Soil Metal Bioavailability

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USEPA

ESTCP Workshop

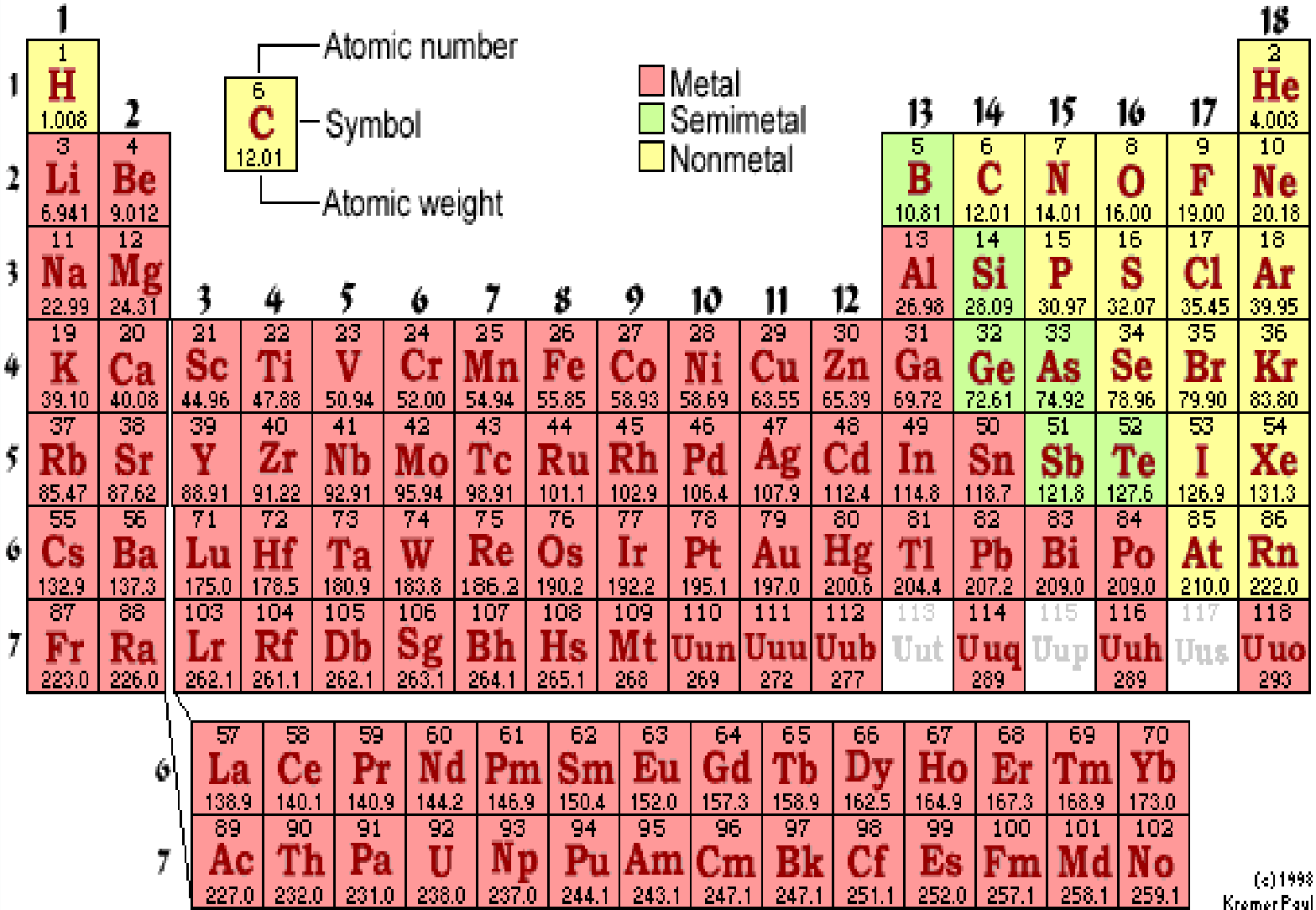
"The Use of In Vitro Soil Metal Bioavailability Methodologies to Adjust Human and Ecological Risk Assessment."

09/15/05

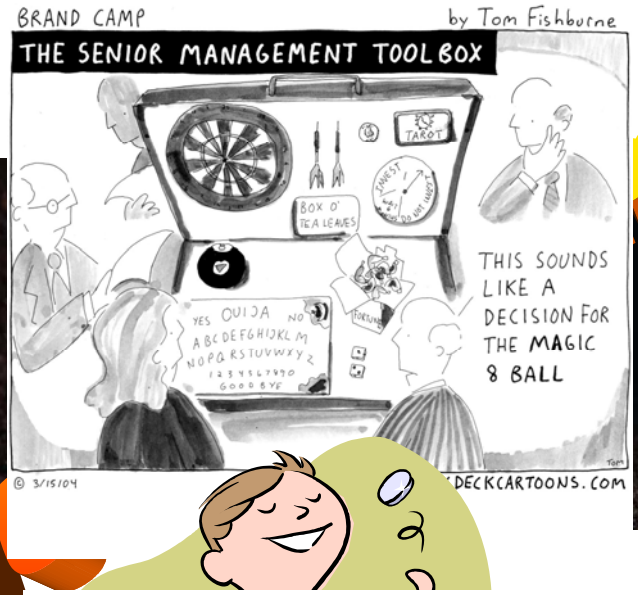
RESEARCH & DEVELOPMENT

Building a scientific foundation for sound environmental decisions

You want a simple in vitro test for how many elements?

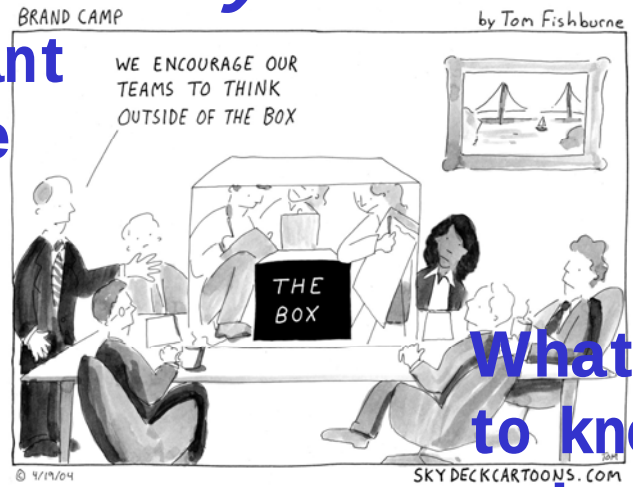


Which soil do you prefer to live with?



How do you decide?

What do you want to know to make a decision?



What do you need to know to make a decision?

Problem formulation

- Define geospatial area
- Composition of area
- Identify environmental controlling factors
  - pH
  - OM
  - Al/Fe/Mn
  - ?
- Naturally occurring biota and sensitivity

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Systematic Characterization of Exposure-Dose-Response Continuum and the Evolution of Protective to Predictive Dose-Response Estimates

Chemical Exposure | **Dose** | **Toxicological Response**

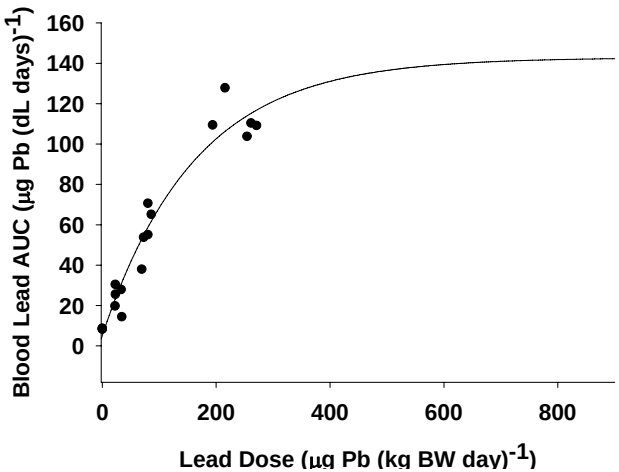
Protective — **Qualitative**

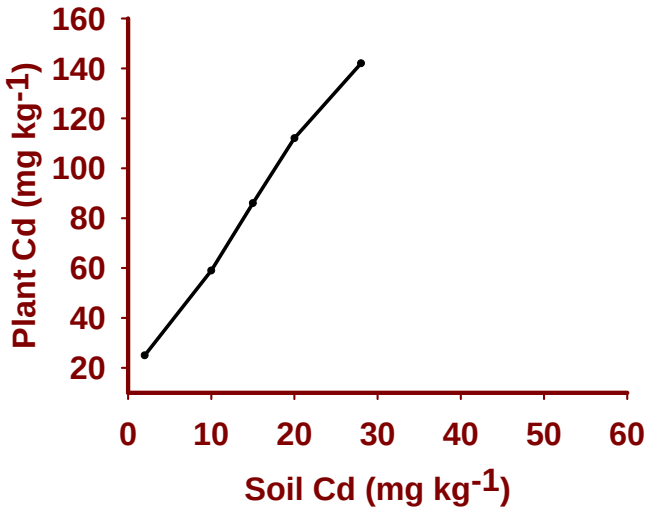
Exposure → ? → Response

Default

Route of Exposure
Air
Water
Food
→ ? → Response

Default

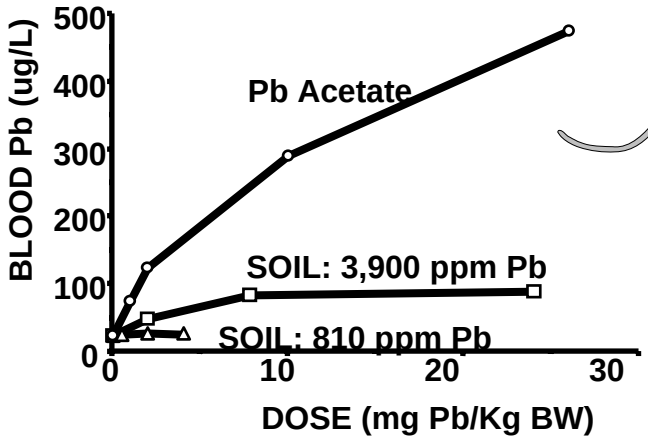




BIOAVAILABILITY

EFFECT OF SOURCE OF Pb ON BIOAVAILABILITY TO RATS

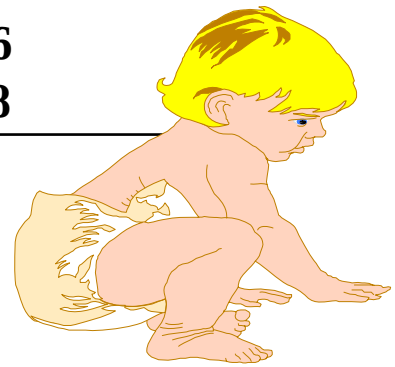
FREEMAN et al. (1991)



EFFECT OF SOURCE OF Pb ON BIOAVAILABILITY TO HUMAN

Steele et al. 1990

SOURCE	BLOOD Pb (μg/dL) / SOIL Pb (1000mg/kg)
SMELTER/URBAN	1.1 - 7.6
MINING	0 - 4.8



- *PHYSIOLOGICAL*
  - *Pharmacokinetics*
- *CHEMICAL*
  - *Form of Pb*
  - *Geochemical matrix*
  - *Size of Pb particle*

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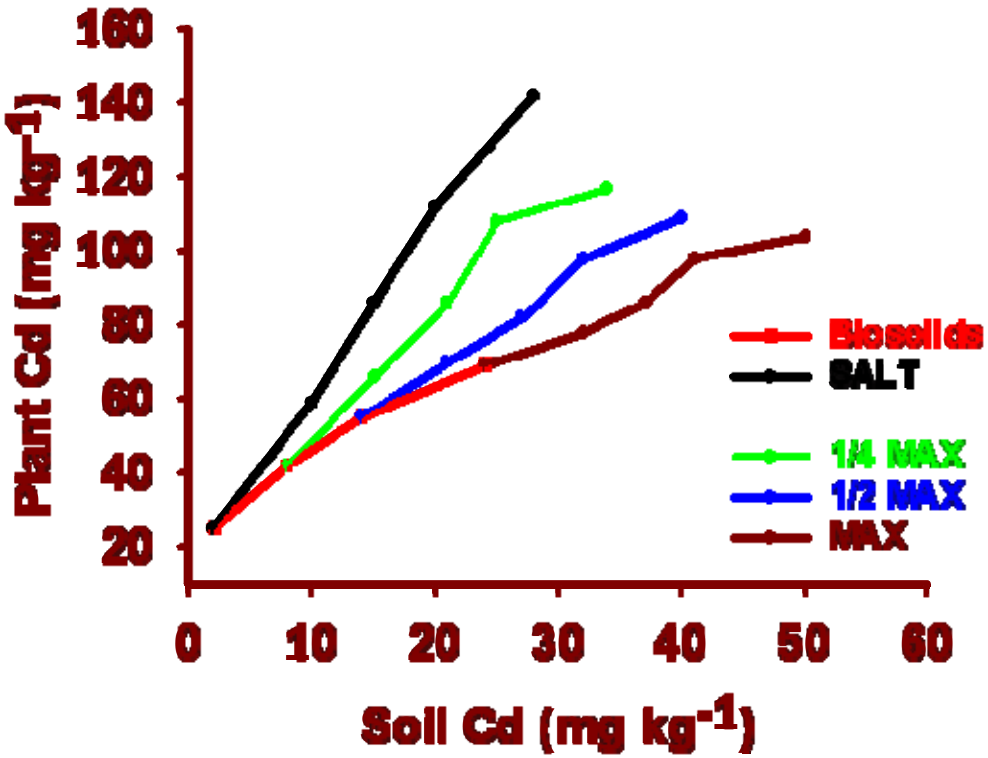
PHYTOAVAILABILITY

Plant response on Illinois long term field plot samples



Bioavailability of Cadmium in Biosolids-Fertilized Swiss Chard Fed at 28% of Diet to Guinea Pigs for 80 Days (Chaney et al., 1978)

Treatment	Rate	Soil Cd	Soil pH	Chard Cd	Chard Zn	Kidney Cd	Liver Cd
	t/ha	mg/kg		mg/kg dry		---mg/kg dry---	
Control	0	0.04	6.0	0.5	70	14.9 a	3.1 a
Biosolid-1	56	0.32	5.7	1.5	950	14.5 a	2.7 a
Biosolid-2	112	0.94	5.5	2.7	580	14.5 a	2.7 a
Biosolid-3	224	0.89	6.6	1.4	257	15.8 a	3.6 a

Lessons learned

- ***Total metal content is not a good indicator of exposure or risk***
- ***Soil chemistry important in determination of bioavailability/phytoavailability***
  - ***Form is important***
  - ***Particle size is important***
  - ***Adsorption is important?***
    - ***Fe/Mn are important adsorptive surfaces***
    - ***Organic matter is important adsorptive surface***
- ***Cannot assume an increase concentration in the foodchain equates to increase transfer through the foodchain***
- ***Predicting the potential transfer of soil metals requires a holistic evaluation of soil, plant, animal, and human processes which may increase or reduce the transfer (bioavailability)***

Use of Bioavailability

- ***503 Biosolids Regulation***
- ***Region 10 As guidance***
- ***Risk Assessment Guidelines for Superfund (RAGS) encourages its use***

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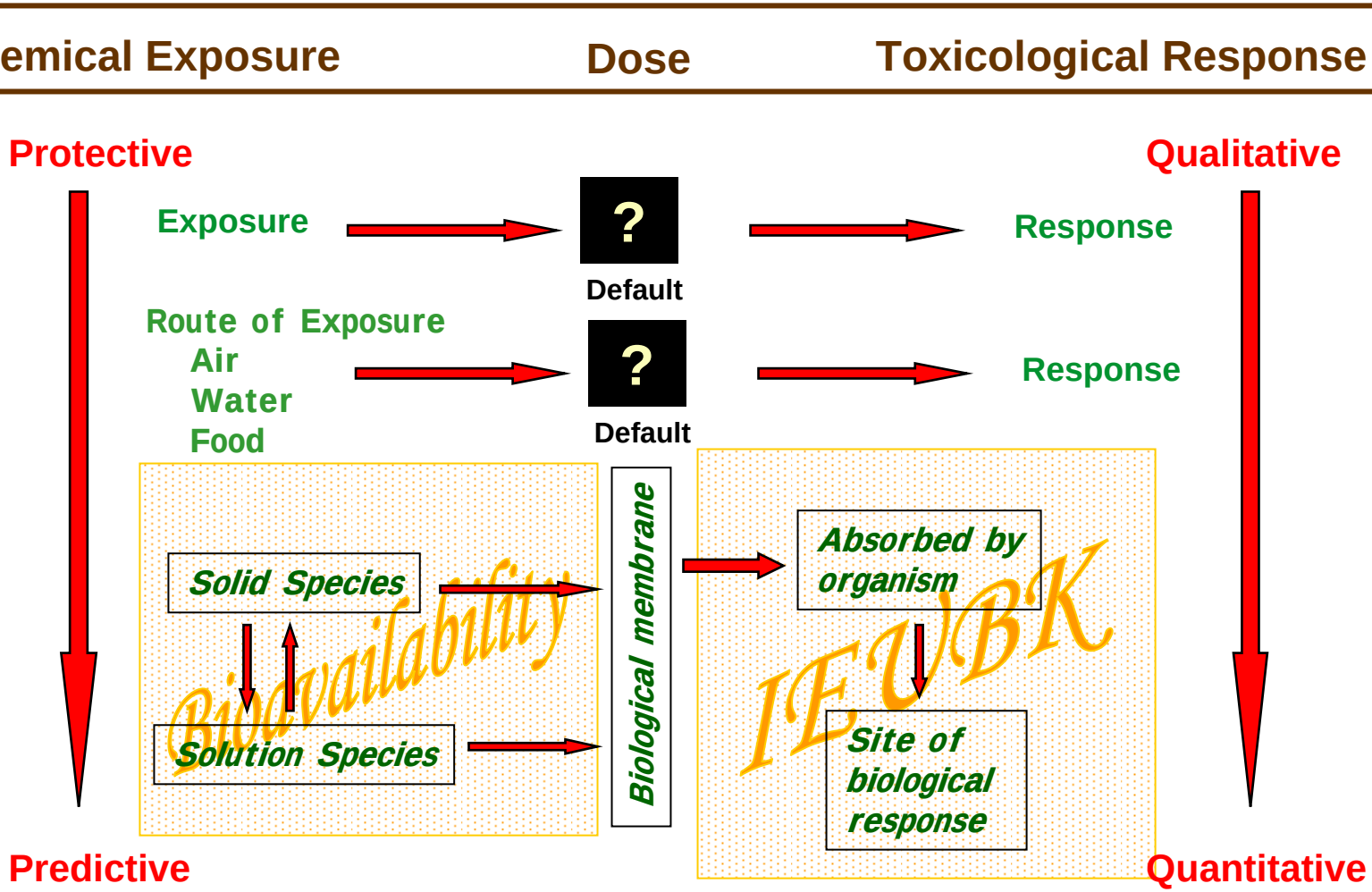
Systematic Characterization of Exposure-Dose-Response Continuum and the Evolution of Protective to Predictive Dose-Response Estimates

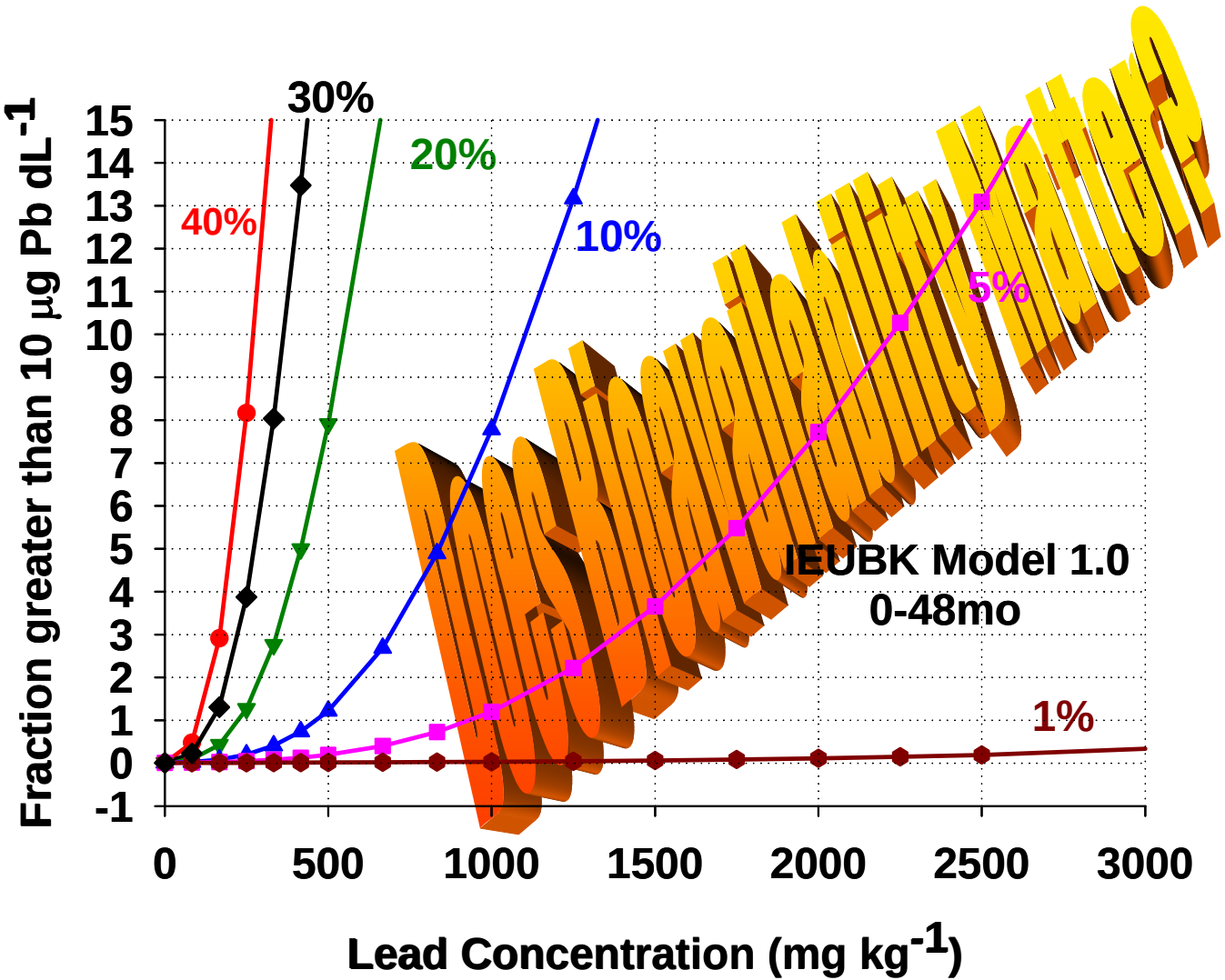


Efforts to clarify the Exposure-Dose-Response Continuum

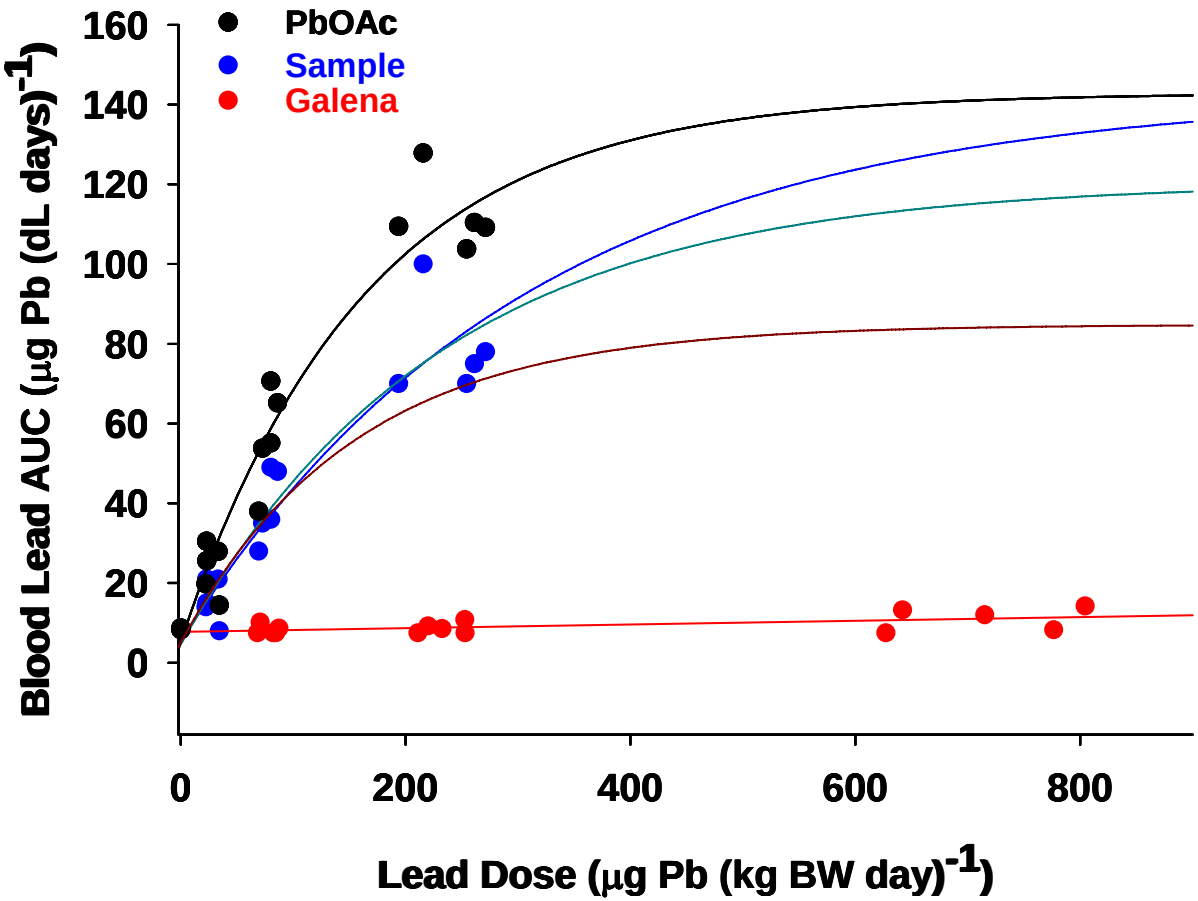
- *(Computational Toxicology) Pharmacokinetic/Pharacodynamic (PBPK/PBPD) models can be utilized to describe adsorption, distribution, metabolism, and excretion within the animal after the metal entered the central compartment (e.g., blood). Currently efforts are underway to expand these traditional approaches and include novel technologies derived from computational chemistry, molecular biology and systems biology in toxicological risk assessment.*

- *However, no consolidated effort to understand the relationships between external environmental exposure (fate and effects) and route of exposure on the transfer to the central compartment of the exposed organism exist and this important process is relegated to a simple term (bioavailability) without clarification of how to measure it or what affects it, its measurement is left to chance.*

Effect of Soil Pb Bioavailability on the Soil Pb Level Required to Cause Blood-Pb in 0-4 year olds to exceed 10 μg/dL



Bioavailability as a function of mineralogy



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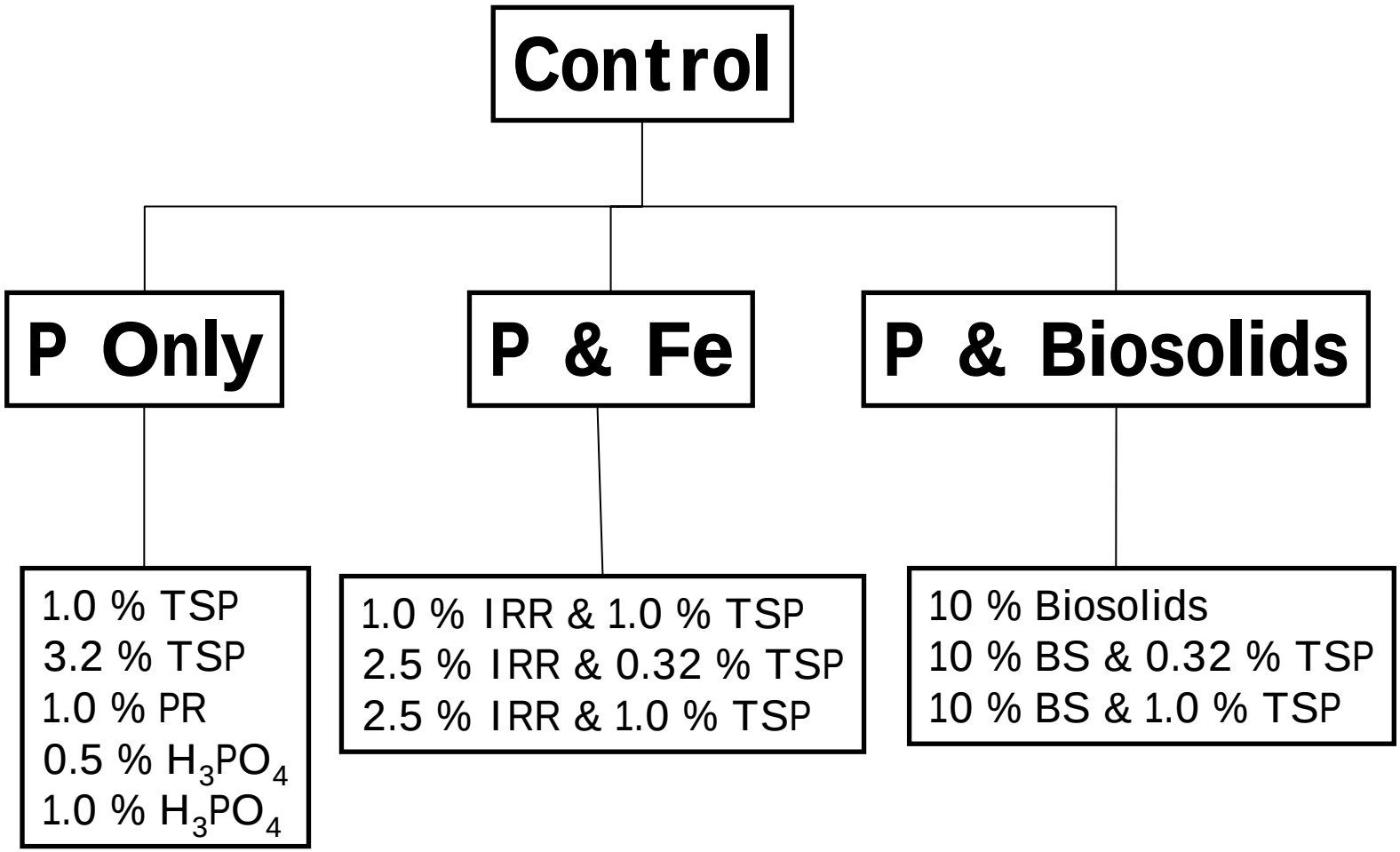
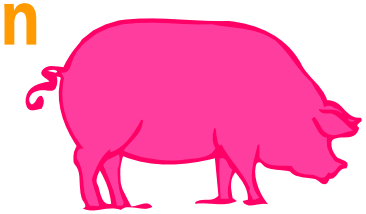
Amendment addition - Spring 1997

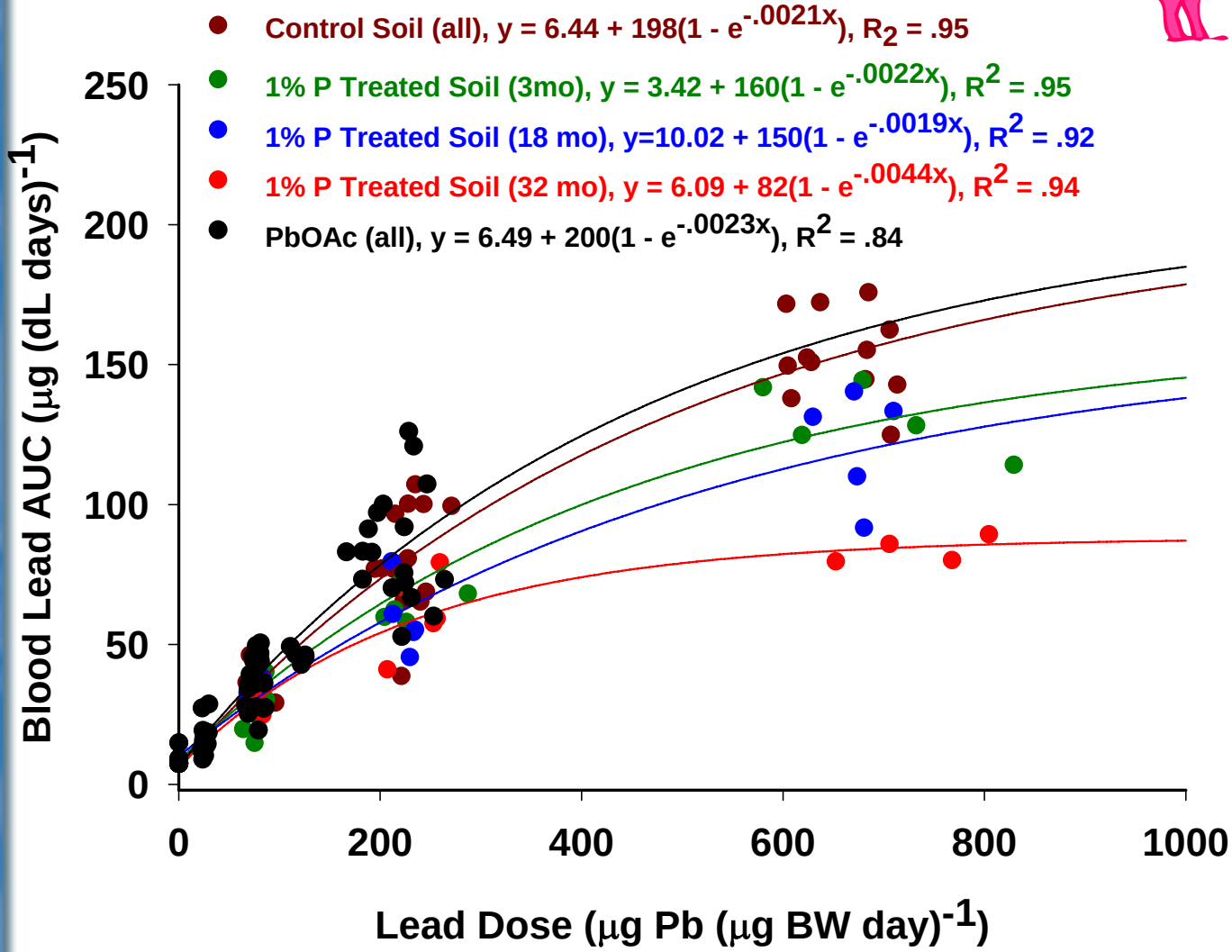
- 2 x 4 m plots, CRD
- Dividers installed
- Plots tilled
- Amendments surface applied
- Plots tilled

The 12 Treatments



Effect of Time and 1% P Treatment on Soil Lead Bioavailability Joplin Swine Ryan et al 2004





Soil Lead Bioavailability Joplin Human

(Grazino et al)

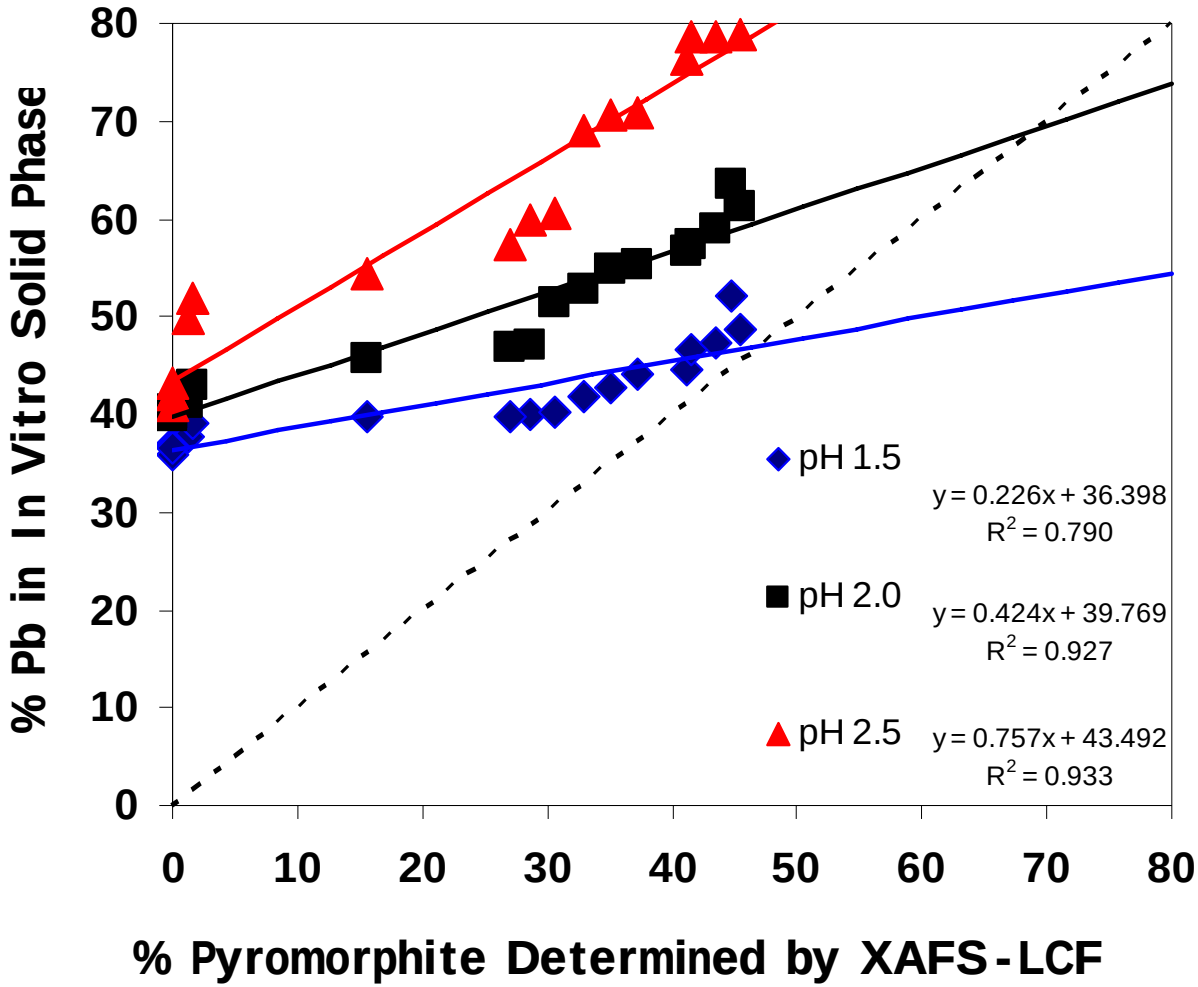
Group	Age (yrs)	Weight (kg)	Pb Dose (ug)	Soil Dose (mg)	Bioavailability (%, Absolute)
Untreated	29.6	62.2	237.5	45.7	**42.2** (26.3-51.7)
Amended*	34.5	72.2	260.8	61.5	**13.1** (10.5-15.8)

*** 1% P 18 mo**

69% reduction in bioavailability

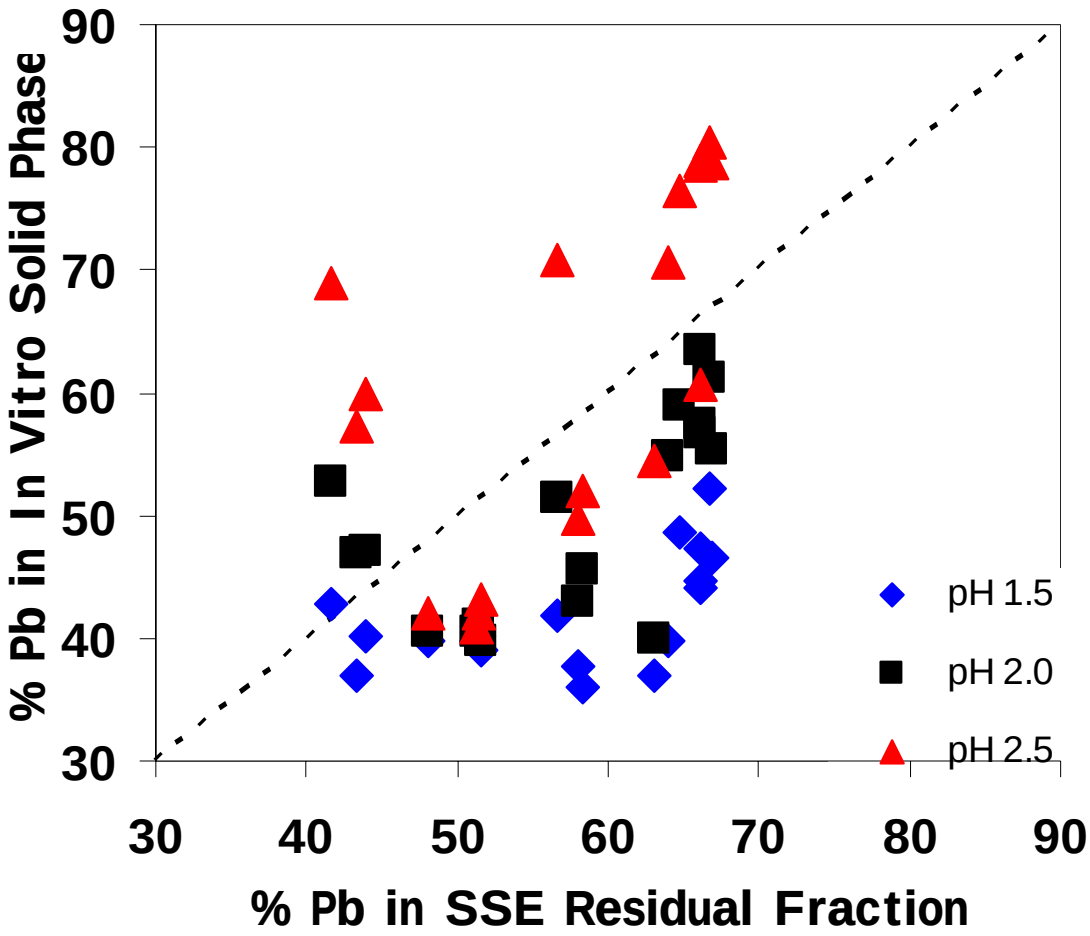
In vitro solid phase Pb vs pyromorphite at different pH's

Scheckel et al 2005



In vitro vs SSE

Scheckel et al 2005



Soil Lead Bioavailability
Joplin 18 mo Sample

	Rat	Swine	In vitro	Human
Control	21.7	34.8	58 pH 2.5 60 pH 2.0 63 pH 1.5	42.2
Treated	7.2	21.6	21 pH 2.5 39 pH 2.0 51 pH 1.5	13.1

Conclusion: Joplin Field Experiment

- **Bioavailability of soil lead is not a simple function of total soil lead.**
- **Soil lead bioavailability can be measured by**
  - **Swine**
  - **Rat**
  - **Human**
  - **In vitro**
- **Soil lead bioavailability can be changed by addition of materials to soil.**
- **The addition of materials to the soil altered the geochemistry of soil lead.**
- **Additional effort is required to fully understand and appreciate the information obtained from the Joplin experiment.**

NRC Comments on bioavailability measurement

"Regulatory acceptance of the tools used to generate bioavailability information in risk assessment is expected to be influenced by several factors, including the relevance of the tools to the site conditions and the extent of tool validation. Validation variously refers to the performance of a tool or approach in term of reproducibility, reliability, and multi-lab calibration. An appropriate body of experimental work to validate a tool would

(1) clarify where and when a tool yields a definitive response;

(2) clarify that the tool can be linked to a biological response of a similar magnitude, and that the linkage stands up across a range of conditions in the type of environment that is being managed;

(3) test the prediction of bioavailability using different types of experiments and field studies;

(4) clarify which types of biological responses are best predicted by the approach; and

(5) include critiques of the best applications and the limits of the tool, especially compared to alternatives. A tool that is well accepted and validated should be given greater weight than one that is new or experimental."

NIH Interagency Coordinating Committee on the Validation of Alternative Methods

http://iccvan.niehs.nih.gov

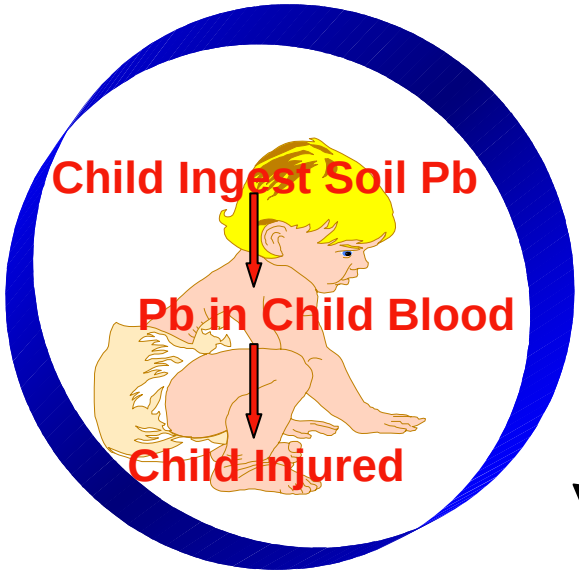
- Independent Scientific Review
- Usefulness for Risk Assessment
- Standard Operating Procedures
- Adequacy of predictions
  - Animals
  - Humans

Requirements for using bioavailability in risk management decisions

1) An appropriate measure
2) Knowledge of the reason for the observed measurement
3) Knowledge of the long-term stability of the measurement

Bioavailability Issues

Surrogate Measures



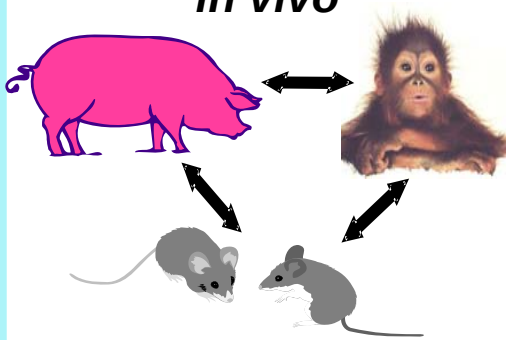
Chemical/Physical Surrogates

In vitro **Chemical Extraction**

Total Soil Analysis

Metal Speciation
Sequential Extraction
SEM/EDX
XRD
XAS

Animal Surrogates
in vivo



Models -what is our concern?

- *Ignorance and distrust of anything mathematical and extrapolation techniques*
  - *Unrealistic expectation that predictions should always be perfect.*
- *Prediction is the natural progression of simulation, the essence of extrapolation using modeling and simulation is that it attempts to capture and integrate all prior information in order to inform the selection and design of the next experiments.*
- *Thus, in any simulation modeling effort, in addition to many influential parameters that we do not know (and hence they are not in the model), there are other relevant parameters that we are aware of and yet we have not fully characterized them .*

Where do we go

- ***Publish existing data which relates in vivo – in vitro – mineralogy***
- ***Expand information on samples which have in vivo data***
- ***Expand the data set to include all sources of contamination***