	Add iron oxide and acidify (pH between 6.0-7.0)
Cadmium-to-Zinc Ratio (Cd:Zn) [1]	Food chain	High ratio = greater bioavailability (risk) of Cd	Add Zn to reduce the Cd:Zn ratio
Chromate (CrO_4^{2-})	Phytotoxicity Runoff Leaching	High pH [2] = more toxic	Add reductants, e.g., OM, biosolids; also acidify to less than 6.5
Copper (Cu)	Phytotoxicity Runoff Leaching Aquatic receptors	Low pH [2] = more toxic; low OM = more toxic	Raise pH (6.0-7.0), add P, OM, and sorbents
Lead (Pb)	Soil ingestion	Low phosphorus (P) = more toxic	With no As present, raise pH to 6.0 or greater; with As present, raise pH to 5.5-6.5; add P, and iron oxide
Manganese (Mn)	Phytotoxicity Runoff Leaching	Low pH [2] = more toxic	Raise pH greater than 7.0
Molybdenum (Mo)	Food chain Cu:Mo ratio	High pH [2] = more toxic; Low Cu = more toxic	Acidify (pH between 5.5- 6.5) and add Cu

The Use of Soil Amendments for Remediation, Revitalization, and Reuse, EPA 542-R-07-013, 2007

Crop Selection

- Root crops vs leafy and fruit bearing vegetables
- Root crops take up more metals compared to leafy and fruit bearing crops

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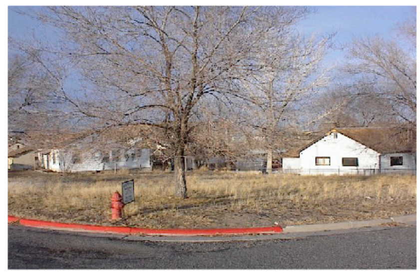
Soil Amendments/BMPs - Summary

- Till and add compost to mitigate compaction
- Add compost/biosolids to improve soil structure, mitigate compaction, to provide nutrients and to reduce bioavailability of contaminants
- Add lime or acidulating materials to adjust pH to reduce bioavailability of contaminants
- Maintain optimum nutrient levels - provide P to reduce bioavailability of metals
- Select suitable crop types

Gardening at Brownfield Sites



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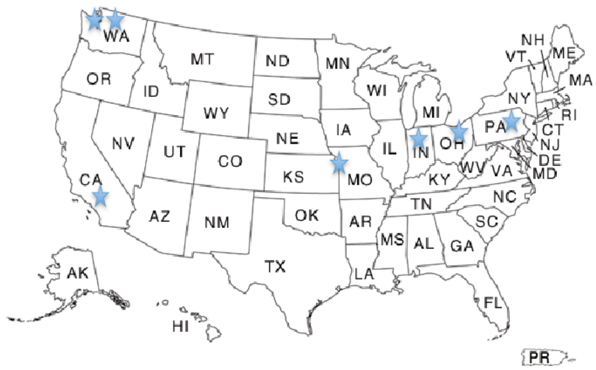
K-State Project: Gardening Initiatives at Brownfields sites

7 test sites across the USA: Kansas City, MO; Tacoma, WA, Seattle, WA; Indianapolis, IN; Pomona, CA; Philadelphia, PA; Toledo, OH



Funded by the EPA Brownfields Training, Research, and Technical Assistance Grants Program

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Process

- Establish site history
- Collect soil samples and testing
- Best management practices (adding soil amendments, raised beds)
- Continuous monitoring, soil and produce sampling
- Training and technical assistance to participating organizations throughout

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Example Site 1: Kansas city, MO

Size ~ 42m x 37m

Silt loam (Sand-4%, Silt-75%, Clay-21%)

The site was screened *in situ*, every ~6 m for trace elements using x-ray fluorescence spectrometer

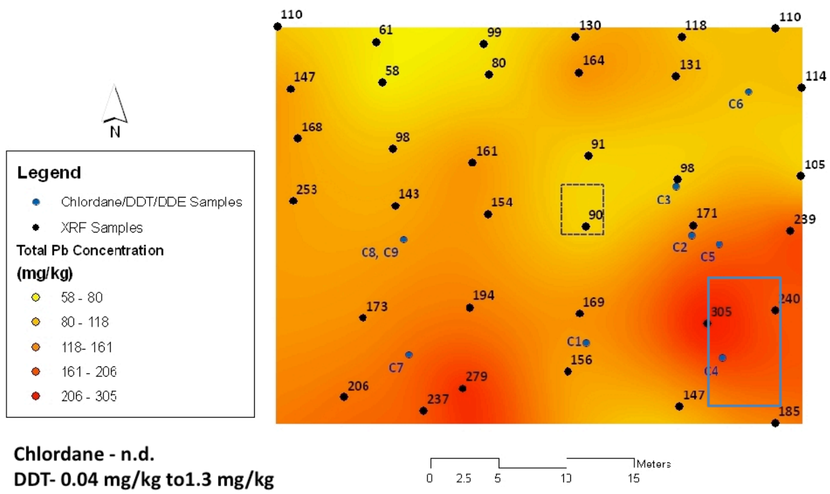
↓

Moderately elevated Pb

Soils were also tested for chlordane

Reference: Attanayake, C.P., G.M. Hettiarachchi, A. Harms, D. Presley, S. Martin, and G.M. Pierzynski. 2014. J. Environ. Qual. Vol. 43, 475-487

Soil Lead Distribution Map



Chlordane - n.d.
DDT- 0.04 mg/kg to1.3 mg/kg
DDE - only detected in two of the submitted samples (0.03, 0.04 mg/kg)

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Selected Soil Properties

Sample ID	pH	Mehlich-3 P	Ext. K	NH_4-N	NO_3-N	OM
		---------------------- mg/kg	----------------------			%
9S	6.6	130	624	53.6	73.2	3.9
9D	6.6	93	455	9.6	35.1	3.4
21S	7.2	116	417	11.8	22.7	3.0
21D	7.2	123	221	9.3	15.0	3.1
26S	7.8	57	255	8.3	4.3	1.5
26D	7.6	80	260	8.2	2.2	1.1
39S	6.9	154	488	15.0	24.2	4.7
39D	6.9	149	334	9.6	13.3	3.3

S = 0-15 cm
D = 15-30 cm

Texture: Silt loam with 21% clay

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Test plot-2010

April 2010

Treatments:
No compost and compost @ ~25 kg/m^2

Crops:
Swiss Chard
Carrots
Tomato

June 2010

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Contaminant Dilution through Compost Addition

Kansas City, MO

Plot #	Total Soil Pb (mg/kg)	
	Prior to Compost Addition	After Compost Addition
1	289	203
2	255	120
5	253	146
8	186	114
Average	246	146

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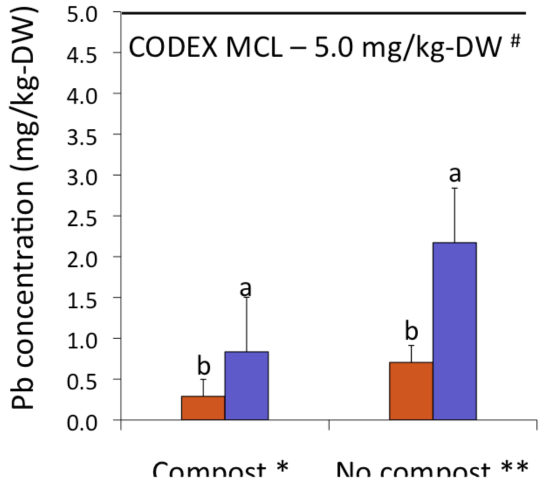
Lead Concentration in Swiss Chard



Lab cleaned
Kitchen cleaned

Compost – ↓ 59 %

Lab cleaning- ↓~ 67 %

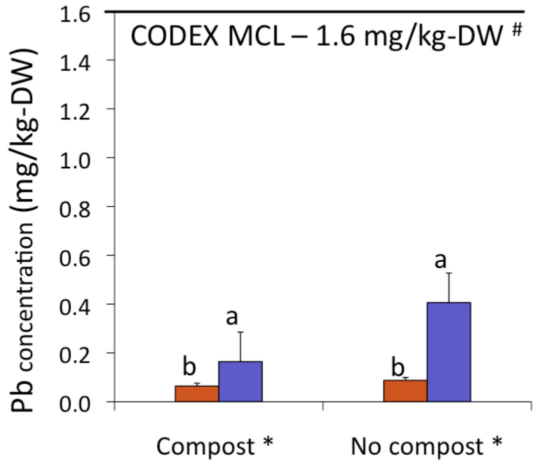
Treatment	Soil Pb (mg/kg)
No compost	128-348
Compost	101-256

$p<0.05$ (split plot design, 4 blocks)

*,** between two categories a, b- within a category

CODEX MCL (FAO/WHO) - 0.3 mg/kg fresh wt. basis (94% moisture)

Lead Concentration in Tomato



Lab cleaned

kitchen cleaned

Lab cleaning- ↓ ~ 61-78%

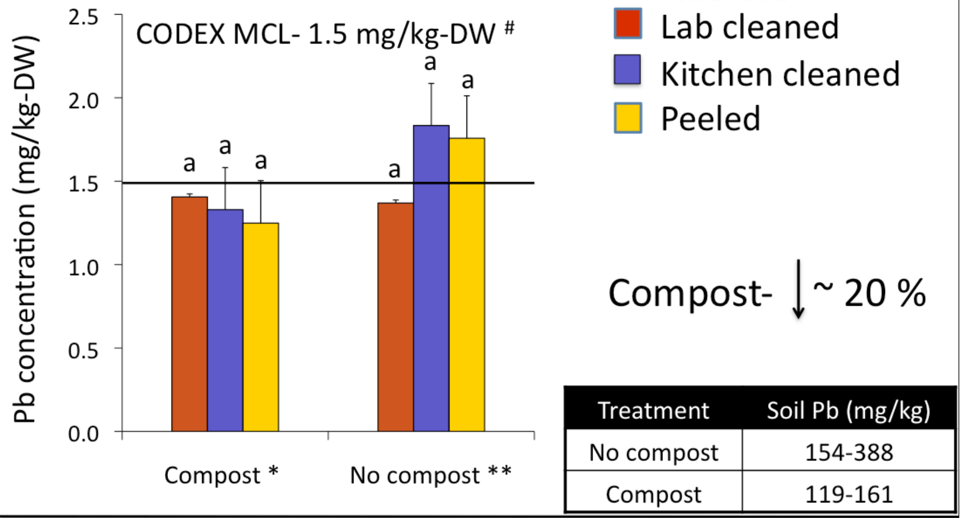
Treatment	Soil Pb (mg/kg)
No compost	143-271
Compost	122-193

$p<0.05$ (split plot design, 4 blocks)

*,** between two categories a, b- within a category

CODEX (FAO, WHO) - 0.1 mg/kg fresh wt. (94% moisture)

Lead Concentration in Carrot



Treatment	Soil Pb (mg/kg)
No compost	154-388
Compost	119-161

p<0.05 (split plot design, 4 blocks)

*,** between two categories   a, b- within a category

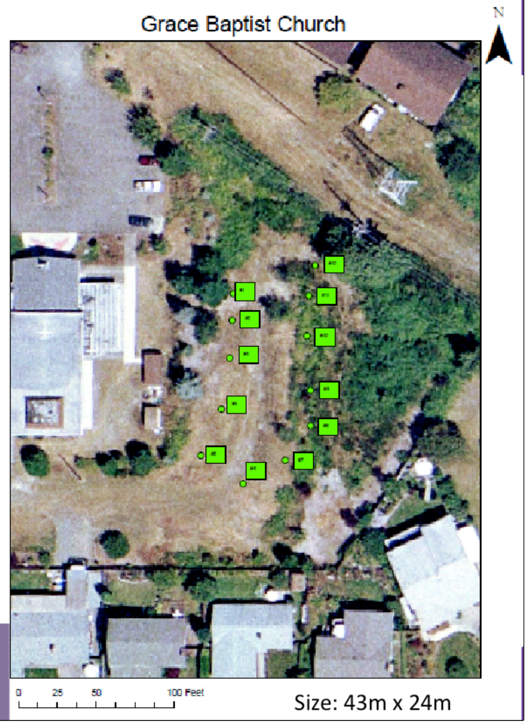
CODEX (FAO, WHO) - 0.1 mg/kg fresh wt. (93% moisture)

Tacoma, WA
Example Site 2

Element	Concentration in soil (mg/kg)
As	17- 162
Pb	17- 427

Texture: Sandy loam

Reference: Defoe P.P., G.M. Hettiarachchi, C. Benedict, S. Martin. 2014. J. Environ. Qual. doi:10.2134/jeq2014.03.0099



Size: 43m x 24m

Tacoma, WA- Community Garden

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Test plots-Tacoma, WA- 2010

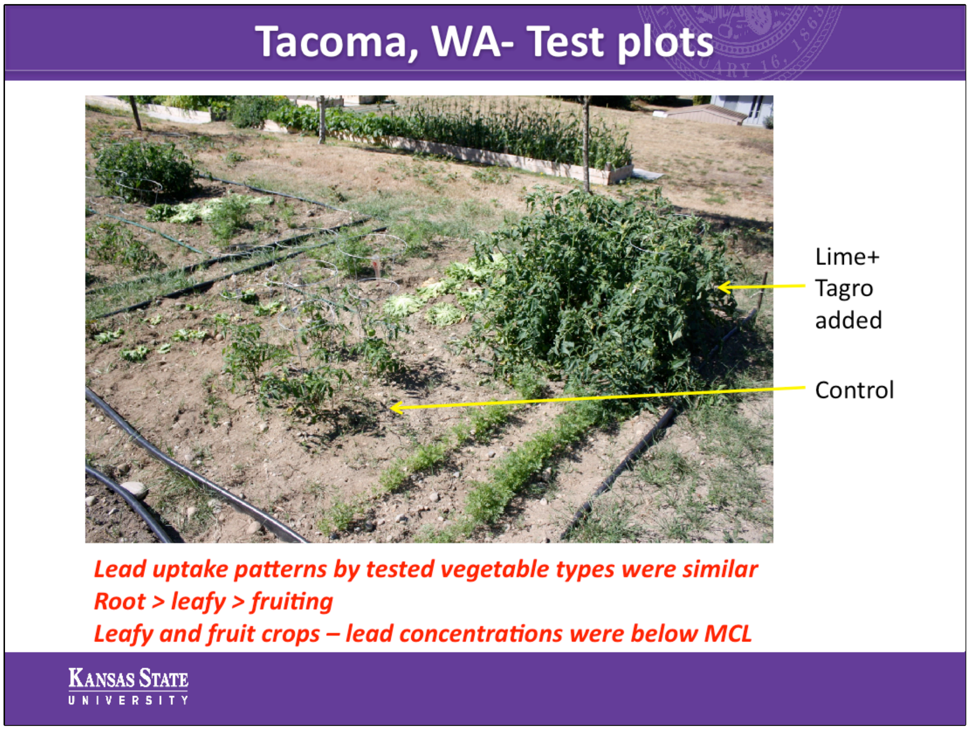
Low to medium available N, P and K in soils

<u>Treatments</u>:

No compost and compost @ ~28 kg/m^2

<u>Crops</u>:

Lettuce, Carrots, Tomato


Tacoma, WA- Test plots
Lime+
Tagro
added
Control
Lead uptake patterns by tested vegetable types were similar
Root > leafy > fruiting
Leafy and fruit crops – lead concentrations were below MCL
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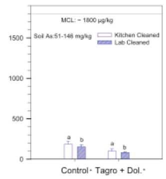
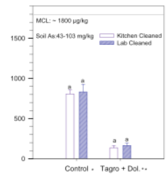
Arsenic in Lettuce



2010

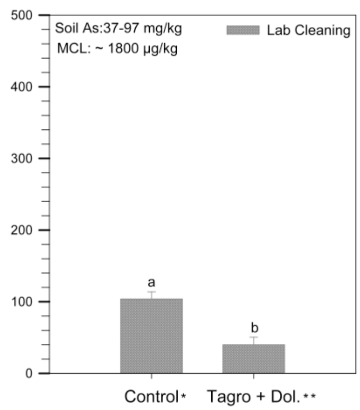


2011

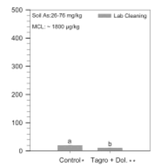
Vertical bars represents the means of four replicates

* MCL- Estimated using daily reference dose limit

Arsenic in Tomatoes



2010



2011

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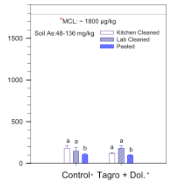
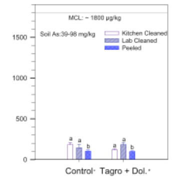
Vertical bars represents the means of four replicates

Arsenic in Carrots





2010

2011

Vertical bars represents the means of four replicates

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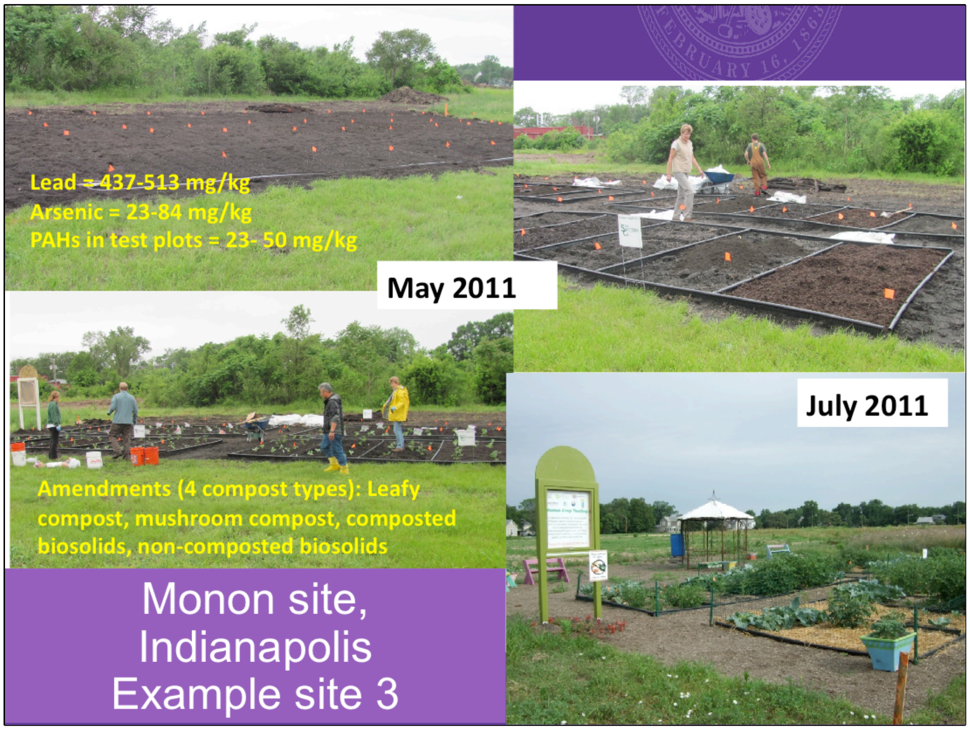
MCL- Estimated using inorganic As daily reference dose limit listed in USEPA, 2003, The Integrated Risk Information System

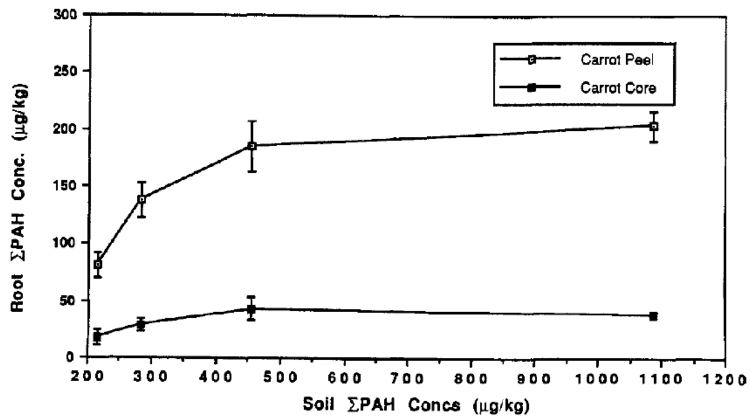

Lead = 437-513 mg/kg
Arsenic = 23-84 mg/kg
PAHs in test plots = 23- 50 mg/kg
May 2011
July 2011
Amendments (4 compost types): Leafy compost, mushroom compost, composted biosolids, non-composted biosolids
Monon site, Indianapolis Example site 3

PAHs in Soils and Vegetables- 2011

# of rings	PAH	Range in test plots (ppm)	Tomato and Carrot (ppm)
2	Naphthalene	<0.4-1.4	< 0.01
3	Acenaphthylene	<0.4-2.4	< 0.01
3	Acenaphthene	<0.4-0.8	< 0.01
3	Fluorene	<0.4-0.8	< 0.01
3	Phenanthrene	6.8-5.6	< 0.01
3	Anthracene	0.5-4.5	< 0.01
4	Fluoranthene	1.6-1.4	< 0.01
4	Pyrene	1.5-1.2	< 0.01
4	Chrysene	1.4-10.4	< 0.01
4	Benzo (a) anthracene	1.1-8.2	< 0.01
5	Benzo(b)fluoranthene	2.6-18.7	< 0.04
5	Benzo(k)fluoranthene	<0.4-6.0	< 0.04
6	Indeno(1,2,3-cd)pyrene	1.1-6.8	< 0.04
6	Benzo(g,h,i)perylene	<2.2-7.2	< 0.04
5	Benzo(a)pyrene	1.4-9.9	< 0.10
5	Dibenz(a,h)anthracene	<0.4-2.3	< 0.10

Toxicity ↓

Plant uptake of organic contaminants



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Source: Wild. S.R. and K.C. Jones. 1992. Polynuclear hydrocarbon uptake by carrots grown in sludge-amended soils. J. Environ. Qual. 21: 217-225.

Trichloroethylene uptake into fruits and vegetables

TABLE 2. Summary of Plant Tissue Samples Collected 2001−03

sample type	2001 total samples collected[a]	2001 detects above MDL	2001 range of concn. (μg/kg fresh wt)	2002 total samples collected[a]	2002 detects above MDL	2002 range of concn. (μg/kg fresh wt)	2003 total samples collected[a]	2003 detects above MDL	2003 range of concn. (mg/kg fresh wt)
fruit	103	15	0.4 to 17.9	257	0	<MDL	149	0	<MDL
trunk core	64	13	0.4 to 7.5	58	10	0.6 to 62	264	93	0.4 to 204
total	167	28		315	10		413	93	

[a] Replicates included, 17 locations sampled in 2001, 31 locations in 2002, and 5 locations in 2003.

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Doucette et al., 2007. Trichloroethylene uptake into fruits and vegetables: Three year study. Environ. Sci. Technol. 41: 2505- 2509.

Plant uptake of chromium

Table 1. Correction of plant Cr for soil Contamination based on plant and soil Ti and soil Cr levels (Cary and Kubota, 1990).

Sample	Soil Cr	Soil Ti	Plant-Cr	Plant-Ti	Soil	Correct Cr
	------mg/kg------		------mg/kg------		g/kg	mg/kg
MD-8	8730	2400	0.29	4.94	2.058	<0.29†
MD-9	6850	1400	0.83	5.36	3.829	<0.83
MD-16	4790	3690	0.32	1.85	0.501	<0.32
NC-5	11060	400	0.97	17.37	40.86	<0.97
NC-6	10680	420	0.67	9.95	23.47	<0.67
NC-6	10680	420	1.12	14.42	34.01	<1.12
CA-2	6760	1280	1.55	4.22	3.289	<1.55
CA-2	6769	1280	0.45	1.13	0.881	<0.45

† Calculated corrected plant Cr levels were greater than measured total Cr in the plant samples indicating that some component of the whole soil (smaller particles with different Cr:Ti ratio) contaminated the plant samples.

Source: Chaney et al. 1996.

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pp. 229-295. *In* S. Canali, F. Tittarelli and P. Sequi (eds.) Chromium Environmental Issues. Franco Angeli, Milano, Italy [ISBN-88-464-0421-1]. [Proc. Chromium Environmental Issues Workshop (San Miniato, Italy, April 12-13. 1996)]

Testing gastrointestinal dissolution of soil As and Pb At pH= 2.5

Physiologically Based Extraction Test-PBET

Percentage bioaccessible Pb at Kansas City garden test plots

Soil fraction/treatment	16 d after adding compost (at planting)		105 d after adding compost (at harvesting)	
	Bioaccessible Pb	% Bioaccessible Pb†	Bioaccessible Pb	% Bioaccessible Pb
	mg kg⁻¹		mg kg⁻¹	
<2-mm fraction (whole soil)				
No compost	13.4 ± 6.4‡	6.3 ± 2.0	12.1 ± 3.4	5.2 ± 1.3
Compost	9.2 ± 1.3	6.0 ± 0.4§	6.4 ± 1.8	3.6 ± 0.6§
<250-µm fraction				
No compost	14.1 ± 4.8	5.6 ± 0.9¶	12.8 ± 5.1	5.1 ± 0.5#
Compost	7.4 ± 1.4	3.9 ± 0.4¶	8.5 ± 1.8	3.9 ± 0.5#
NIST 2711 a	–	–	–	–

†Bioaccessible Pb as a percentage of soil total Pb
NIST 2711a- 35.2% bioaccessible Pb

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Summary

- Soil → plant → Human "Non-significant"
- In general, concentrations of contaminants in aboveground biomass are low
- Root crops will be affected by elevated levels of Pb as well as some persistent organic contaminants in soils
- Compost/biosolids addition reduces contaminant uptake as well as bioaccessibility of contaminants through dilution as well as improved binding capacity of soils
- Thorough cleaning of vegetables further reduced the potential of transferring soil contaminants to humans via vegetable consumption

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Summary, cont.

- Use clean soil/compost raised beds or containers to grow root crops
- Follow BMPs to minimize
  - Soil → Human (mainly contaminated soil ingestion)
- Bioaccessibilities of Pb, As and persistent organic chemicals in soils were low- detailed chemical analysis (Pb, As, PAHs) and *in vitro/lab* chemical extractions suggested that they are strongly bound

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