Ecological Effects of Land Application of Biosolids

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Workshop on Microconstituents and Ecological Impacts of Biosolids and Effluent Reuse; June 26, 2008
School of Environment and Natural Resources
Ohio State University

Environmental Science / Ecosystem Science
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
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

- Total Contaminant Content in Soil
  - Soil Chemical Properties
    - pH, OC, Clay, etc
  - Soil Contaminant Partitioning
    - Soluble / Available Soil Contaminant
    - Insoluble / Unavailable Soil Contaminant

Potential Bioavailability / Toxicity
- High
- Low

Potential Human/Ecological Risk
Soil Chemical Properties and Solid Phases affect Contaminant Solubility / Bioavailability

Surface Chemistry - Adsorption Reactions in Soil

\[
\text{SOM} + \text{Pb}^{2+} \rightarrow \text{SOM-}\text{Pb}^{2+}
\]

Precipitation Reactions in Soil

\[
\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2 + x\text{Pb}^{2+} \rightarrow \text{Ca}_{10-x}\text{Pb}_x(\text{PO}_4)_6(\text{OH})_2 + x\text{Ca}^{2+}
\]
Soil / contaminant chemistry affects availability, contaminant transmission, and ecological risk.
Soil Chemical Properties / Solid Phase Components affect Solubility, Bioavailability, and Toxicity

5 pots of the same Zn contaminated soil

<table>
<thead>
<tr>
<th>Low pH</th>
<th>High pH</th>
<th>High pH</th>
<th>Mod pH</th>
<th>Low pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low OC</td>
<td>High OC</td>
<td>High OC</td>
<td>Low OC</td>
<td>High OC</td>
</tr>
<tr>
<td>Low Clay</td>
<td>Mod Clay</td>
<td>Mod Clay</td>
<td>Mod Clay</td>
<td>Mod Clay</td>
</tr>
</tbody>
</table>

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.;
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

Soil Chemical Properties affected Phytotoxicity

Lettuce grown in soil spiked with 250 mg/kg As
22 soils with a wide range of properties

Similar results for Pb, Cd, Zn
Soil Chemical Properties affect Pb Bioaccumulation

Earthworm Bioassay

Earthworms in soil spiked with 2000 mg/kg Pb
22 soils with a wide range of properties

Similar results for Cd, Zn, As
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

Using Soil Chemical Properties to Adjust/Predict Soil Ecotoxicological Endpoints
Advanced Statistical Approaches
Prediction Equations used to Model Food Chain and Contaminant Transmission

- Soil
- Available Contaminant
  - Contaminant Solubility
  - Bioavailability to earthworm
  - Dermal bioavailability and/or Oral Bioavailability
- Earthworm
- Shrew
  - Oral or Gastrointestinal Bioavailability to Shrew

How do you measure effects from ingestion of contaminated soil?
Soil Contaminant Oral Bioavailability
Soil Ingestion Exposure Pathway

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

How do we measure BIO for children?
for other ecological receptors?
**OSU In Vitro Gastrointestinal Method**
An Inexpensive, Fast, Accessible Alternative

Sequential extraction, 37°C

**in vitro “(bio)availability”** = dissolved contaminant
= bioaccessible contaminant

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.

Pb with/out dosing vehicle
Schroder et al., 2004

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
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

Biosolids + Pb\(^{2+}\) → Biosolids

Available

Unavailable
Immobilization of Pb Contaminated Soil 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 pyromorphitate
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

Large-Scale Ecological Restoration Using Biosolids
University of Washington, USDA-ARS, USEPA

Before
Bunker Hill, ID; Joplin, MO; Leadville, CO; others
http://faculty.washington.edu/slb/

After
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

72 plots on Pb, Zn, Cd contaminated land
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

Remediased Site

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

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

Earthworm Toxicity Testing
Zn, Pb, Cd Contaminated Smelter Soil


No toxicity to *Eisenia fetida* in alkaline biosolids treated soil!
Organic Matter Amendments Increase Earthworm Cocoon Production

More Earthworms!

$r^2 = 0.61$
$P < 0.01$
Did the Amendments Decrease Soil Ingestion Risk?

*In-vitro* Pb GI Bioavailability in Amended Soil

- **Control**
- **Alk. Biosolids**
- **NViro**
- **PO₄ Biosolids**


*J. Environ. Qual.* 30:1222-1230
Soil Contaminant

Soluble Released In Gut Bioaccumulated in Organism

Drinking Water Ingestion of Soil Food Chain

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

Combination Amendment

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

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

Ecological Test Species
Earthworms
Eisenia andrei

Percent Mortality
Reproduction (cocoons, juveniles)
Contaminant Bioaccumulation

Dry matter growth
bioaccumulation
germination

Ecological Test Species
Perennial Ryegrass
Lolium perenne L.
### Soil Properties / Nutrients

<table>
<thead>
<tr>
<th>Biosolids, Mg/ha</th>
<th>pH</th>
<th>Organic C (%)</th>
<th>Total N (%)</th>
<th>P* (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7.00</td>
<td>1.20</td>
<td>0.115</td>
<td>63</td>
</tr>
<tr>
<td>150</td>
<td>6.67</td>
<td>1.98</td>
<td>0.209</td>
<td>456</td>
</tr>
<tr>
<td>300</td>
<td>5.58</td>
<td><strong>2.73</strong></td>
<td>0.279</td>
<td>663</td>
</tr>
</tbody>
</table>

* Mehlich 3 Extraction

**Long Term Improvement in Soil Quality and Fertility**
Soil Metal Contents

Increase in Zn, Cu, Pb, Cd

<table>
<thead>
<tr>
<th>Mg/ha</th>
<th>Zn</th>
<th>Cu</th>
<th>Pb</th>
<th>Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>109</td>
<td>24</td>
<td>43</td>
<td>0.60</td>
</tr>
<tr>
<td>300</td>
<td>374</td>
<td>85</td>
<td>67</td>
<td>4.90</td>
</tr>
</tbody>
</table>

metal in mg/kg soil
Effect of Biosolids on Ryegrass Dry Matter Growth

Large increase in dry matter growth with Biosolids Application Rate

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

- Hatchlings Day 14
- Hatchlings Day 28
- Hatchlings Total

* No food

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:

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