Ecological Effects of Land Application of Biosolids



Nick Basta
Professor of Soil and Environmental Chemistry
School of Environment and Natural Resources
Ohio State University



Workshop on Microconstituents and Ecological Impacts of Biosolids and Effluent Reuse; June 26, 2008

School of Environment and Natural Resources
Ohio State University

<u>Environmental Science / Ecosystem Science</u>

Terrestrial Wildlife and Ecology
- **mammals, avian (including migratory birds)**
- **reptiles,**

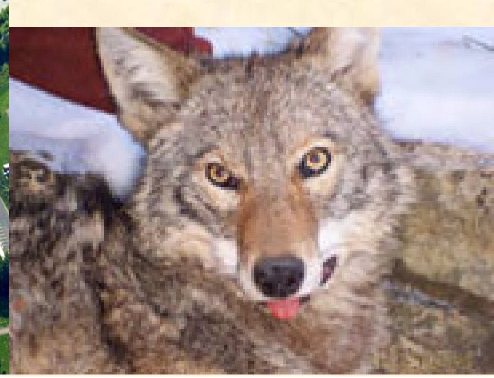
Soil Science (including soil ecology)
- **Carbon Management and Sequestration Center**

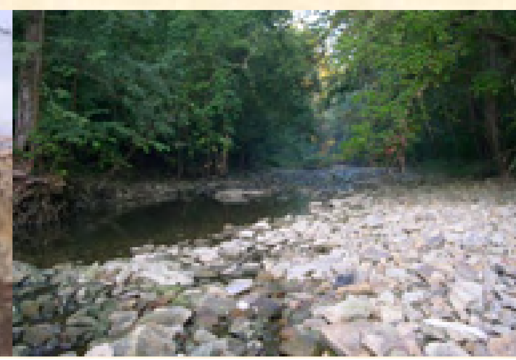
Wetland Science / ecosystems
- **Olentangy River Wetland Research Park**

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; ecotoxicology
- Development and evaluation of remediation technologies of contaminated land
- Beneficial use of industrial by-products via land application
- Biogeochemical cycling of trace elements in soils

Today’s Presentation

Contaminant Exposure (bioavailability) in Contaminated Soil Systems and Ecological Effects

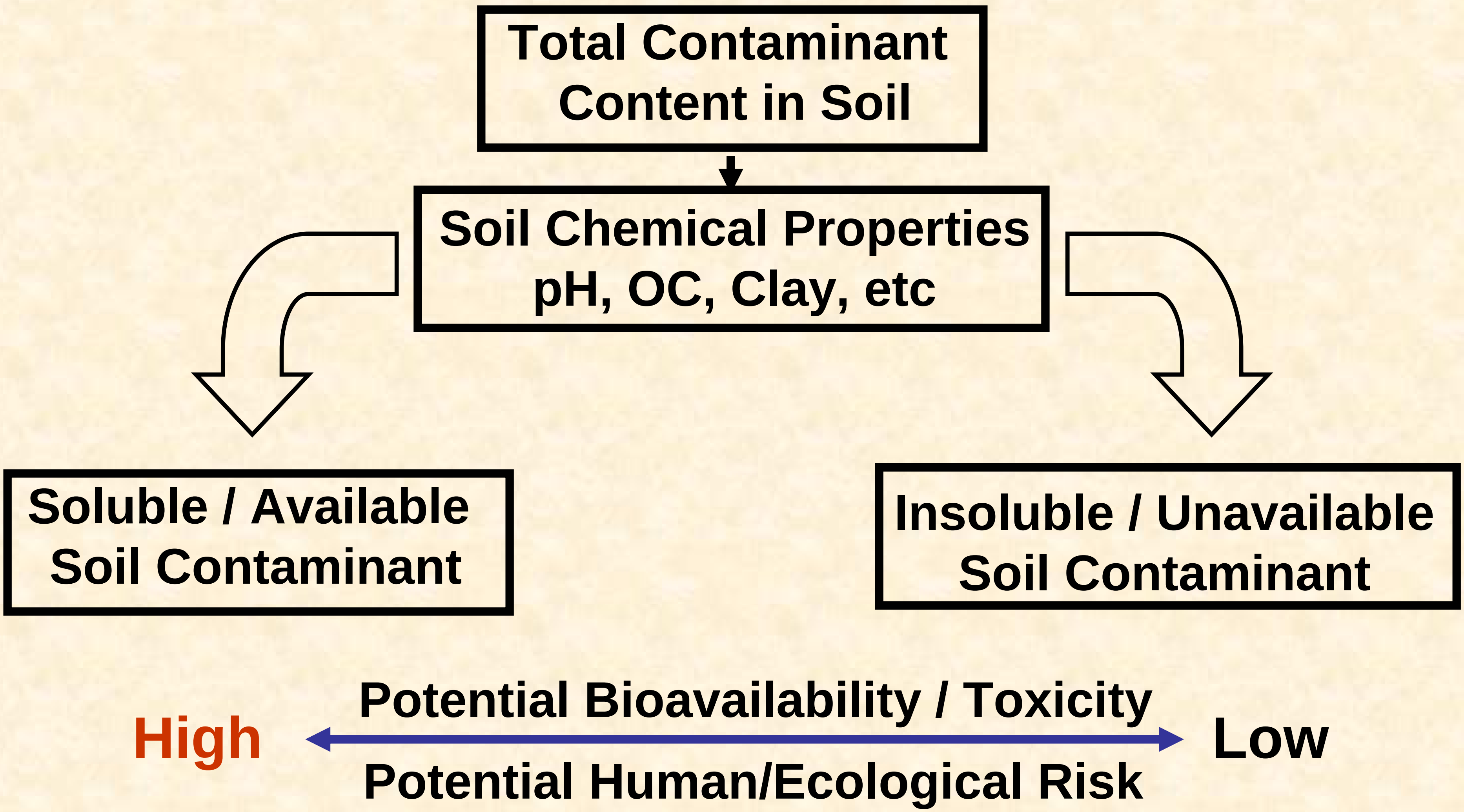
Use of Soil Amendments and Biosolids to Reduce Contaminant Exposure / Ecological Effects

Long-term Ecological Effects of Biosolids Application to Agricultural Land

Soil Environmental Chemistry, Contaminant Bioavailability, and Toxicity

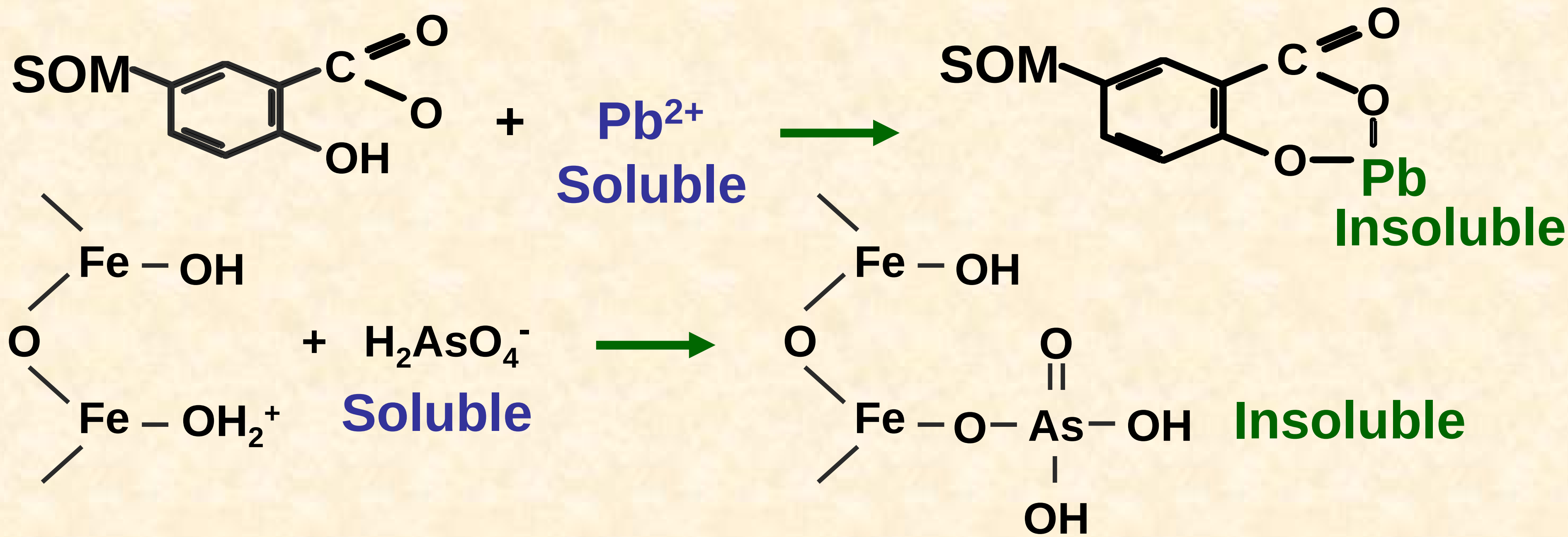
Soil / contaminant chemistry affects availability, contaminant transmission, and human and ecological risk

Soil Chemistry affects Contaminant Partitioning and Availability



Soil Chemical Properties and Solid Phases affect Contaminant Solubility / Bioavailability

Surface Chemistry - Adsorption Reactions in Soil

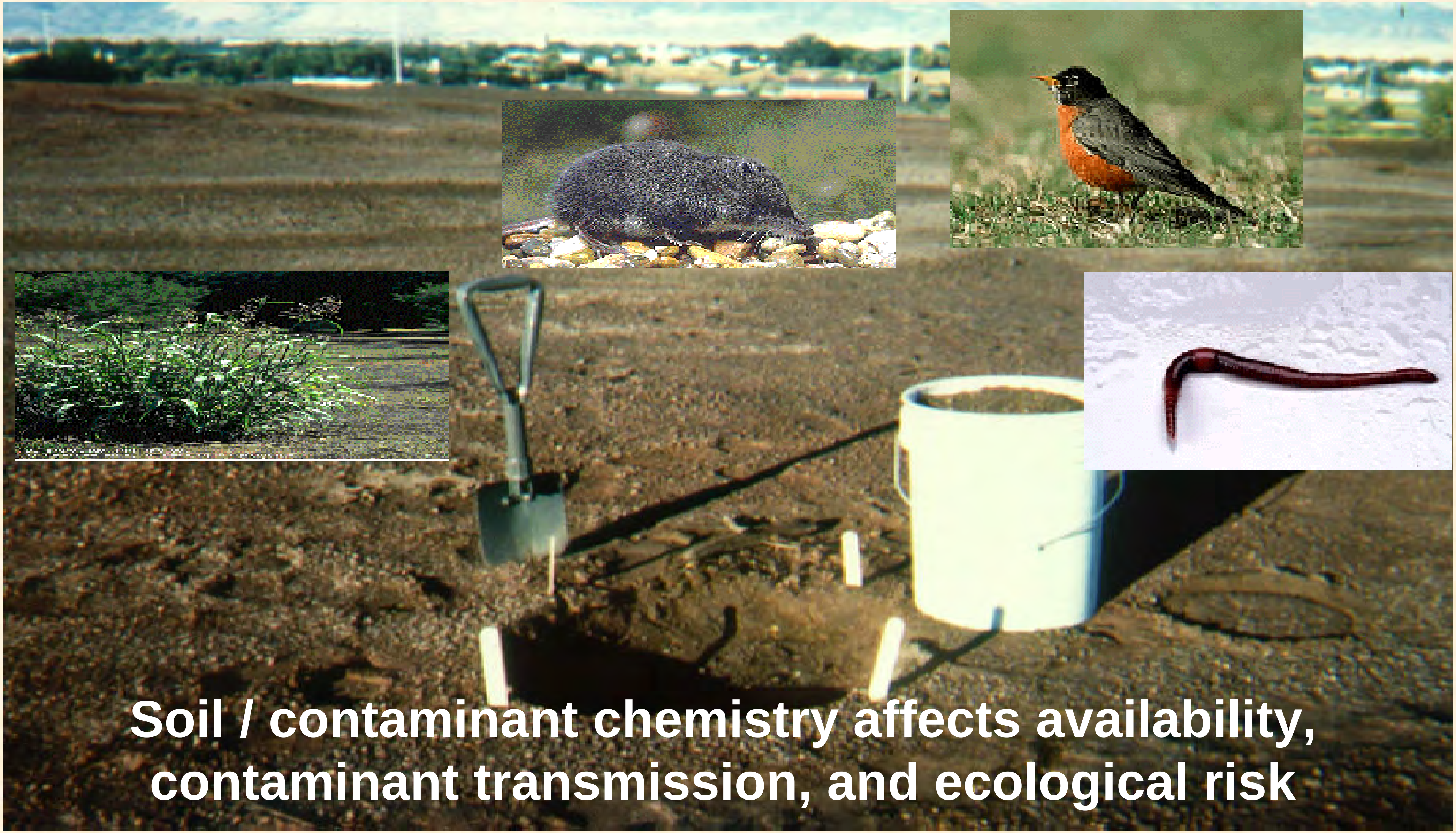


Precipitation Reactions in Soil

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

Soluble (Pb²⁺) — Insoluble ($Ca_{10-x}Pb_x(PO_4)_6(OH)_2$)

Contaminant Exposure in Soil Systems and Ecological Effects

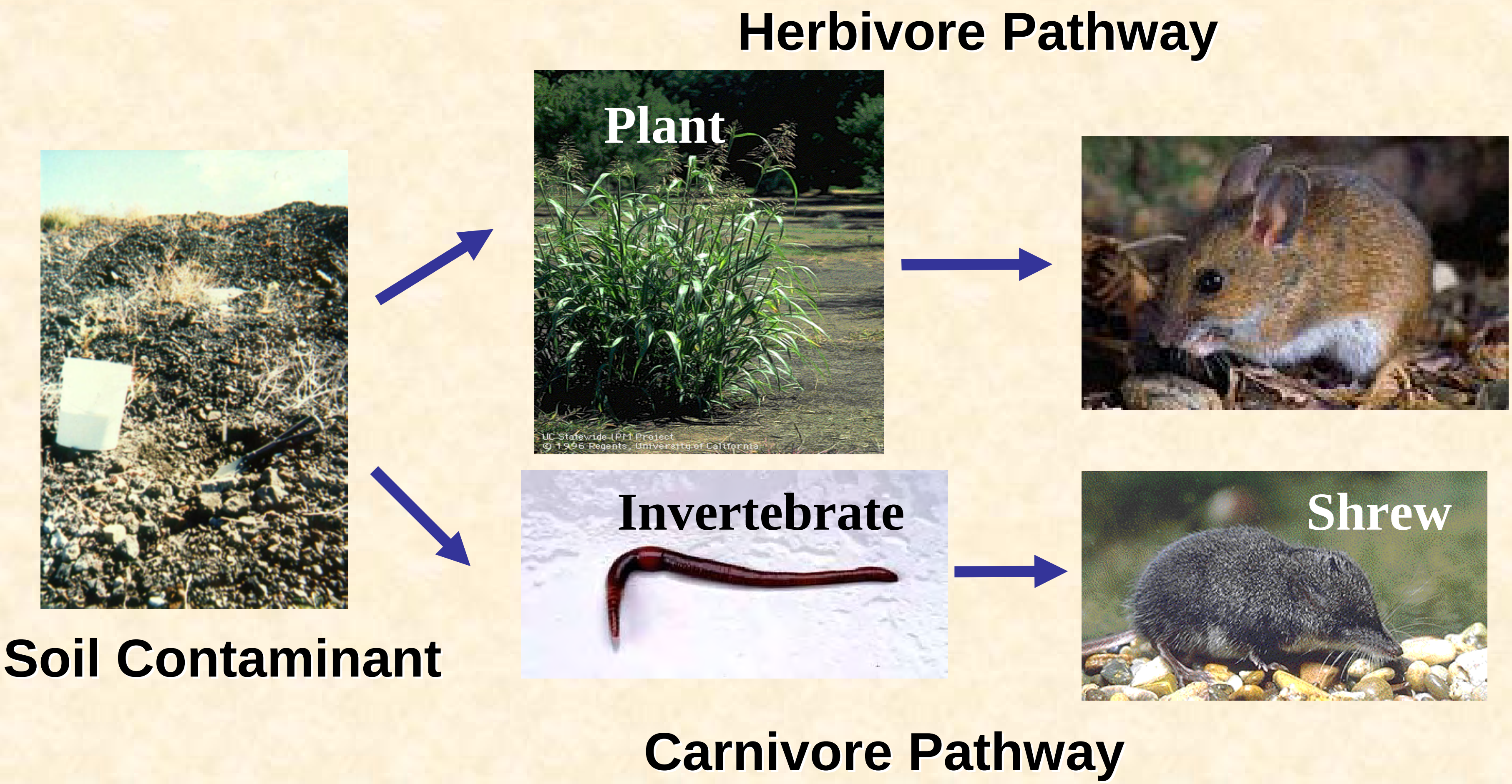


Soil Chemical Properties / Solid Phase Components affect Solubility, Bioavailability, and Toxicity

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

All pots have same total soil Zn but different bioavailable Zn

How Do We Adjust for the Effect of Soil on Contaminant Transmission to Ecological Receptors?



Quantifying the Effect of Soil Chemical Properties on Soil Ecotoxicity for Ecological Risk Assessment

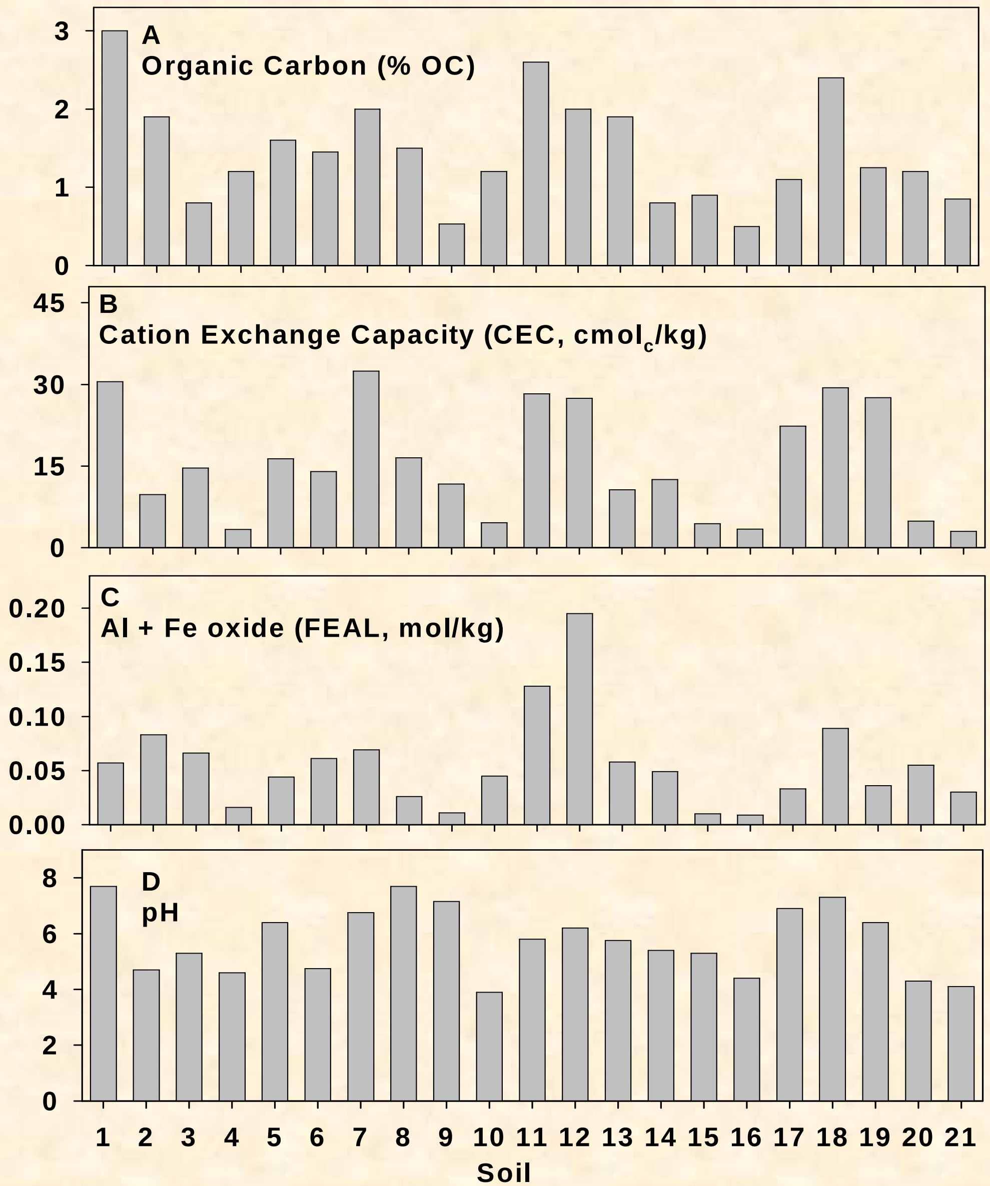
contaminated soil research (not biosolids)

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.;

U.S. EPA NCEA Study



22 soils with wide range of properties / constituents

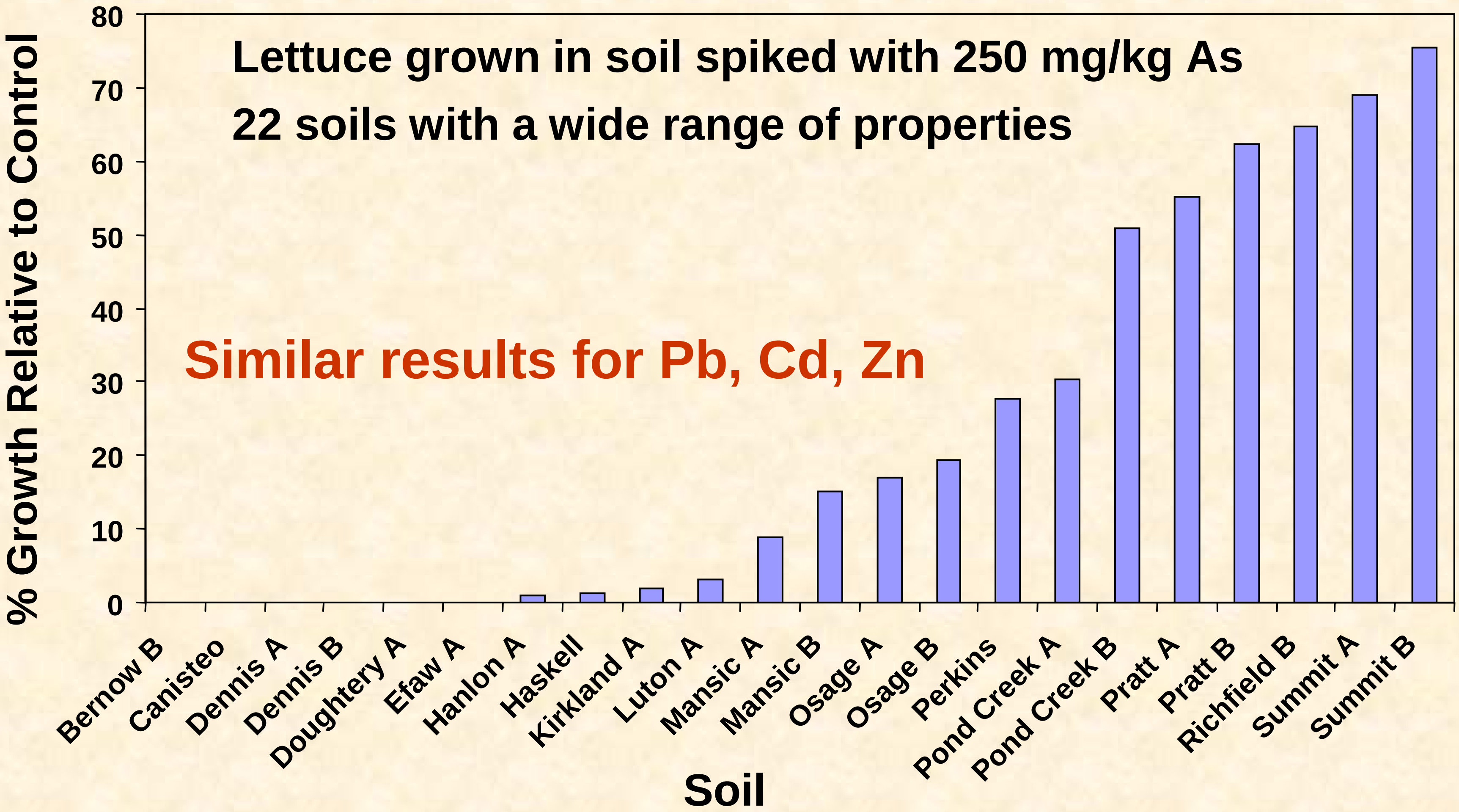
soils spiked with one level of As, Pb, Zn, or Cd

ecotoxicological endpoints lettuce, earthworms

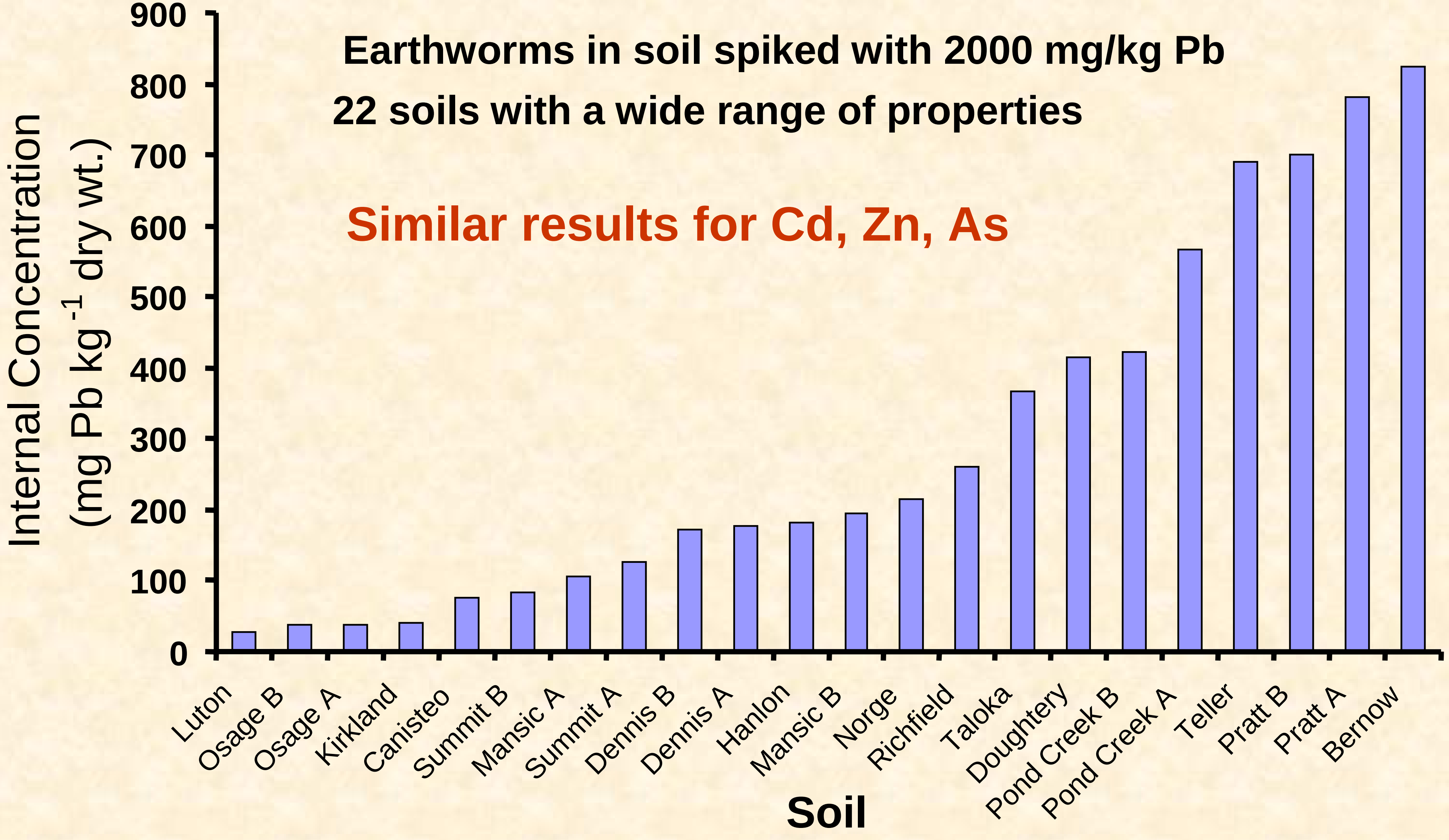
Bradham et al. 2006. Environ. Tox. Chem. 25(3):769-775

Dayton et al. 2006. Environ. Tox. Chem 25(3):719-725

Soil Chemical Properties affected Phytotoxicity



Soil Chemical Properties affect Pb Bioaccumulation
Earthworm Bioassay



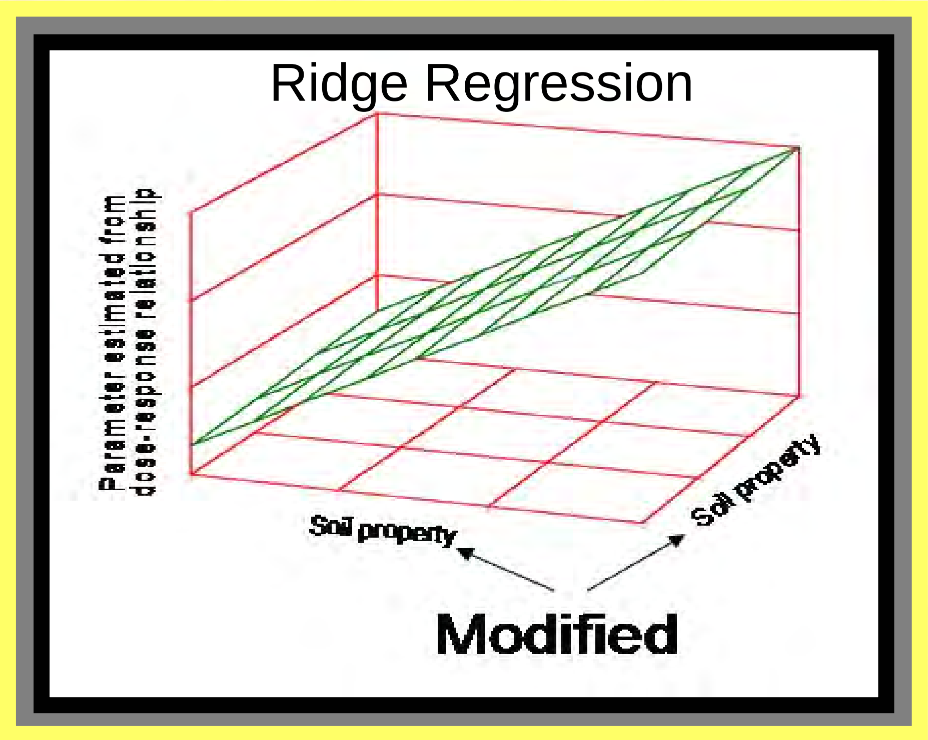
Using Soil Chemical Properties to Adjust/Predict Soil Ecotoxicological Endpoints

Advanced Statistical Approaches

Remedial Techniques for Soil Property Multicollinearity

Many soil properties are inherently strongly intercorrelated (soil pH, CEC, organic carbon, clay content, etc)

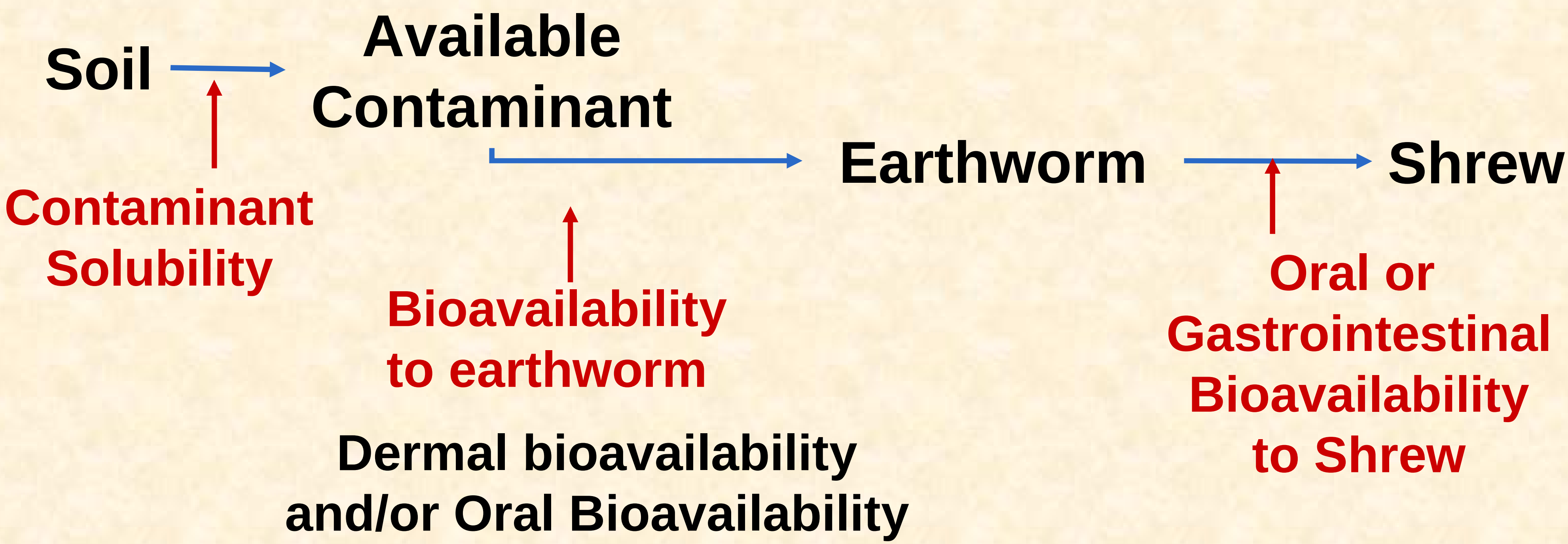
Usual Multiple Regression Techniques will produce highly inaccurate ecotoxicological endpoints



Solution: specialized methods

- **Structural equation modeling**
  Path analysis
- **Multiple Regression Models**
  Ridge regression

Prediction Equations used to Model Food Chain and Contaminant Transmission



How do you measure effects from ingestion of contaminated soil?

Soil Contaminant Oral Bioavailability
Soil Ingestion Exposure Pathway

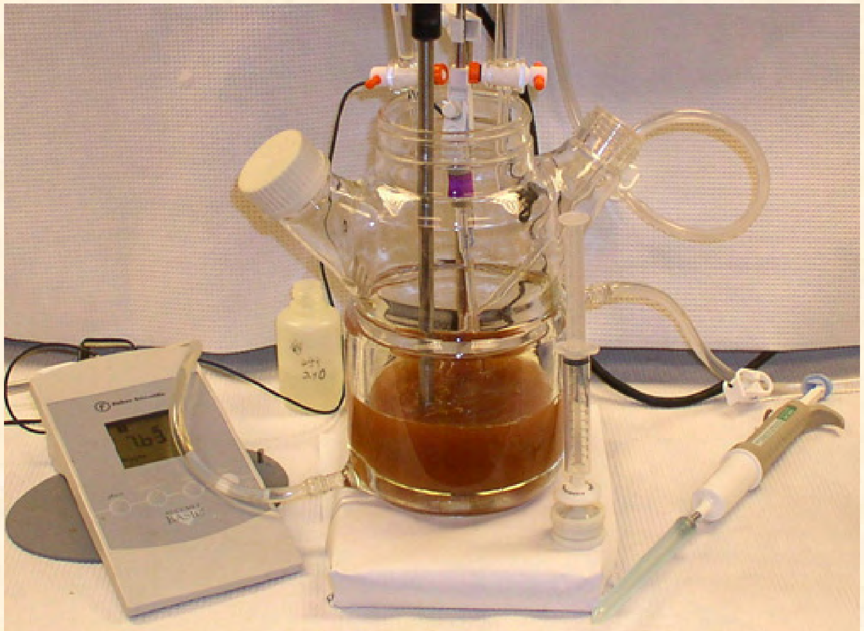
$$\text{Risk} = [\text{Soil}]\ \frac{(EF)\ (ED)\ (IR)\ (BIO)}{(BW)\ (AT)}$$

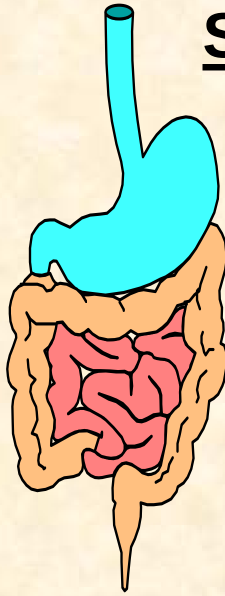
How do we measure BIO for children?

for other ecological receptors ?

OSU In Vitro Gastrointestinal Method

An Inexpensive, Fast, Accessible Alternative





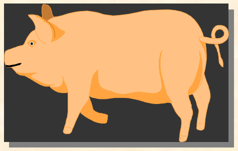
<u>Sequential extraction, 37^{o}C</u>

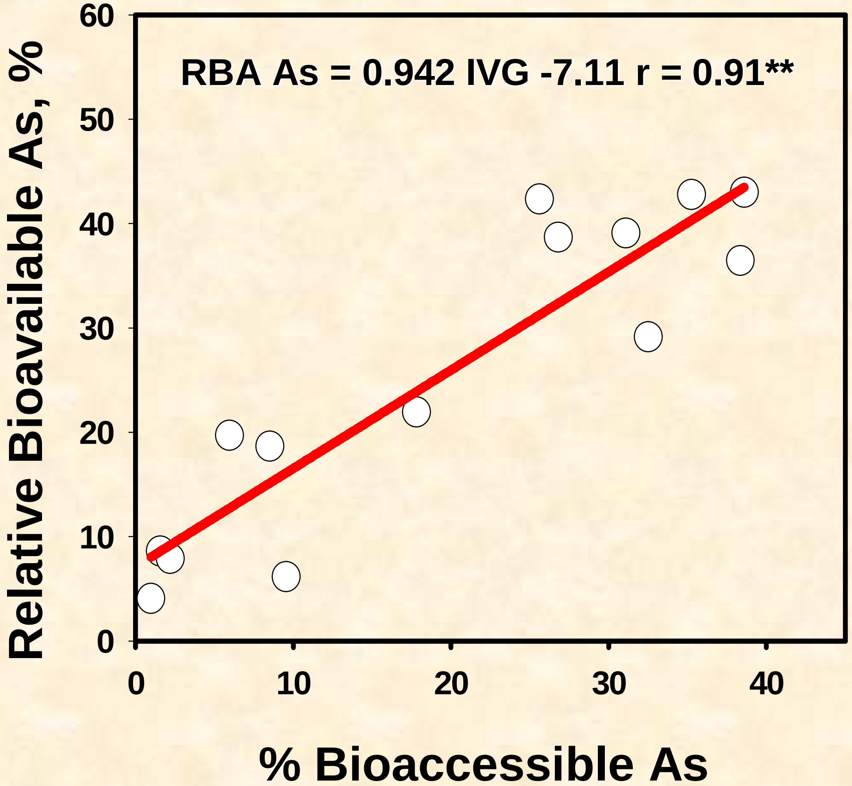
stomach phase
intestinal phase

in vitro **"(bio)availability"** **= dissolved contaminant**
= bioaccessible contaminant

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 Bioaccessibility Method





OSU IVG correlation with in vivo

As with dosing vehicle

Rodriguez et al. 1999. ES&T 33:642-649

As without dosing vehicle

Basta et al., 2007. J. Environ. Health Sci. Part A 42:1275-1181.

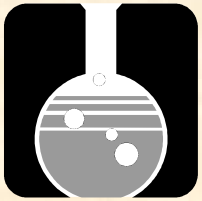
Pb with/out dosing vehicle

Schroder et al., 2004 J. Environ. Qual., 33:513-521.

Cd with/out dosing vehicle

Schroder et al., 2003. ES&T 37:1365-1370.

Basta et al. 2003.
Grant R825410 Final Report.
submitted to U.S. EPA ORD



Prior Use of *in vitro* methods for estimating ecotoxicological risks from ingestion of contaminated soil

Ecotoxicological Risks Associated with Land Treatment of Petrochemical Wastes from Petrochemical-Contaminated Soils

Landfarming of Petrochemical Waste Resulted in Soil Contamination

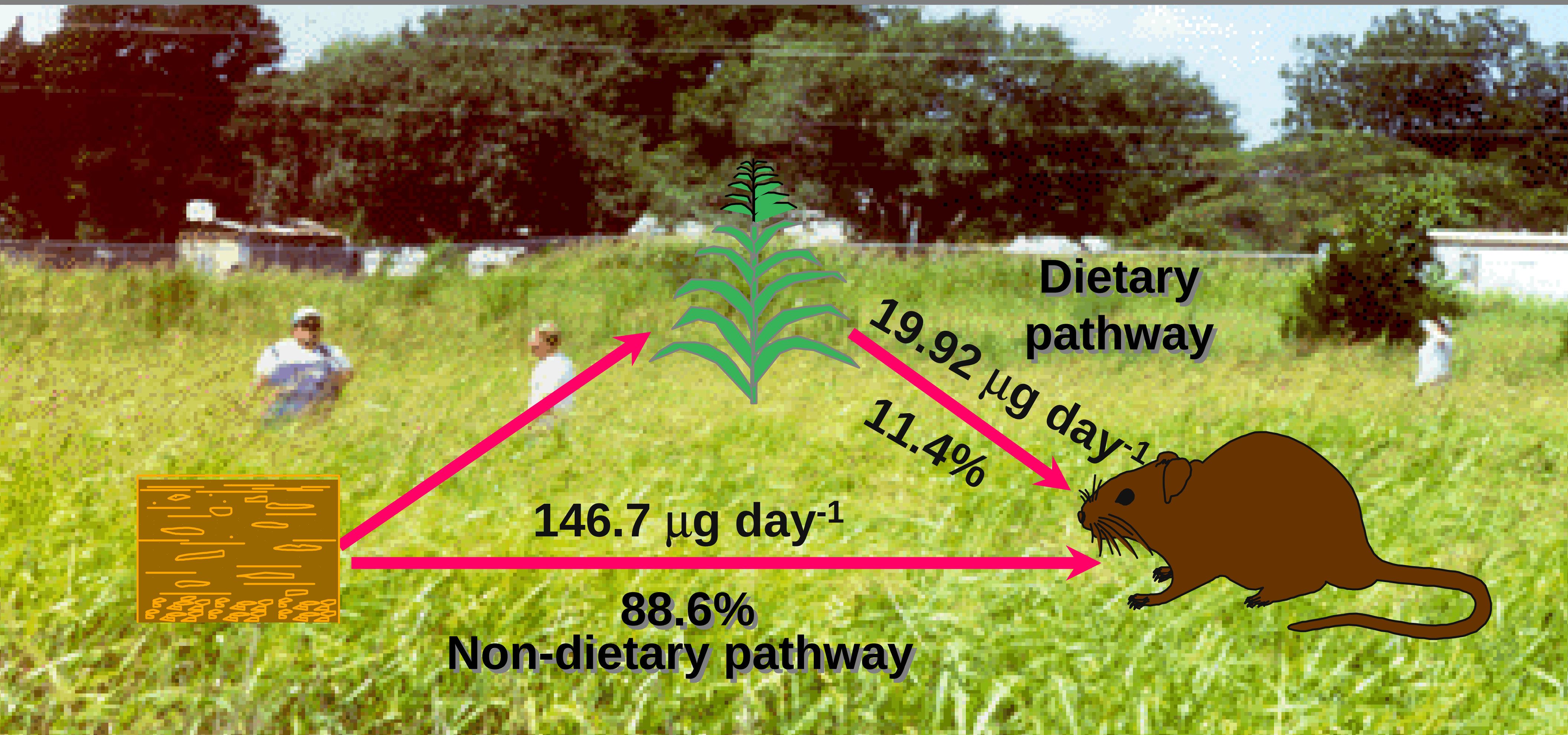
Oily/acid petrochemical sludge pit

Organic chemical wastes
HF- octane production
Pb - tetraethyllead
catalysts (Zn, Cr, V, other metals)

Heavily vegetated landfarm creates an attractive “ecological nuisance”

Contaminant Indicator Species
Cotton Rats (*Sigmodon hispidus*)
small mammal with a critical functional role in terrestrial food chain

Incidental ingestion of soil is a major contaminant exposure pathway for cotton rats



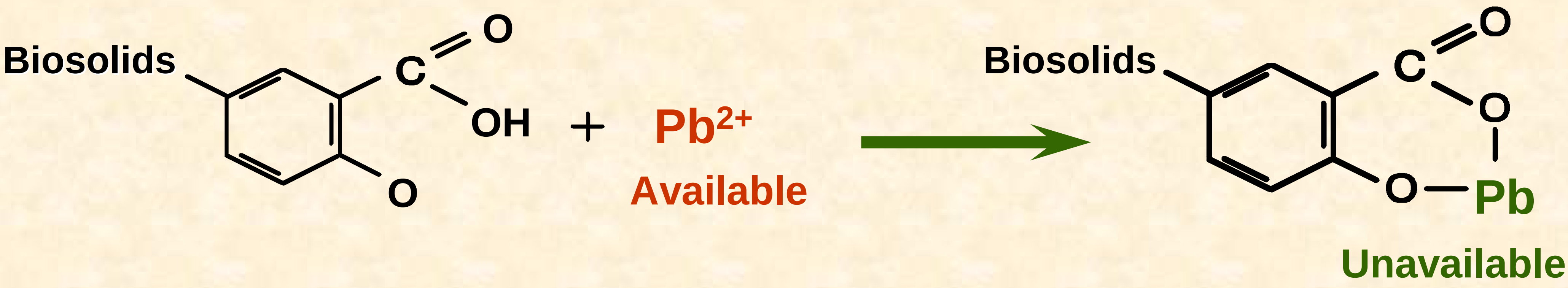
F exposure from incidental ingestion of soil associated with dietary (soiled food) and non-dietary pathways

Soil Remediation by *in situ* Soil Amendments

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

- ❖adjust soil pH
- ❖increase clay/oxide content
- ❖add organic matter, etc.

In Situ Chemical Immobilization of Pb



Immobilization of Pb Contaminated Soil
Phosphates / P Fertilizer

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

Hydroxyapatite + available Pb

Lead pyromorphite
Low bioavailability

Hydroxyapatite (Ma et al., 1995; Laperche et al., 1997)

Soluble phosphate fertilizer
Basta and McGowen, 2004; McGowen et al., 2000

Soil Remediation Using Byproducts
Large-Scale Field Studies

Before **After**

Bunker Hill, ID; Joplin, MO; Leadville, CO; others

http://faculty.washington.edu/slb/

Brown, Chaney, et al. 2004. J. Environ. Qual. 33:522-531.

Palmerton, PA, 1980; Dead Ecosystem on Blue Mountain.

Palmerton, PA, 1999: Looking down revegetated Blue Mountain.

Soil Remediation in Picher, OK using Byproducts

Univ. of Washington, USEPA ERT, OSU

<u>72 plots on Pb, Zn, Cd contaminated land</u>

Alkaline Biosolids

Biosolids Compost

Commercial phosphorus fertilizer

Al-Drinking water residuals

Fe-Drinking water residuals

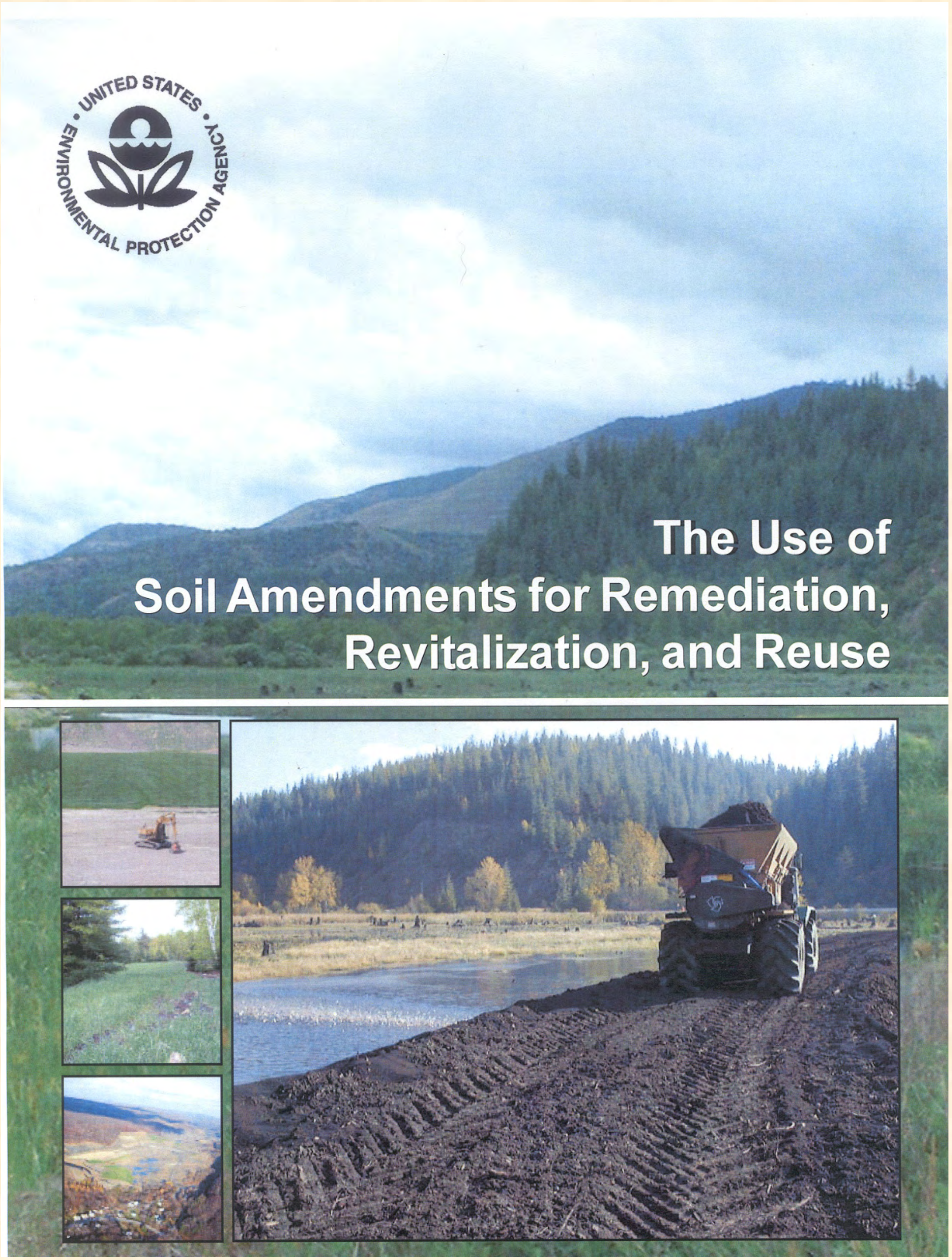
Seeded with Bermudagrass

Soil Remediation in Picher, OK using Byproducts
Univ. of Washington, USEPA ERT, OSU

Soil Remediation and Ecological Restoration

"Ecological Revitalization" of contaminated Superfund sites

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



Ecological Restoration Soil Amendments

- biosolids
- manures
- compost
- pulp sludges
- yard /wood waste
- lime
- wood ash
- coal combustion products
- sugar beet lime
- foundry sand
- steel slag
- FGD
- water treatment residuals
- etc

Ecological Restoration
Evaluating Contaminant Remediation
http://www.cluin.org/products/tpm/

Technology Performance Measures

Step 1 – Selecting the Goal of the Soil Amendment Application

Step 2 – Selecting the Exposure Pathway of Concern

Step 3 – Select the Performance Endpoint

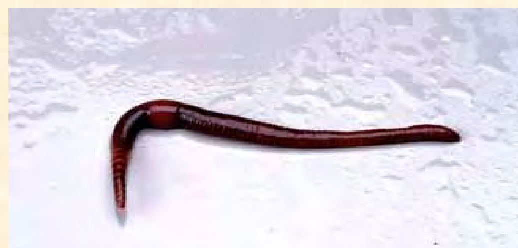
Step 4 – Select What You Want To Measure

Step 5 – Select the Performance Measurement

TPM to Evaluate Amended Soil Reductions in Bioavailability and Ecological Exposure

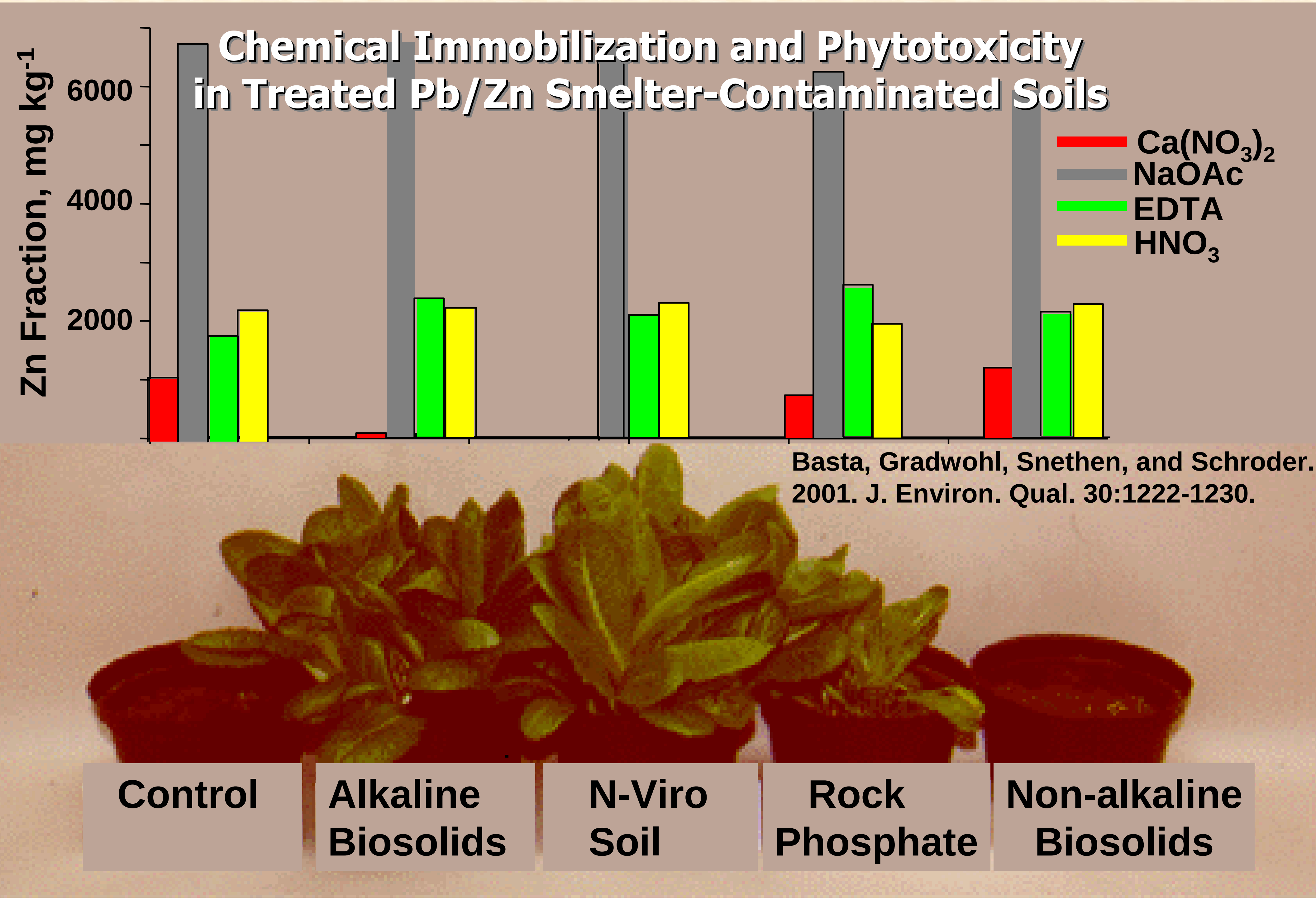
Herbivore Pathway

Soil Contaminant



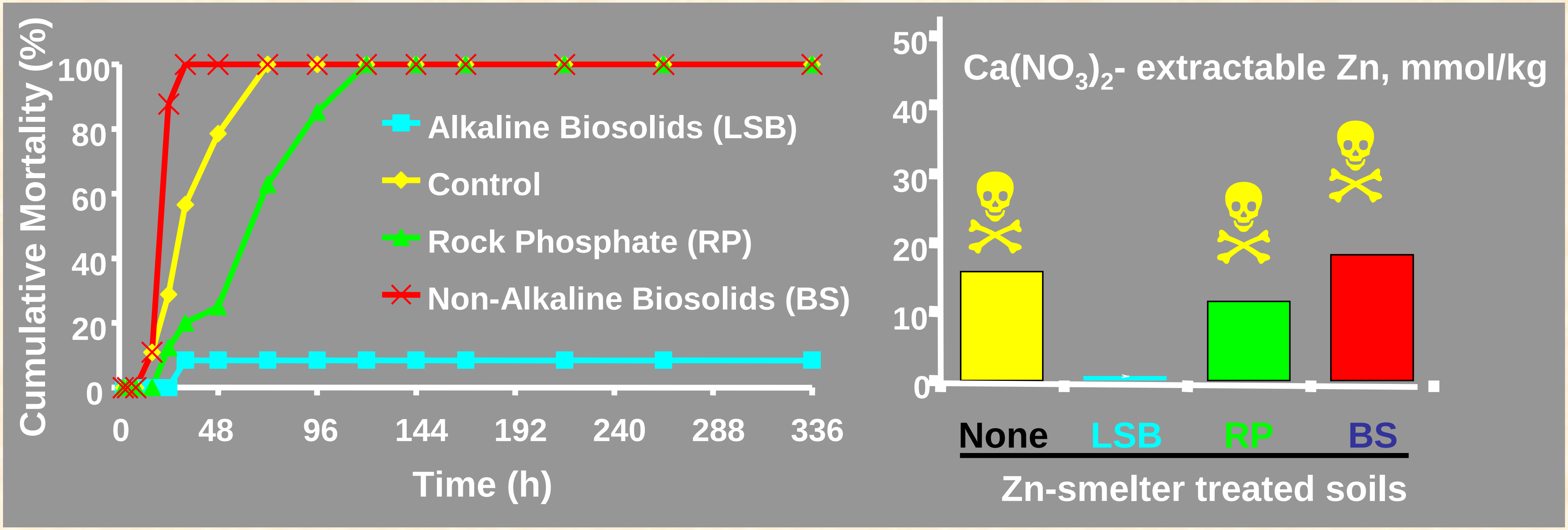
Carnivore Pathway

TPM for herbivore pathway: plant bioassay / metal bioaccumulation
TPM for carnivore: earthworm bioassay / bioaccumulation
TPM for both pathways: plant/worm ingestion- in vitro GI methods


Chemical Immobilization and Phytotoxicity
in Treated Pb/Zn Smelter-Contaminated Soils
Zn Fraction, mg kg^{-1}
6000
4000
2000
$Ca(NO_3)_2$
NaOAc
EDTA
HNO_3
Basta, Gradwohl, Snethen, and Schroder.
2001. J. Environ. Qual. 30:1222-1230.
Control
Alkaline Biosolids
N-Viro Soil
Rock Phosphate
Non-alkaline Biosolids

Quantifying Efficacy of In Situ Remediation Treatments: Treatment Effects on Ecological Risk

Earthworm Toxicity Testing
Zn, Pb, Cd Contaminated Smelter Soil

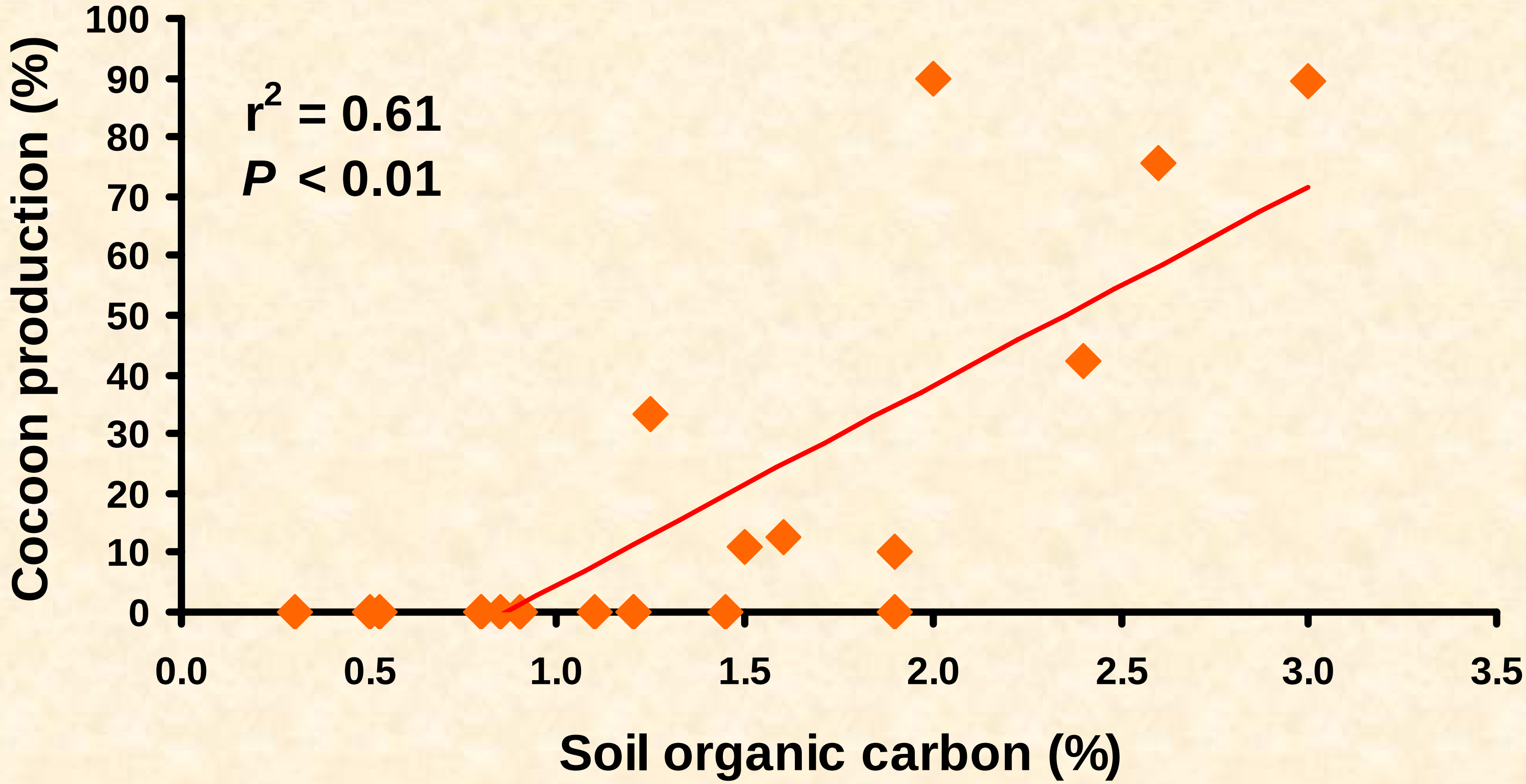


Condor, Lanno, and Basta. 2001. J. Environ. Qual. 30:1231-1237.

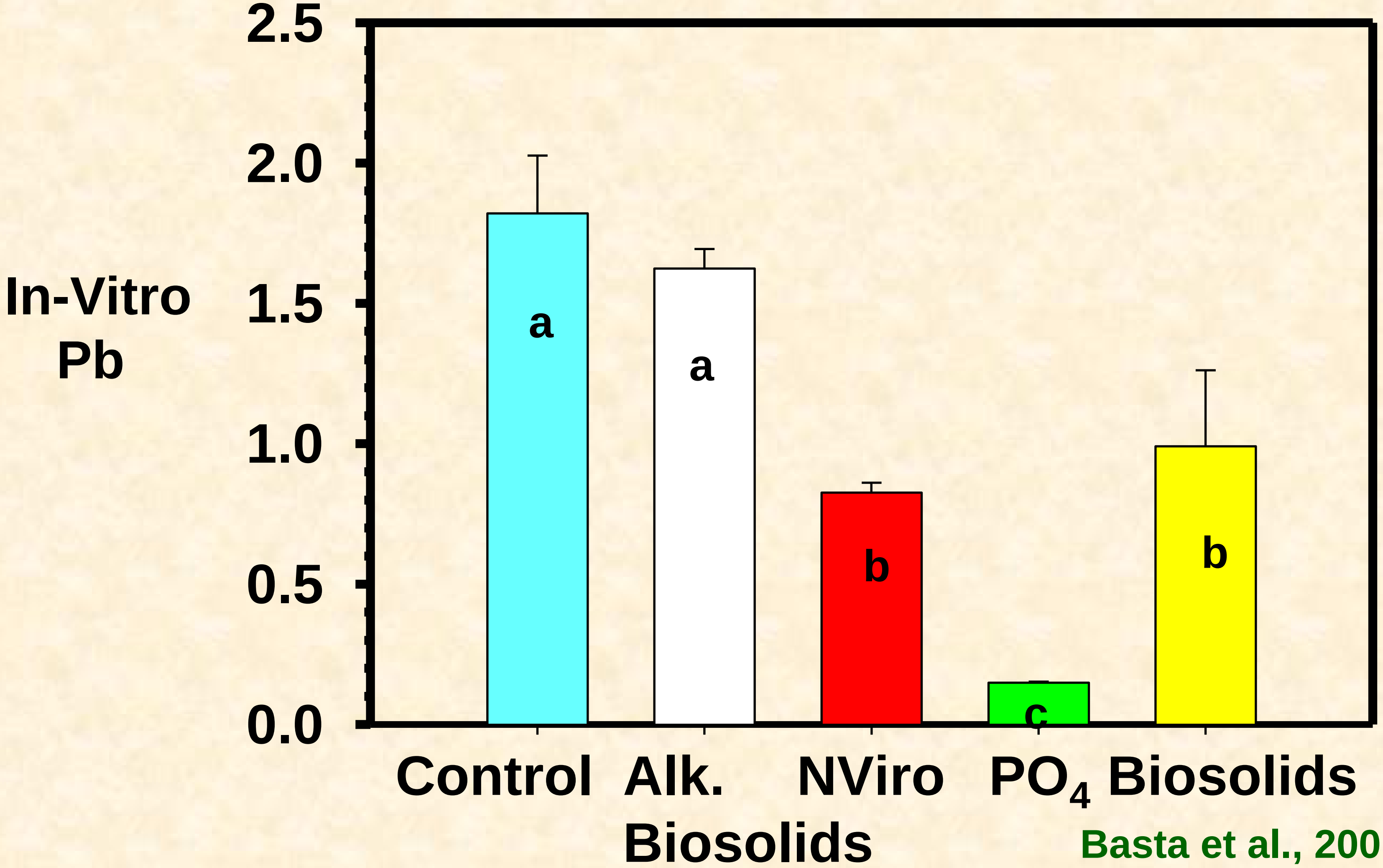
No toxicity to *Eisenia fetida* in alkaline biosolids treated soil !

Organic Matter Amendments Increase Earthworm Cocoon Production

More Earthworms!

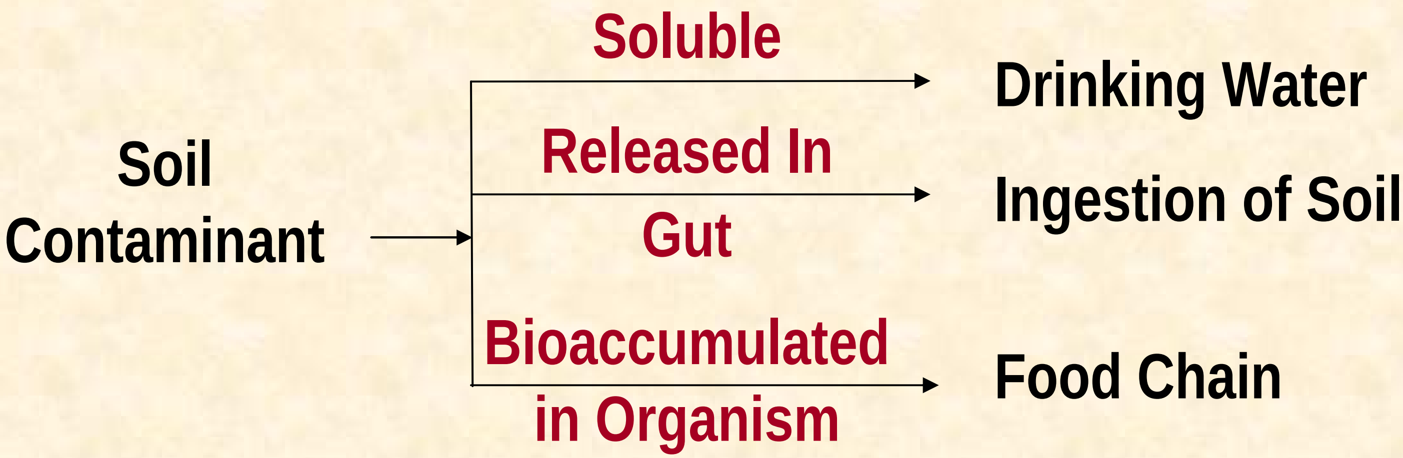


Did the Amendments Decrease Soil Ingestion Risk?
in-vitro Pb GI Bioavailability in Amended Soil



Basta et al., 2001.
J. Environ. Qual. 30:1222-1230

Best Amendment to Reduce Bioavailability / Mobility and Transmission via Exposure Pathways



Combination Amendment

Biosolids + Phosphorus Fertilizer (for Zn / Pb / Cd)

Brown, S.L., H. Compton, and N.T. Basta. 2007.
Field Test of *In Situ* Soil Amendments at the Tar Creek National Priorities List Superfund Site
J. Environ. Qual. 36:1627-1634.

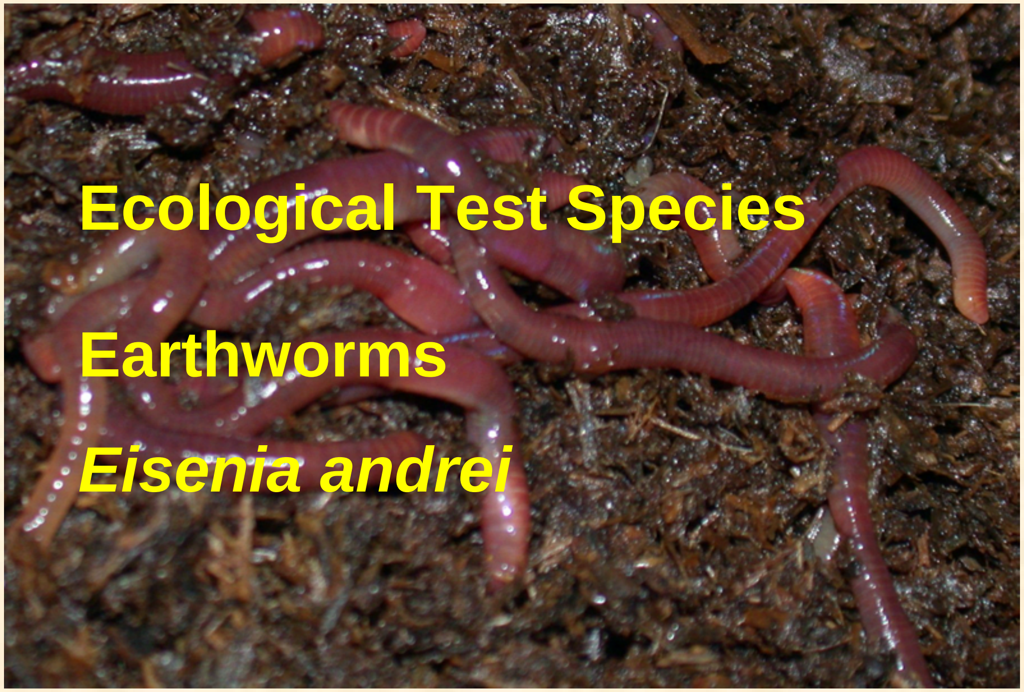
Long-Term Ecological and Environmental Benefits from Land Application of Biosolids

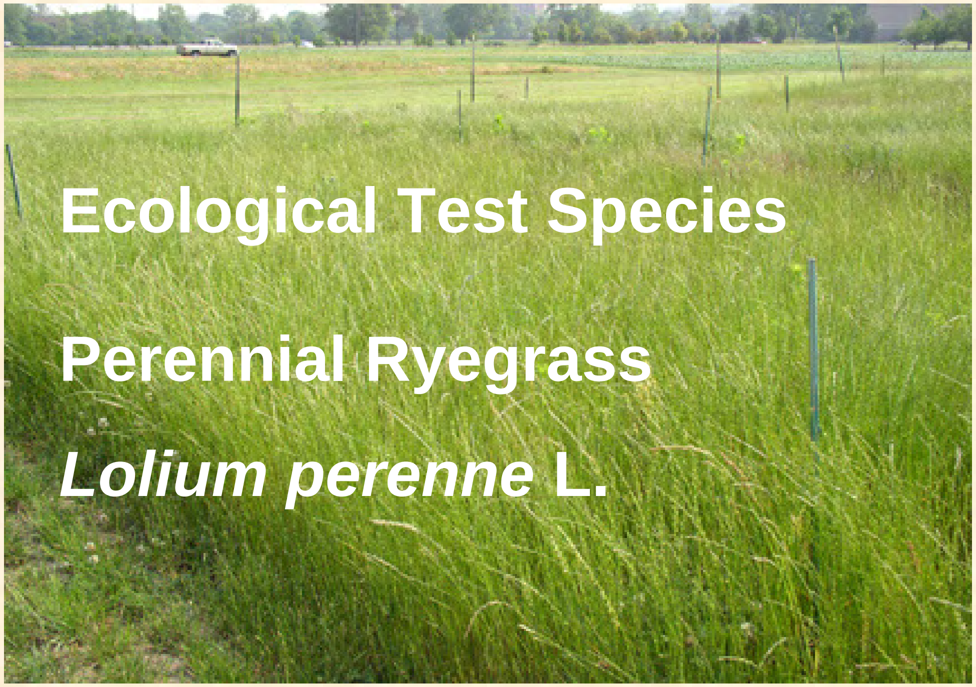
Nick Basta, Shane Whitacre, SENR
Roman Lanno, Dept. of Entomology

Plots established by Dr. Terry Logan in 1992
One time application of biosolids.
10 application rates ranging from 0 to 300 Mg/ha

Experimental Design

Plots established by Dr. Terry Logan in 1992
One time application of biosolids
10 application rates ranging from 0 to 300 Mg/ha





Percent Mortality
Reproduction (cocoons, juveniles)
Contaminant Bioaccumulation

Dry matter growth
bioaccumulation
germination

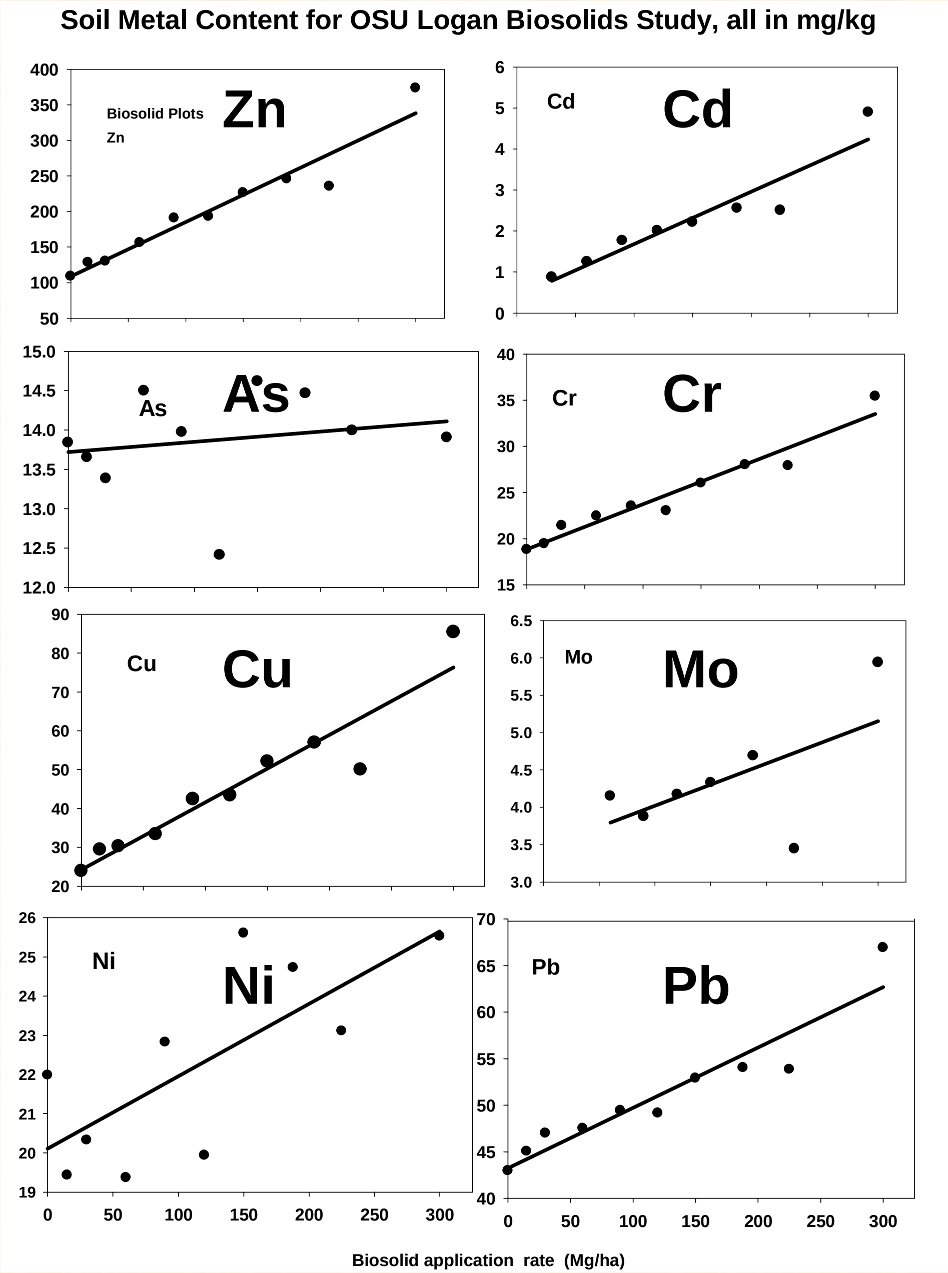
Soil Properties / Nutrients

Biosolids, Mg/ha	pH	Organic C (%)	Total N (%)	P* (mg/kg)
0	7.00	1.20	0.115	63
150	6.67	1.98	0.209	456
300	5.58	2.73	0.279	663

*Mehlich 3 Extraction

Long Term Improvement in Soil Quality and Fertility

Soil Metal Contents



Increase in Zn, Cu, Pb, Cd

Mg/ha	Zn	Cu	Pb	Cd
0	109	24	43	0.60
300	374	85	67	4.90

metal in mg/kg soil

Effect of Biosolids on Ryegrass Dry Matter Growth



0 Mg/ha **150 Mg/ha** **300 Mg/ha**

Large increase in dry matter growth with Biosolids Application Rate

Metal Bioaccumulation in Perennial Ryegrass

Concentrations of two metals increased in Ryegrass grown on plots amended with biosolids:

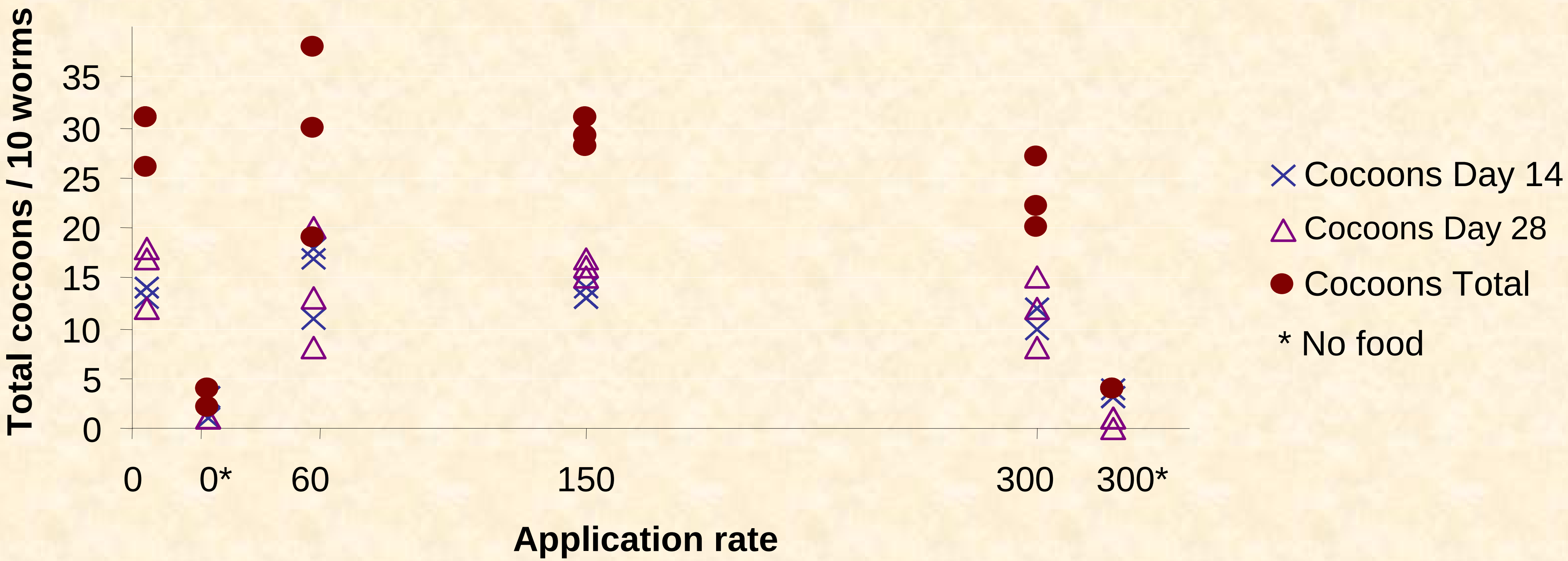
Zn: 36 mg/kg for 0 Mg/ha
111 mg/kg for 300 Mg/ha

Cu: 3.7 mg/kg for 0 Mg/ha
4.7 mg/kg for 300 Mg/ha
Cu sufficiency for Ryegrass is 5 mg/kg

Biosolids improved micronutrient status of soil and improved soil and plant nutrition for Cu and Zn

Soil Ecotoxicity- Invertebrates

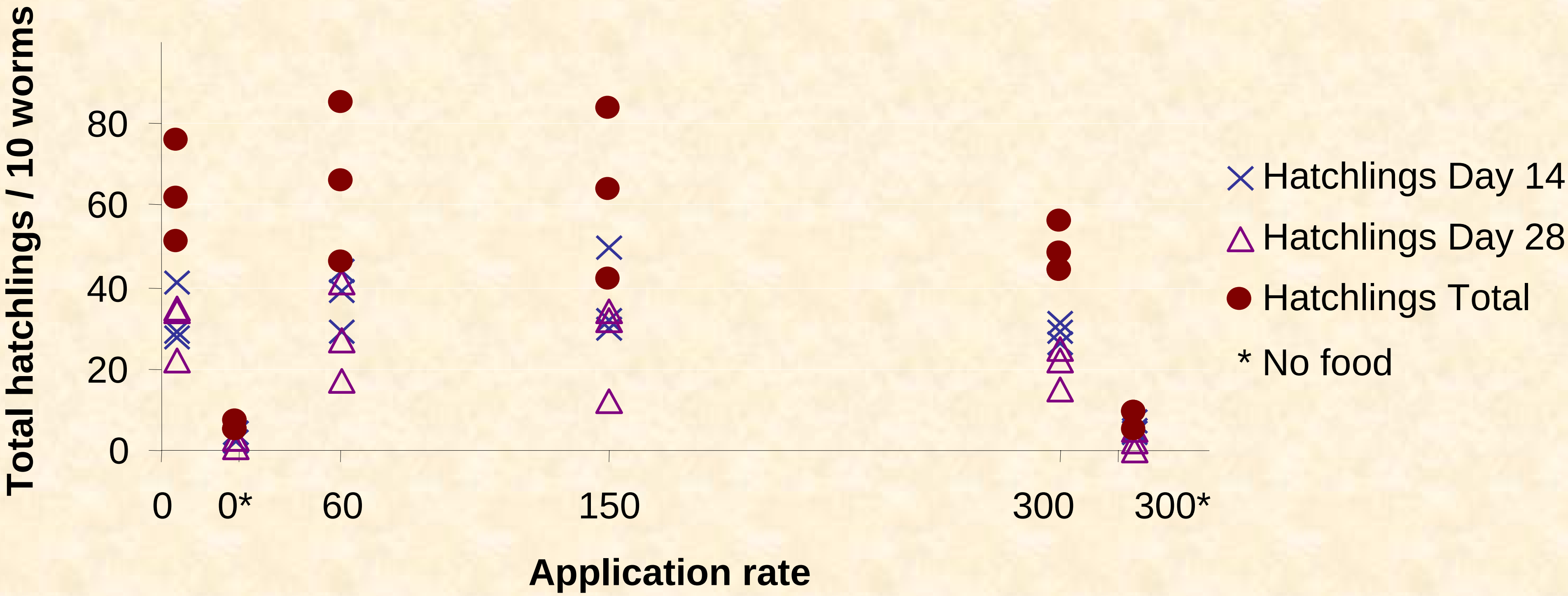
Cocoon production of *Eisenia andrei* in reproduction test



Biosolids had no effect on cocoon production

Soil Ecotoxicity- Invertebrates

Hatchling production of *Eisenia andrei* in reproduction test



Biosolids had no effect on hatchling production

Summary

- **Biosolids increased concentrations of several metals in amended soil**
- **Biosolids improved soil quality and fertility**
- **Long term increase in ryegrass dry matter growth**
- **Improved Cu and Zn in ryegrass (removed deficiency)**
- **No effect on reproduction in *E. andrei***

Thank you for your attention

More information? Please contact:

Nick Basta, SENR OSU

basta.4@osu.edu