Assessing Soil's Ability to Reduce Human Exposure to Urban Contaminants: Lead and Arsenic

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School of Environment and Natural Resources
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Soil Science
Terrestrial Wildlife and Ecology
Wetland Science / ecosystems
Forest Ecosystems
Stream, Lake Ecosystems and Fisheries
Environmental Social Science

School of Environment and Natural Resources
Soil Environmental Chemistry Program

Research program

- Soil/Environmental contaminant chemistry
- Development and evaluation of soil remediation technologies
- Beneficial use of by-products via land application
- Use of sorbent technology to protect surface water quality
- Biogeochemical cycling of trace elements in soils

Reuse and Remediation of Vacant Land Soil in Cleveland

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

Nationwide Creation of Vacant Urban Land

Reuse of Brownfields and Ecological Restoration of Superfund Sites

USEPA Brownfields program
Convert slightly contaminated industrial / military sites into usable land in urban/suburban areas

"Ecological Revitalization" of contaminated Superfund sites

http://www.cluin.org/ecotools/

Environmental Assessment of Residential Land

Disclosure of Pb-based paint
Pb testing of soil

Residential development
of agricultural land, old orchards,
cotton fields (arsenical pesticides),
CCA-treated wood products

Vacant Land Reuse Opportunities

- **Urban agriculture/gardening**

  improve the availability of healthy, fresh foods,
  improve nutrition and health of residents

- **Creation of parks, playgrounds and other commons**

What do we do if we find soil contamination?

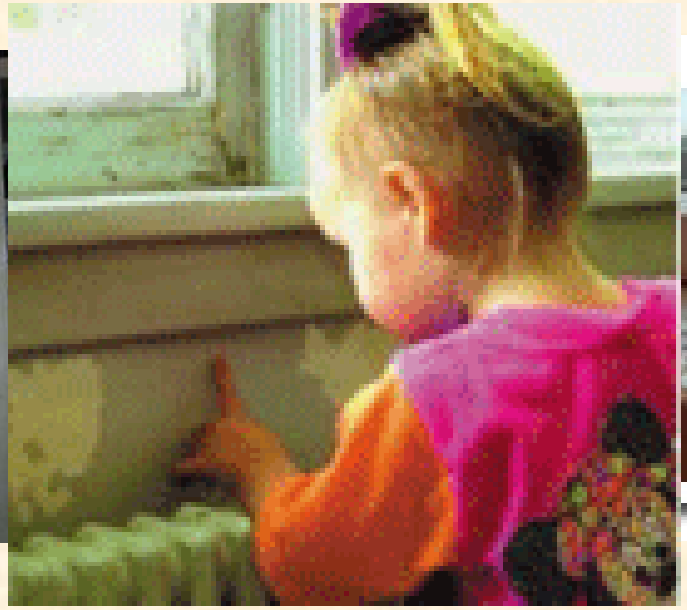
Many urban soils have Pb contamination
Effect of distance from the center of Baltimore on Pb concentration in garden soils (1983)

Distance	N	Mean	Med.	90%-ile	Max.	%>500
km		--------mg Pb/kg dry soil--------				
1-50	549	424	124	992	10900	20.9
1-4	90	1020	664	1810	10900	61.1

Similar soil Pb historical legacy in many cities

Soil Pb Pollution

Pb in paint until 1978



Leaded gasoline

Phased out in 1970s

50% deposited within 100 m of road

other 50% dispersed

Arsenic Pollution from historical Herbicides

old orchards
areas where As, Pb, Cu, Zn
etc were commonly used

As herbicides -- cotton fields;
grassed areas-- As weed killer

Arsenic Pollution from the presence of chromated copper arsenate (CCA)-treated wood products

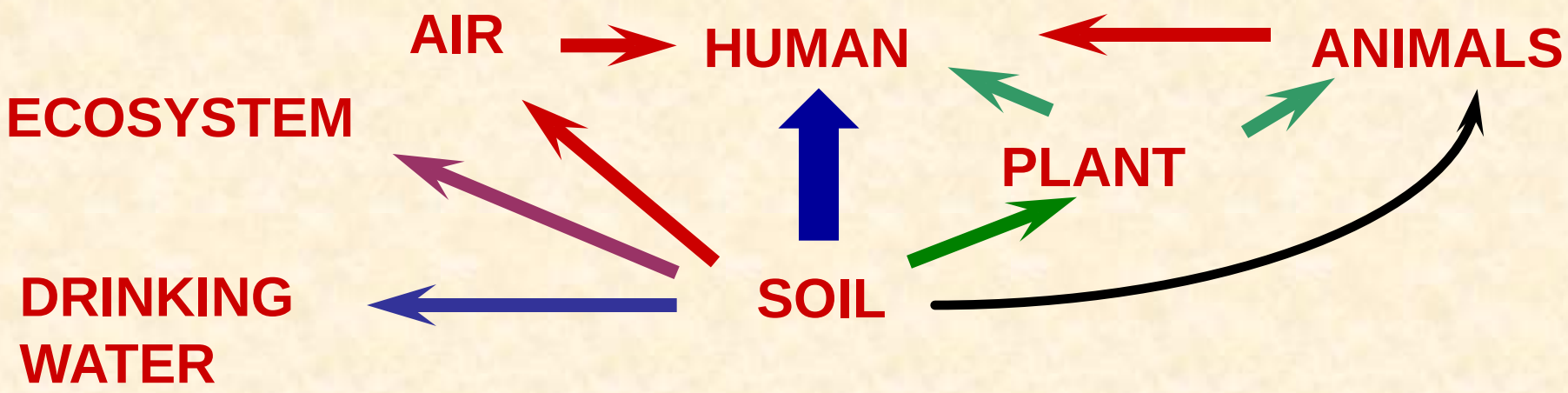
- Lumber treated in large pressure vessels
- Production for most consumer uses in the US ended Dec. 31, 2003
- Pressure-treated wood typically lasts 20-40 years

Two Possible Urban Garden Sites

Can these be used for gardening?

Risk Assessment Guidance-Human Health

Risk-Based Pathway Analysis



If risk is unacceptable ➔cleanup /remedial action required

Detailed risk assessment: Very expensive process

First, use Soil-Screening levels to evaluate contamination and determine if detailed risk assessment is needed

Soil Contaminant Assessment: Pb and As
Screening Levels based on Total Soil Pb or As

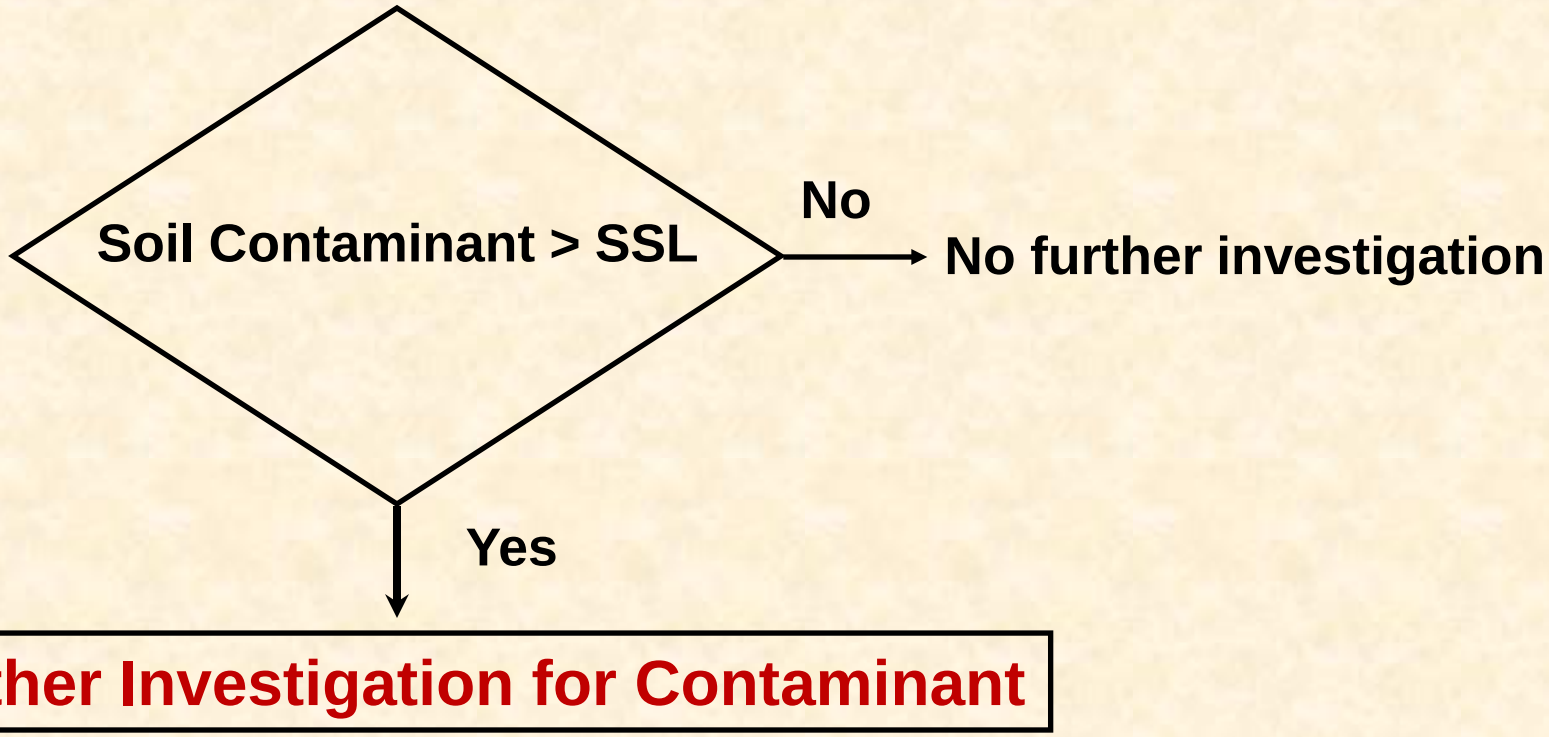
Strong acid digestion used to dissolve soil and release Pb and As

USEPA Method 3051, 3051A, 3052

USEPA Method 3050

Analysis of dissolved “soil” by inductively coupled plasma atomic emission spectroscopy

Contaminated Soils
Soil Screening Levels (SSL) Human, Superfund



<u>Generic SSLs (with default assumptions)</u>

Pb SSL: 400 mg/kg (soil ingestion)

As SSL: 0.39 mg kg^{-1} (soil ingestion)

Contaminated Soils
Ecological Soil Screening Levels
Eco-SSL
http://www.epa.gov/ecotox/ecossl

Soil Contaminant > EcoSSL

No → **No further investigation**

Yes → **Further Investigation for Contaminant**

Contaminated Soils
Ecological Soil Screening Levels (EcoSSL)
Pb Eco-SSL

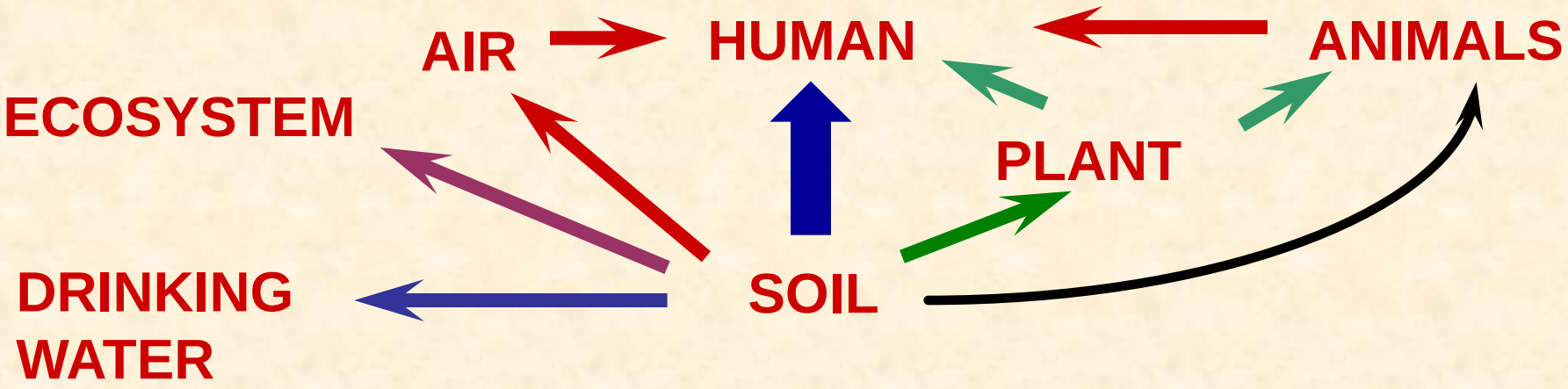
Plant 120 mg/kg Pb in soil

Soil Invertebrates 1,700 mg/kg Pb in soil

Mammalian 56 mg/kg Pb in soil

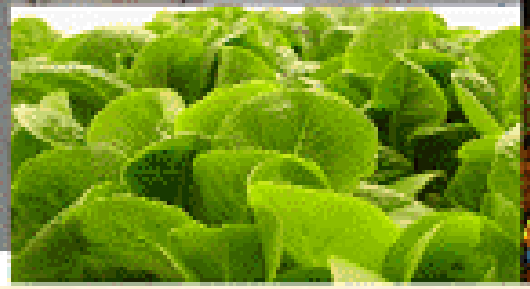
Avian 11 mg/kg Pb in soil

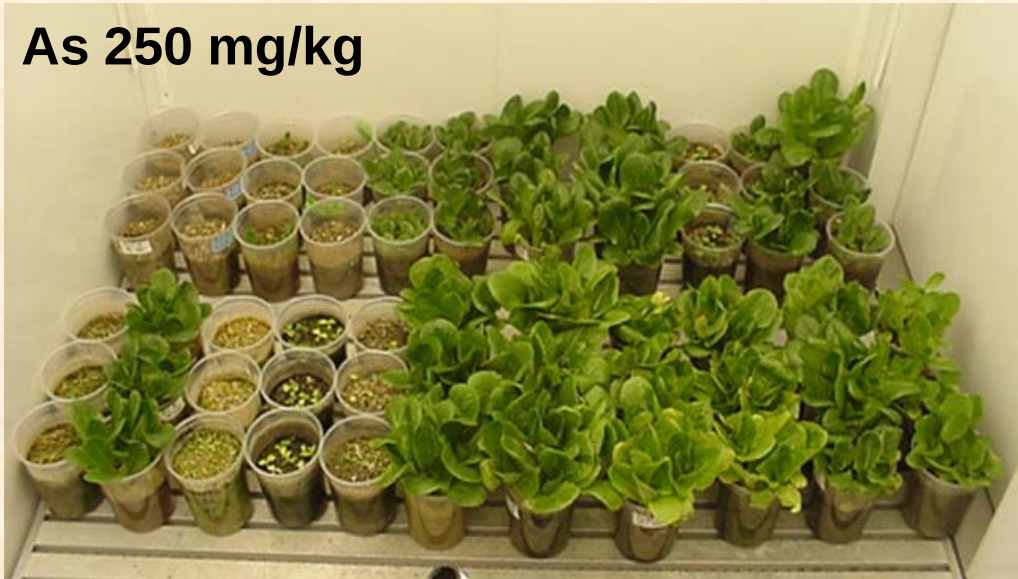
Soil Contaminant Assessment
Further Investigation



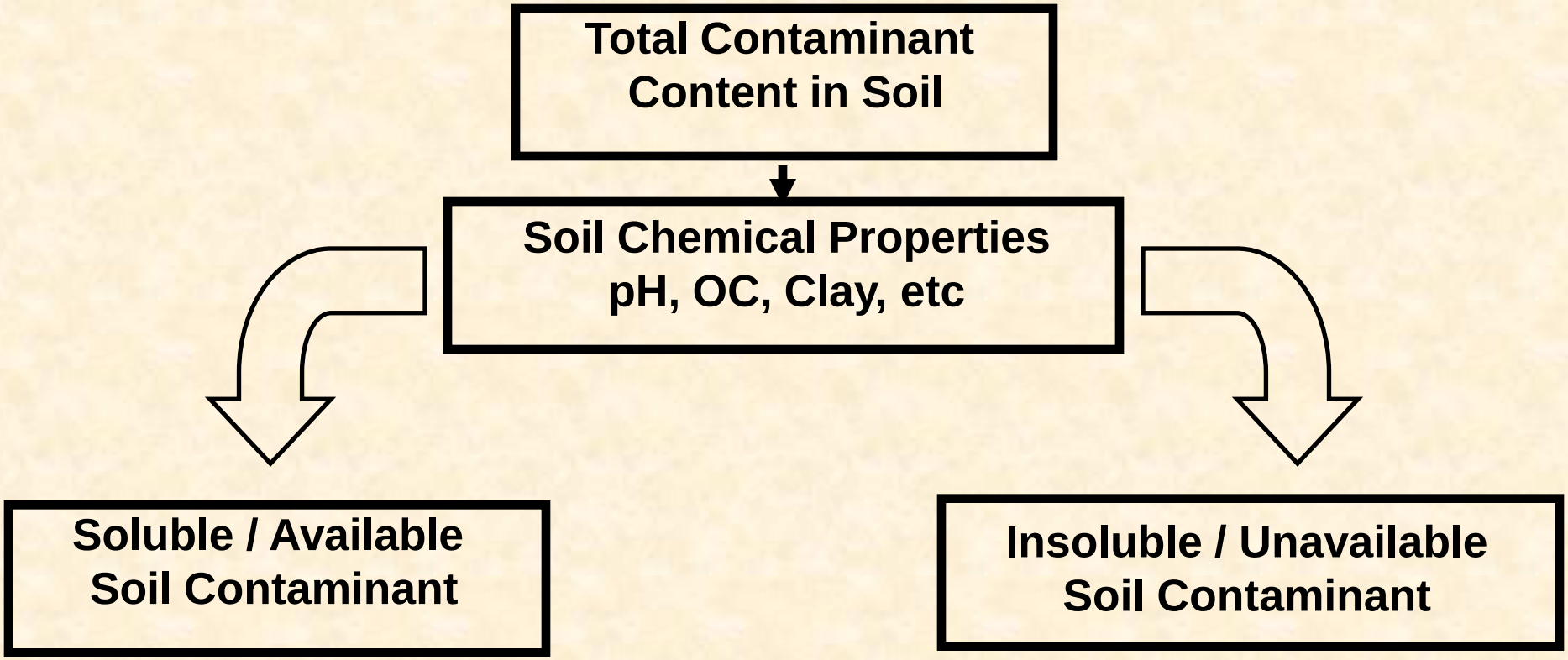
Determine contaminant mobility, bioavailability for risk assessment

Soil Type affects availability, mobility contaminant transmission, and human and ecological risk





Soils affect Contaminant Partitioning and Availability

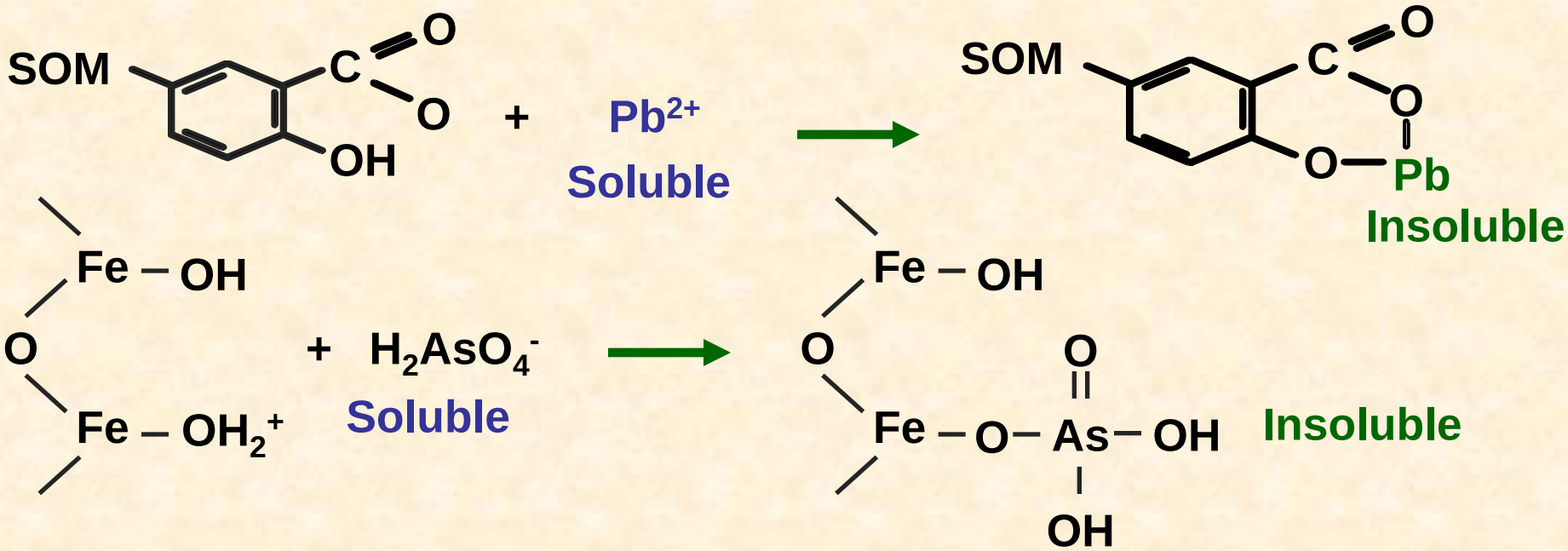


High ← Potential Bioavailability / Toxicity → Low

Potential Human/Ecological Risk

Soil Types affects Contaminant Solubility / Bioavailability

Surface Chemistry - Adsorption Reactions in Soil



Precipitation Reactions in Soil

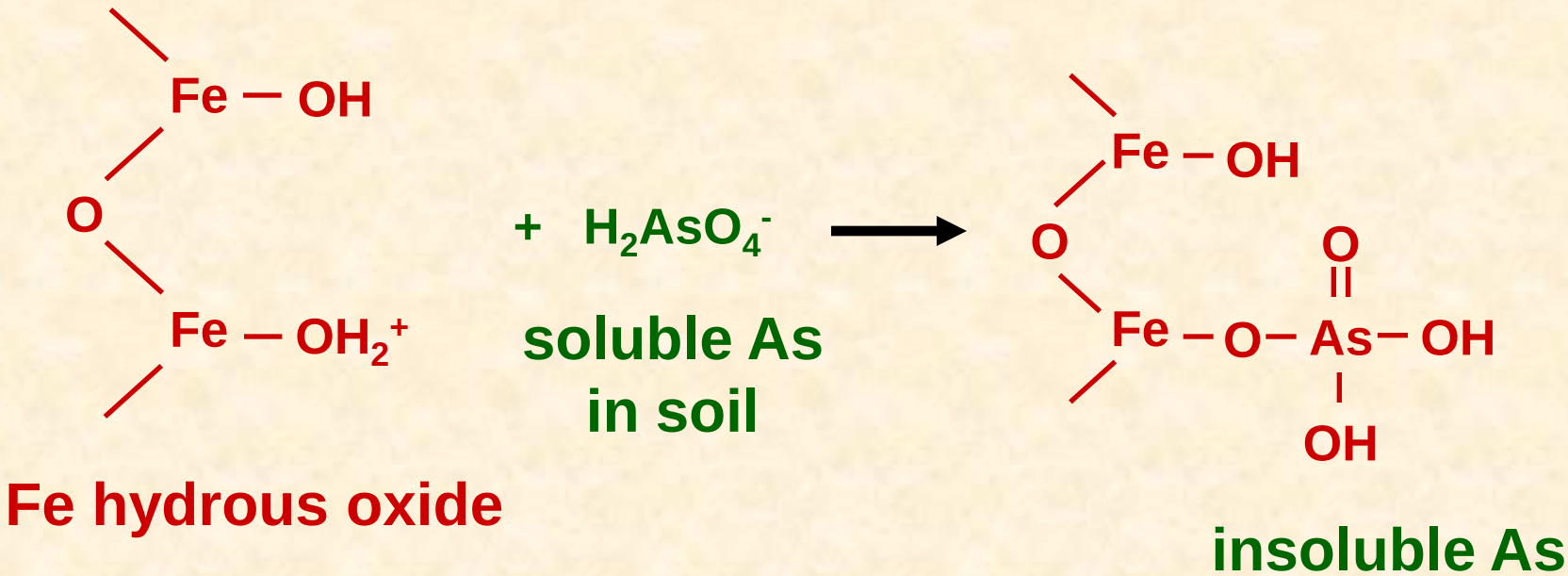
$$Ca_{10}(PO_4)_6(OH)_2 + xPb^{2+} \longrightarrow Ca_{10-x}Pb_x(PO_4)_6(OH)_2 + xCa^{2+}$$

Soluble → Insoluble

All pots have same total soil Zn
but different amounts of bioavailable Zn

Low pH	High pH	High pH	Mod pH	Low pH
Low OC	High OC	High OC	Low OC	High OC
Low Clay	Mod Clay	Mod Clay	Mod Clay	Mod Clay

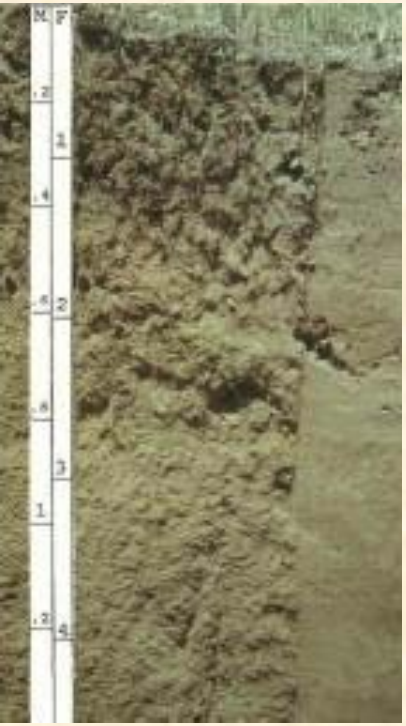
Chemical Sequestration of Arsenate by Fe oxide in Soil



Inner-sphere metal strong surface complexes -- "unavailable metal"

adsorption capacity: Fe, Mn oxides > Al oxides

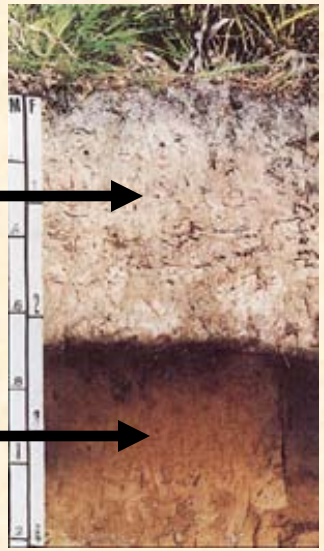
Fe Oxide "Deficient" Soils



Sandy soils
very low Fe oxide content
very poor As "scavengers" (e.g. adsorbers)
Potentially higher As bioaccessibility / bioavailability

Sandy low Fe

Subsoil Fe

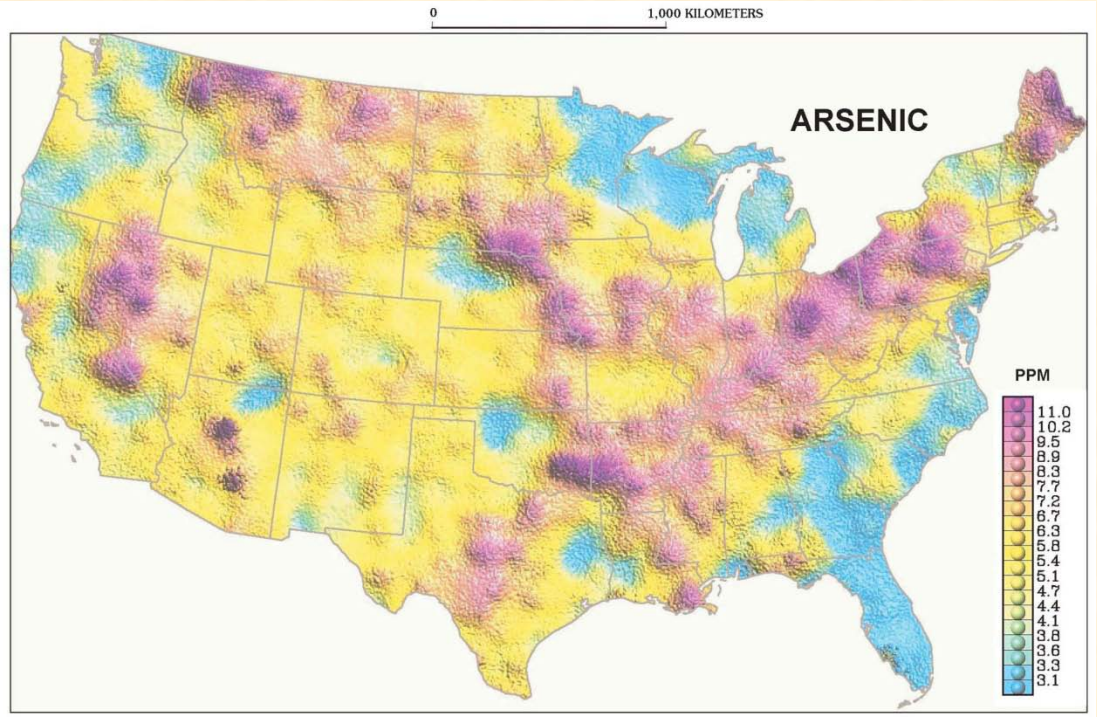


Weathered soils, high Fe oxide content
High adsorption capacity for arsenate
Expected low As bioaccessibility / bioavailability

Fe Oxide "Rich" Soils

Is Soil a Source or Sink for Arsenic?
Could be Both !

natural background soil arsenic



Low sorption - possible source
high sorption - likely sink

Smith et al. 2005. USGS / CGS Study

Gold mining contaminated soils
is Soil a Sink of bioavailable As?

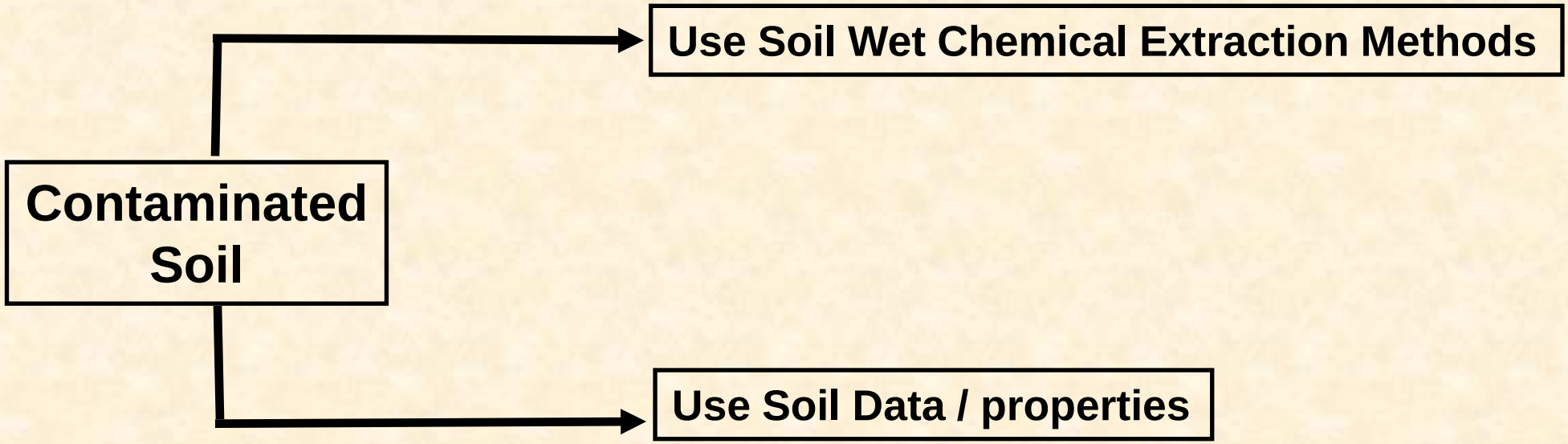
Using Soil Type to Adjust Risk from Soil Contaminants

OSU Soil Science Research Projects

Environmental Security and Technology Certification Program
Strategic Environment Resource Development Program
(DOD, DOE, USEPA consortium)
USEPA National Center for Ecological Assessment

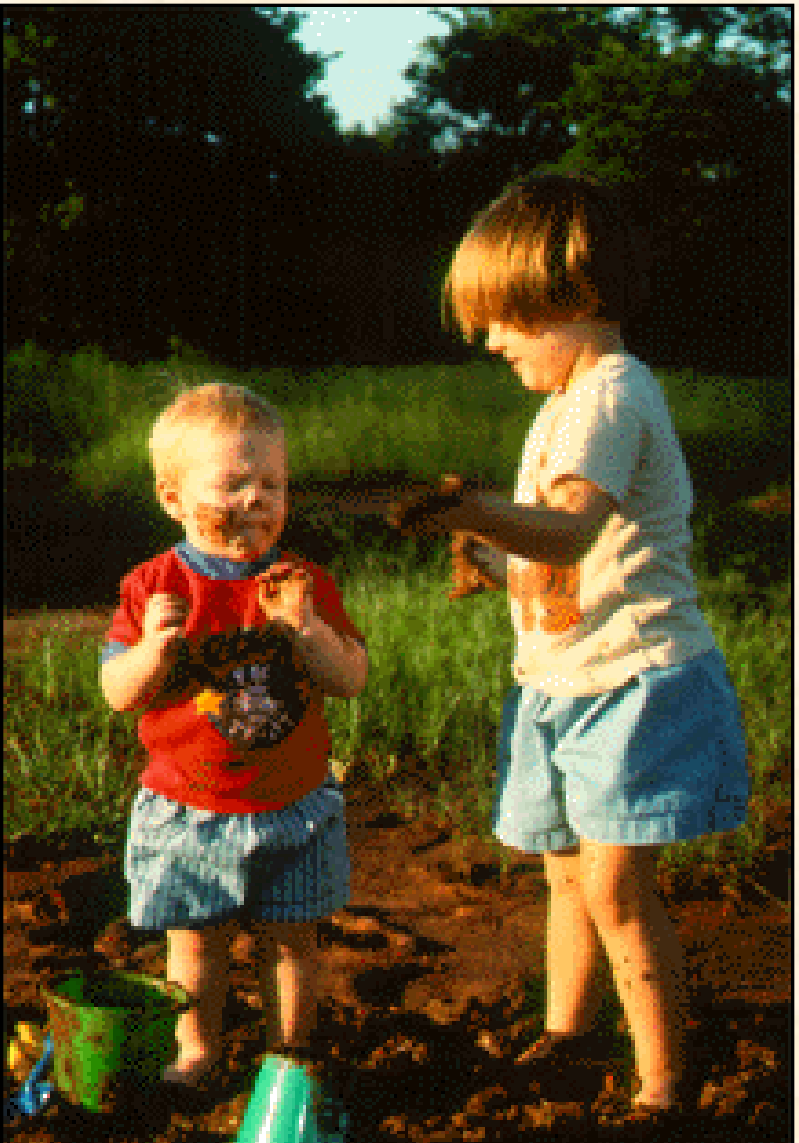
Ohio State University; US Army Edgewood Chem. Biol. Ctr; Oak Ridge National Laboratory; Stanford Univ.; Univ. of Missouri; USEPA National Risk Management Lab; USEPA National Exposure Research Lab; Auburn Univ.

Using Soil Data to Estimate Contaminant Bioavailability and Adjust/Predict Risk



Both approaches are being evaluated in our studies

Using Oral Bioavailability to Assess Human Health Risk of the Soil Ingestion Pathway



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

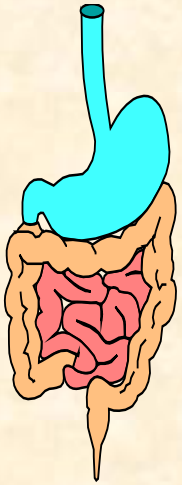
CDI = chronic daily intake of Pb
= Pb absorbed into blood
[Soil Pb] = total soil Pb

BIO = Bioavailability of Pb in soil which ranges from 0.0 to 1.0

How do we assess the CDI (risk)?

In Vitro Gastrointestinal Methods

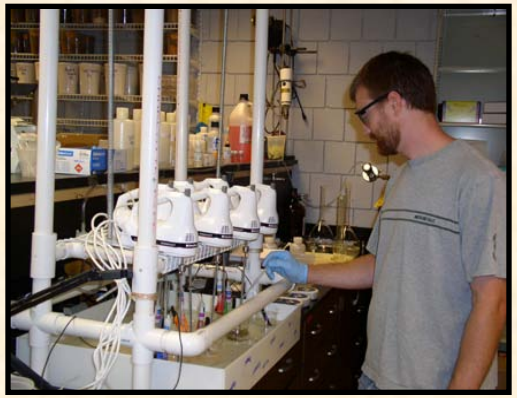
An Inexpensive, Fast, Accessible Alternative



Simulated human gastrointestinal extraction

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

IVG extraction



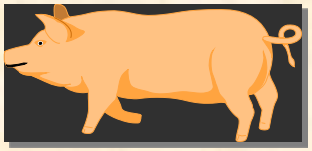
OSU IVG

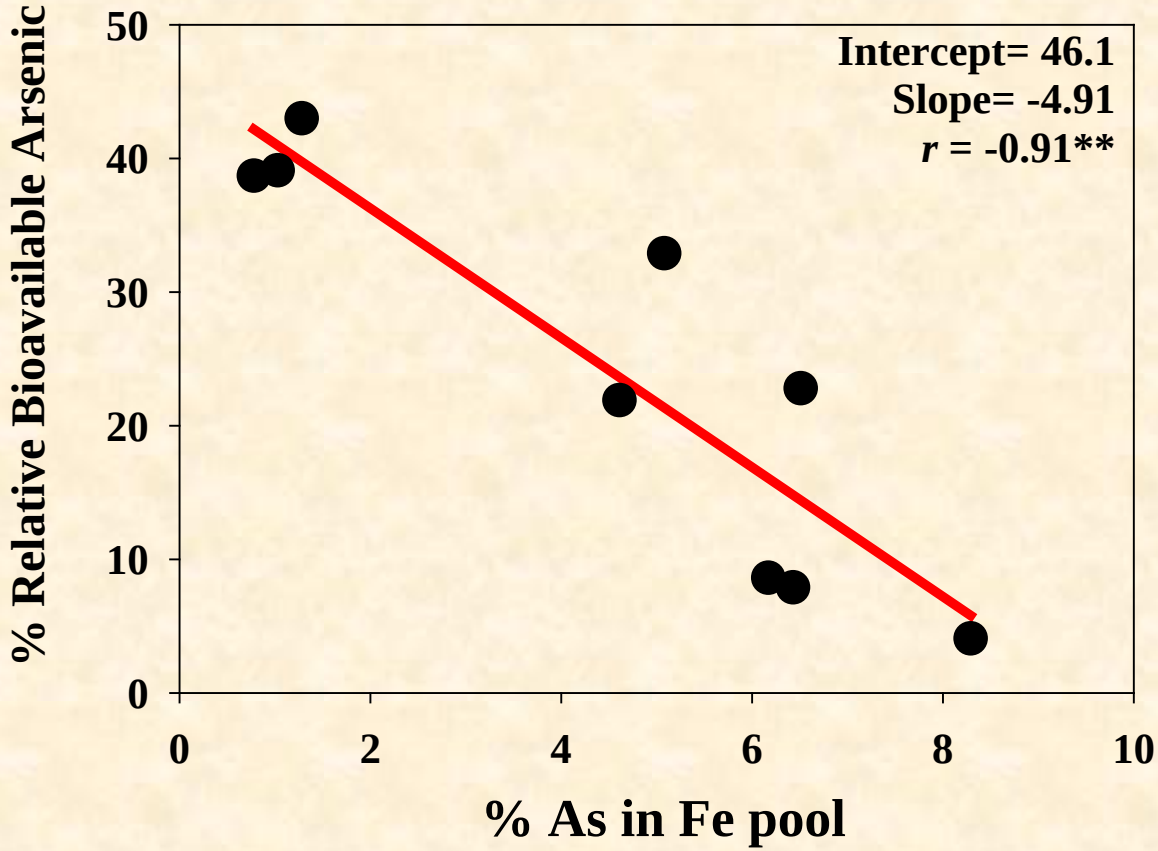
$$\% \text{ IVBA} = \left(\frac{\textbf{In vitro dissolved metal}}{\textbf{Total soil metal}} \right)$$

metal analysis by ICP

Bioavailable As and Reactive Soil Fe

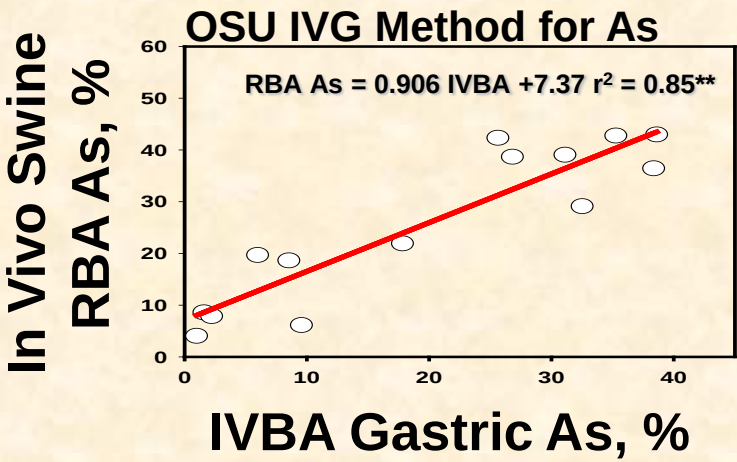
Soil Chemical Extraction Methods





Bioavailable As inversely related to As in Soil Fe pool

Using IVG Methods to Predict Bioavailable Soil Pb and As and Adjust Risk

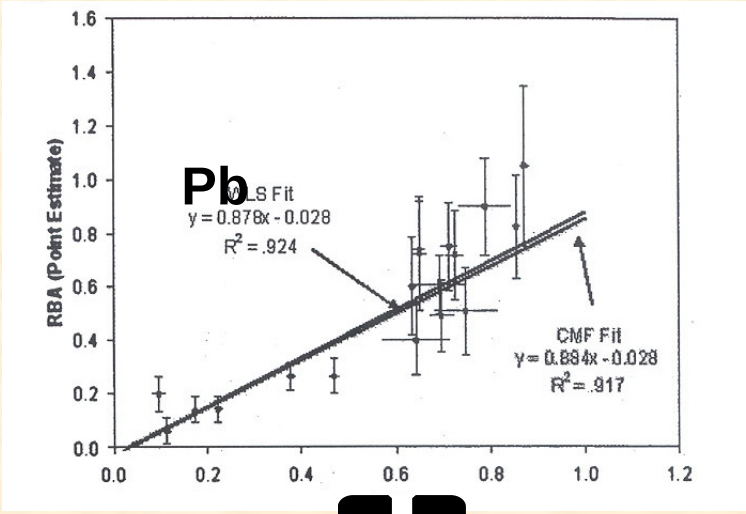


Arsenic

OSU IVG:
Bioavailable As (%) = 0.906 (% IVBA) + 7.37, $r^2 = 0.85$

Lead

RBALP Method of Drexler and Brattin:
Bioavailable Pb (%) = 0.887 (%IVBA) -0.028, $r^2 = 0.92$



Using Soil Data to Predict Bioaccessible (IVBA) As

<u>Yang et al. (2002), PBET method</u>

IVBA As (%) = 11.3 soil pH - 30.5 log Fe_{cbd} , r^2 = 0.74

<u>Whitacre et al. (2008), OSU IVG method</u>

IVBA As (%) = 30.7 - 22.6 log Fe_{ox} + 12.3 pH, r^2 = 0.84

IVBA As (%) = 88.2 - 33.2 log Fe_{cbd} + 12.2 pH, r^2 = 0.92

Using Soil Chemical Properties to Adjust Soil Ecotoxicological Exposure / Risk

Earthworm mortality for Pb-spike soil

% Mortality = 133 - 44 (OC) -0.43 (pH*Clay) +0.98(OC*Clay)

R^2 = 0.79, P<0.01

Earthworm bioaccumulation of Pb

Tissue Pb = 3430 - 976(pH) - 93(OC) +74 $(pH)^2$

R^2 = 0.72, P<0.01

Lettuce phytotoxicity for As-spiked soil

Log dry matter As = -0.74(pH) + 0.08(OC) + 0.85(Clay)

R^2 = 0.76, P<0.01

Lettuce bioaccumulation of Pb

Log tissue Pb = -0.2(pH) – 0.55 (OC) -0.24(Clay)

R^2 = 0.64, P<0.01

Two possible urban garden sites

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

Total Pb < 400 mg/kg SSL
no further investigation needed
OK for use

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

Total Pb > 400 mg/kg SSL
further investigation needed

Assessment / adjustment for Pb bioavailability

Total soil Pb, 800 mg/kg

→ Soil Pb bioavailability of 30%

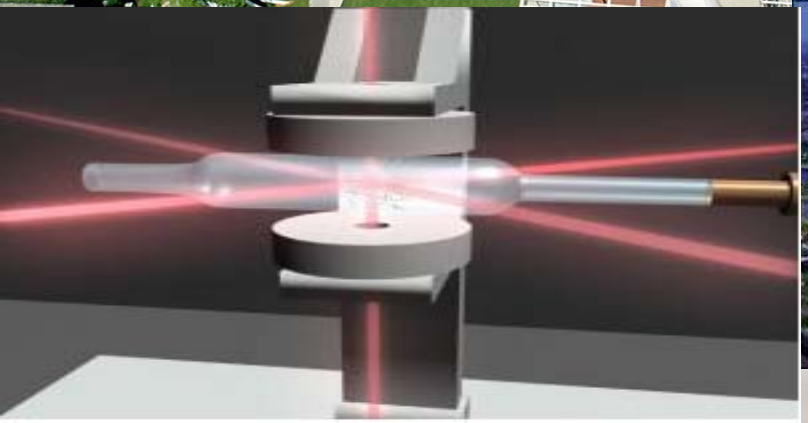
↓

"adjusted soil Pb"
800 mg/kg x 0.3 = 240 mg/kg

below total Pb SSL of 400 mg/kg

OK for use

Thank you for your attention

More information? Please contact:

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