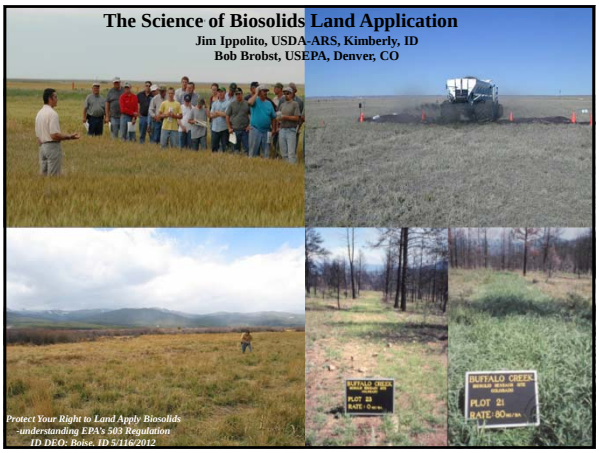


US History Tidbits - NYC

- 1884: Sewage first treated in NYC
  - Discharged at streambanks
    - Then piped into rivers
      - Then piped further out into the harbor
- 1924: NY Harbor putrefied in places
  - Result from decaying sludge
  - NYC began disposing in the ocean
    - Successful until the 1960s
      - Sludge accumulation at ocean floor; changes in benthic organisms
      - Continued through 1992
- 1992: Land application

US EPA 40 CFR Part 503

- Mid 1970s
  - Risk assessments began
- 1984
  - Part 503 development began
    - 25 pollutants
      - 14 exposure pathways
- 1989
  - Part 503 rule was proposed by EPA
    - Went through a four-year review
- 1993
  - 503 regulations put in place

Science of Land Application

Projects

- **Biosolids land application to:**
  - **Dryland: Wheat-fallow, wheat-corn-fallow, WWCSF**
  - **Overgrazed shortgrass steppe ecosystems**
    - **(biosolids, composted biosolids, and WTR)**
  - **Disturbed high-plains desert ecosystems**
  - **Forest fire burned areas**
  - **Fluvial Mine Tailings**

(*systems approach:* soil nutrients/metals, plant uptake, trace metal movement in soils/runoff, microbial responses)

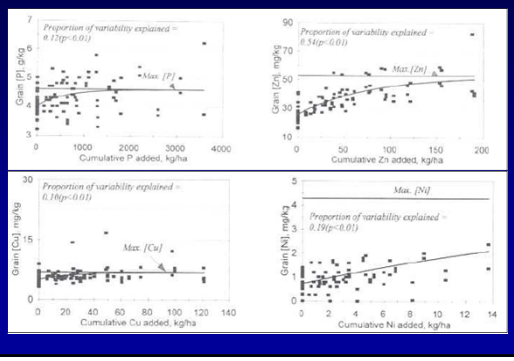
Biosolids Effect on P, Cu, Zn, and Ni Concentrations in Dryland Wheat

(Journal of Environmental Quality, 1995. 24:608-611)

- Biosolids applied on plots at two locations
  - Site A:1982, '84, '86, '88, '90, '92
  - Site B: 1983, '85, '87, '89, 91
    - 0, 3, 6, 12, 18 dry tons/ac
    - Incorporated into the top 20 cm
- Biosolids analyzed for total elements according to Part 503 regulations
- Wheat–fallow rotation
  - Total grain elements analyzed
- Grain elemental content vs cumulative biosolids elements, over time, analyzed.

Biosolids Effect on P, Cu, Zn, and Ni Concentrations in Dryland Wheat

(Journal of Environmental Quality, 1995. 24:608-611)



Extractable Trace Elements in the Soil Profile after Years of Biosolids Application

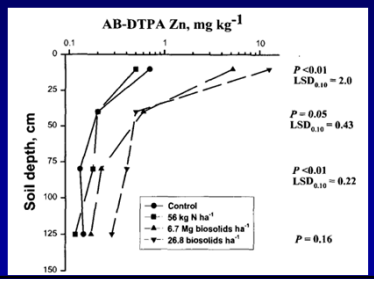
(Journal of Environmental Quality, 1998. 27:801-805)

- Biosolids applied on plots at two locations
  - A: 1982, '84, '86, '88, '90, '92
  - B: 1983, '85, '87, '89, 91
    - 0, 3, 6, 12, 18 dry tons/ac
    - Incorporated into the top 20 cm
    - A typical N fertilizer rate was included
- Biosolids analyzed for total elements according to Part 503 regulations
- Wheat–fallow rotation
  - Soils analyzed for plant-available elements
    - 0-20, 20-60, 60-100, 100-150, 150-200 cm depths
- Plant-available soil elemental content vs cumulative biosolids elements, over time, analyzed.

Extractable Trace Elements in the Soil Profile after Years of Biosolids Application

(Journal of Environmental Quality, 1998. 27:801-805)

- Cd, Cr, Cu, Mo, Ni, and Pb accumulation in plow layer



Nitrogen Fertilizer Equivalency/Mineralization of Biosolids in a Dryland Wheat Agroecosystem

(Journal of Environmental Quality, 2000. 29:1345-1351; Agronomy Journal, 2007. 99:715-722)

- Utilized 12 years of data
  - 6 applications (0-6 tons/ac) to two sites
  - Commercial N fertilizer applied plots also used
    - Linear regression analysis for comparisons
- Correlation of biosolids vs N fertilizer wheat-grain N uptake
  - 16-18 lbs N/ton biosolids
- Mineralization Rates
  - First 6 years: 25-32% (avg = 28%); wet years
  - Second 6 years: 21-27% (avg = 24%); dry years

Biosolids Impact Soil P Recovery, Fractionation, and Potential Environmental Risk

(Journal of Environmental Quality, 2007. 36:764-772)

Agronomic rates based on crop N requirements

Excess P addition/accumulation

P-based vs N-based approach:

Utilizing long-term N-based data to make future P-based decisions

- **Approach**
  - **Account for all P added with biosolids application.**
  - **Account for all P removed with grain or straw.**
  - **Determine total soil P at the end of the project.**
    - **From the above, can we predict total P present?**
  - **What soil fraction(s) dominate P in this system?**
  - **Determine environmental risk based on the Colorado P Index (Sharkoff et al., 2005).**
    - **efotg.nrcs.usda.gov/references/public/CO/COATN_95v3.pdf**

Site Information

- Littleton/Englewood, CO – CSU land application program
  - Dryland wheat-fallow agroecosystem
    - 1982 through 2003
    - 0, 6.7 ("agronomic rate"), 13, 27, 40 Mg ha^{-1} biosolids
    - Applied every other year, except 1998
    - 3.6 x 16.8 m plots; 4 replicates; RCB design
    - Incorporated to 20 cm

Phosphorus Accountability

- Biosolids P analysis completed for every application year.
- Total grain and straw P determined at every harvest.
- Total soil P (4M HNO_3) determined at July 2003 harvest.
- Composite soil samples from plot center (July 2003).
  - 0-20cm and 20-60cm depths.
  - Near plot center to avoid potential biosolids redistribution due to years of tillage (Yingming and Corey, 1993).
  - Air dried, sieved, weighed for analysis.

Biosolids Application Rate (Mg ha^{-1})	Cumulative (1982-2002) kg biosolids-borne P applied
0	0
6.7	9.54
13	18.51
27	38.45
40	18.40
	Cumulative (1983-2003) kg grain and straw P removed
0	0.49
6.7	0.66
13	0.57
27	0.59
40	0.44
	predicted kg biosolids-borne P accumulated in soil (2003)
0	-0.49
6.7	8.88
13	17.94
27	37.86
40	17.96

Prediction of Soil P Content

Biosolids Application Rate	1982 Background	2002-2003 Harvest Soil	Actual Increase	Predicted Increase (from previous table)	Adjusted Actual Increase	Adjusted Percent Recovery
Mg ha^{-1}	---------- kg P in the 0-60-cm depth ----------					%
0	30.02	35.43	5.41	-0.49	-0.49	100
6.7	30.02	47.28	17.26	8.88	11.36	128
13	30.02	52.69	22.67	17.94	16.77	93
27	30.02	74.65	44.63	37.86	38.73	102
40	30.02	54.52	24.50	17.96	18.60	104

To adjust, we used the control plots:
5.41 – (-0.49) = 5.90 kg P added overall.

Therefore, subtract 5.90 kg P from actual.

What soil fraction dominates P?

P Fractionation (Kuo, 1996)

Biosolids Rate	Soluble/ Loosely Bound P	Al-Bound P	Fe-Bound P	Occluded P	Ca-bound P
Mg ha^{-1}	---------- mg kg^{-1}; 0-20-cm depth ----------				
0	0.31	16.7 a	154 a	96.6 a	343
6.7	11.5	83.3 b	400 ab	185 a	364
13	1.83	144 c	525 ab	228 a	331
27	22.2	200 d	1110 c	416 b	531
40†	13.8	104 b	779 bc	192 a	547
Probability Level (P)	0.129	< 0.001	0.007	0.002	0.240

	Soluble/Loosely Bound + Al-Bound + Fe-Bound P	Occluded P	Ca-Bound P
	---------- mg kg^{-1}; 20-60-cm depth ----------		
0	9.58	28.6 a	872
6.7	14.8	50.9 a	813
13	21.8	119 a	835
27	29.8	310 b	921
40†	24.3	89.7 a	719
Probability Level (P)	0.453	0.033	0.616

Colorado P Index Risk Assessment Sharkoff et al. (2005):

efotg.nrcs.usda.gov/references/public/CO/COATN_95v3.pdf

Risk interpretations:

Net score	Potential for Off-Site P Movement	
<8	Low	Organic nutrient application based on crop N requirements.
8 to 11	Medium	Organic nutrient application based on crop N requirements. Some management changes may be needed.
12 to 15	High	Organic nutrient application based on crop P requirements.
>15	Very High	Do not apply organic nutrients.

Factors	Class	Biosolids Rate (Mg ha^{-1}) 6.7	13
		---------- rating ----------	
Runoff class Soil permeability class Slope	Slow 0-1%	1 (low)	1 (low)
AB-DTPA soil test (0- to 20-cm depth)		3 (high; 38 mg kg^{-1})	4 (very high; 47 mg kg^{-1})
P application rate		4 (very high; > 370 kg P_2O_5 ha^{-1})	4 (very high; > 370 kg P_2O_5 ha^{-1})
P application method	Summer applied-incorporated	3 (high)	3 (high)
Best Management Practice	None	0 (none)	0 (none)
Net Score		11	12
Risk Level		Medium	High

What happens if you receive a "high" P risk index rating?

- Apply base on crop P requirements.
  - Will significantly alter application approach
    - Supplemental N fertilizer addition
- Consider using other BMPs
- No alternative?... You can wait
  - From our other research it appears that ~ 3 years is required for P concentrations to be reduced to levels that would reduce to P risk index.

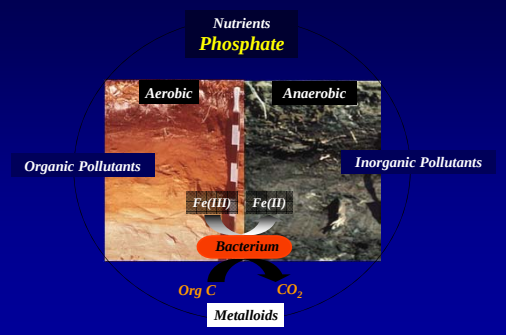
Fate and Transport of Phosphorus in Biosolids and Water Treatment Residuals Amended Soils under Anaerobic Conditions

Thomas Borch, Yared Assefa Mulisa,
Jim Ippolito, Neil Hansen and Jennifer Jones

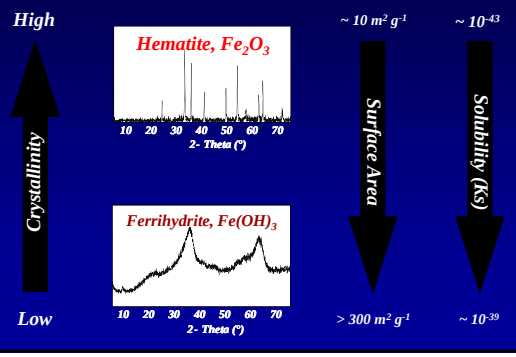
Department of Soil and Crop Sciences

Colorado State University
Knowledge to Go Places

Biogeochemical Processes Controlling the Dynamics of Nutrients and Contaminants



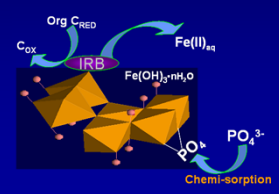
Physical Properties of Iron (hydr)oxides



Objectives

Establish the role of iron reduction and/or anaerobic conditions on the fate of phosphate in shortgrass steppe ecosystems

Determine the impact of biosolids and/or water treatment residuals (WTR) on the fate of phosphate in shortgrass steppe ecosystems



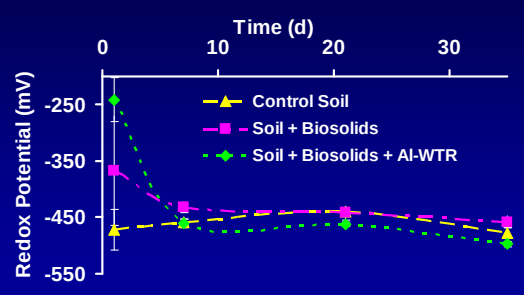
Anaerobic Batch Setup

Treatment	Soil (g)	DI Water (mL) (deoxygenated)	Biosolids (Mg ha^{-1})	Al (Mg ha^{-1})
Shortgrass Steppe Ecosystem (SSE)	60	50	0	0
SSE + Biosolids	60	50	10	0
SSE + Biosolids + Al-WTR	60	50	10	21

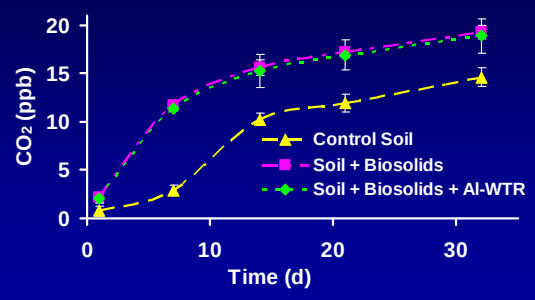
Selected Biosolids and WTR Characteristics

Property	*1991 Biosolids*	*2002 Biosolids*	*1991 WTR*	*2002 WTR*
P (mg kg^{-1})	*16141*	*11350*	*550*	*545*
Fe (mg kg^{-1})	*4948*	*19050*	*19500*	*14576*
Al (mg kg^{-1})	*8618*	*12650*	*63300*	*59016*
Organic N (mg kg^{-1})	*41161*	*41750*	*3885*	*3485*
NO_3-N (mg kg^{-1})	*98*	*3*	*64*	*118*
NH_4-N (mg kg^{-1})	*3640*	*5442*	*51*	*9*
pH	*7.3*	*7.3*	*6.8*	*7.1*

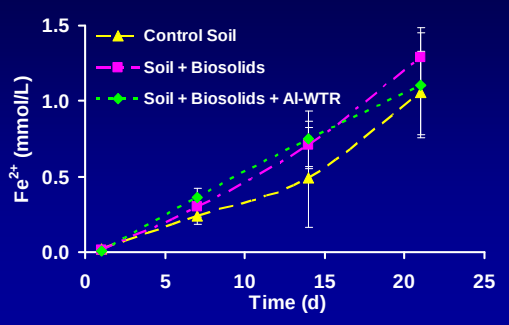
Redox Conditions



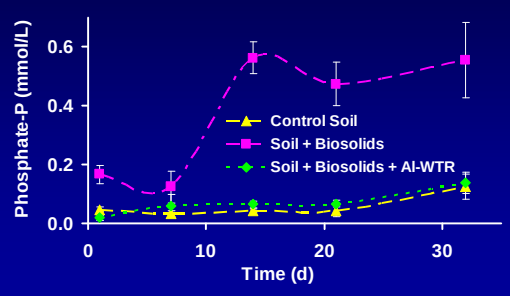
Carbon Mineralization



Reductive Iron Dissolution



Fate of Phosphate Under Reducing Conditions

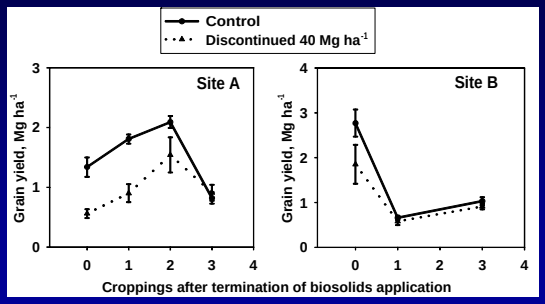


Termination of Biosolids Application: Wheat Yield and Other Agronomic Characteristics

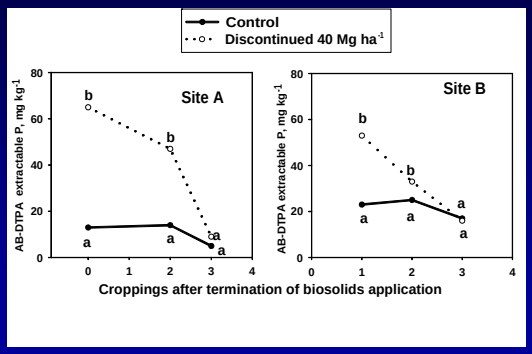
(Agronomy Journal, 2003. 95:1288-1294)

- What happens if you make a major oops?
  - Biosolids overapplication over years
- Treatments:
  - 0 biosolids/ac
  - 18 dry tons biosolids/ac
    - Applied to wheat-fallow, every other year, over a 10-year period, at two sites.
      - 6-9x the agronomic rate for dryland wheat.
- Application terminated after 10 years and monitored for recovery

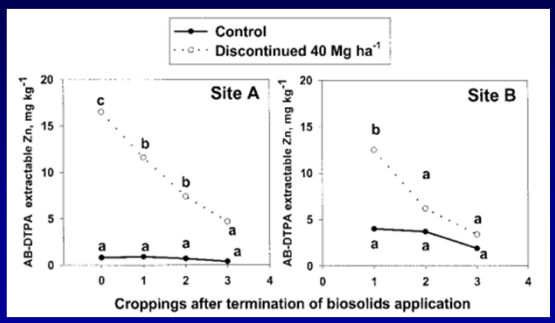
Grain Yield



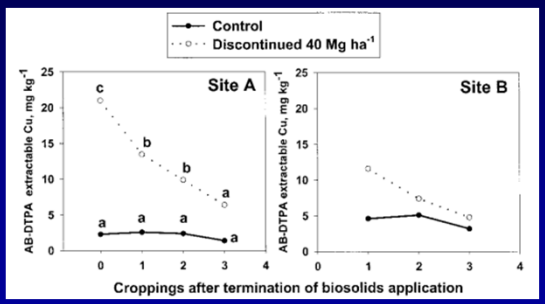
AB-DTPA (plant-available) Phosphorus



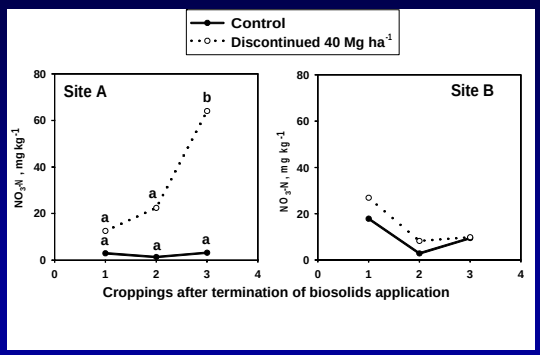
AB-DTPA (plant-available) Zinc



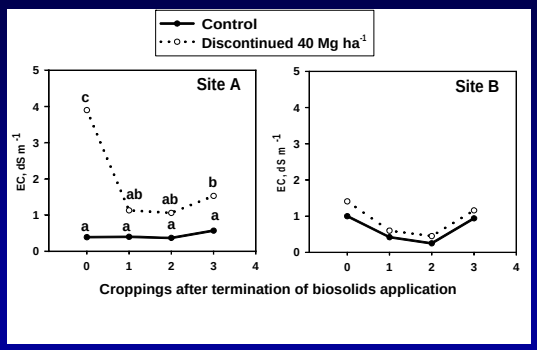
AB-DTPA (plant-available) Copper

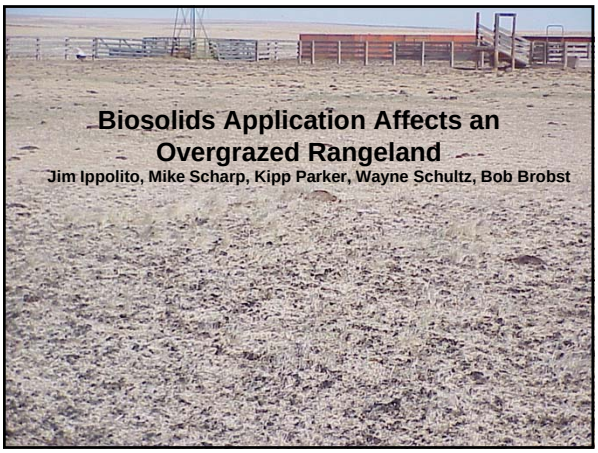


Soil NO_3-N



Soil Electrical Conductivity





Background

- Biosolids beneficial-use programs effectively recycle plant nutrients
  - Based on agronomic rates

- Determining agronomic rates for overgrazed rangelands can be challenging
  - Supplying adequate N
  - Increasing biomass production
  - Increasing species diversity
  - Improving soil quality

Materials and Methods

- Lamar, CO overgrazed rangeland received:
  - NYC biosolids in 1999
    - 0 (control); 160 acres
    - 1-2 dry tons A^{-1}; 126 acres
    - 5 dry tons A^{-1}; 160 acres
    - 10 dry tons A^{-1}; 20 acres
    - 20 dry tons A^{-1}; 20 acres

  - Surface application, no incorporation
    - Biosolids met Table 3 metal limits

Enclosures

- 2000:
  - Individual plant species collected
- 2000-2004:
  - Plant biomass determined using a 2 m^2 quadrant
    - Protein content
    - Acid detergent fiber
    - P, Fe, Mn, Cu, Zn concentrations

Enclosures

- 2003 Soil Sampling:
  - Top 12" collected
    - AB-DTPA As, Cd, Cu, Pb, Hg, Mo, Ni, Se, Zn

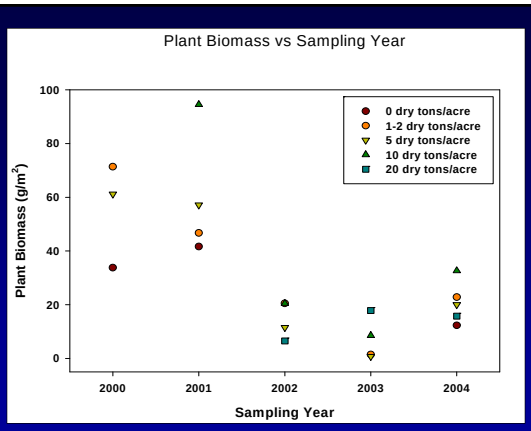
- 2006:
  - Field saturated hydraulic conductivity
    - Single ring infiltrometer
      - 0, 10 dry tons $acre^{-1}$
  - Porosity, Bd, antecedent moisture content
      - 0, 10, 20 dry tons $acre^{-1}$

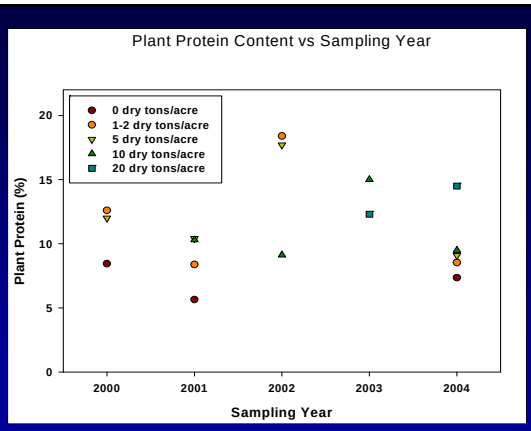
RESULTS

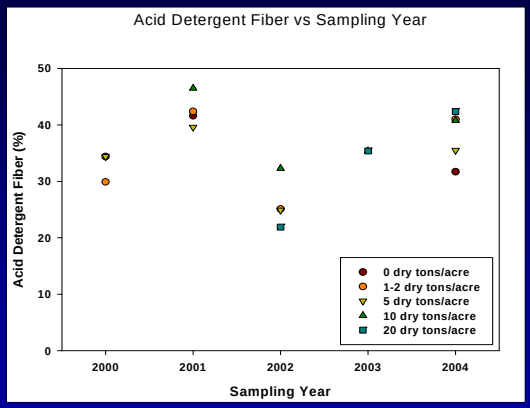
PLANTS

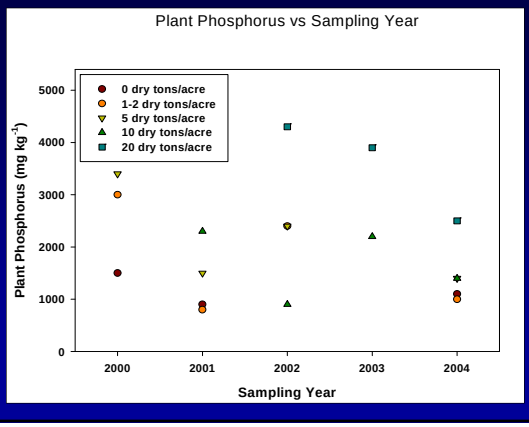
Plant Species Present in 2000

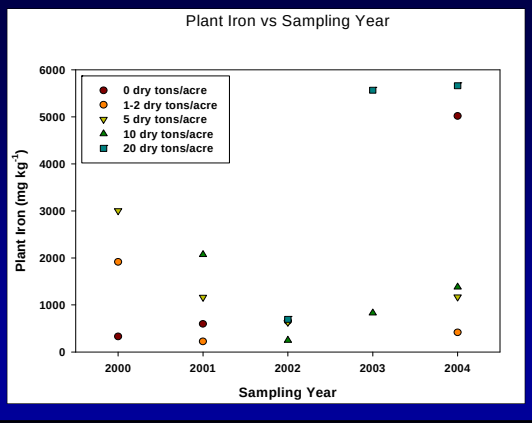
Biosolids Application Rate (dry tons acre^{-1})	Number of Plant Species Present	Actual Species Present
0	7	Prairie coneflower, little barley, 6 week fescue, squirreltail grass, threeawn grass, blue grama, buffalo grass
1-2 ("agronomic rate")	8	Tansy mustard, russian thistle, little barley, wooly indian wheat, 6 week fescue, squirreltail grass, blue grama, buffalo grass
5	10	Russian thistle, tansy mustard, prickly lettuce, narrowleaf poisonvetch, 6 week fescue, little barley, wooly indian wheat, squirreltail grass, blue grama, buffalo grass

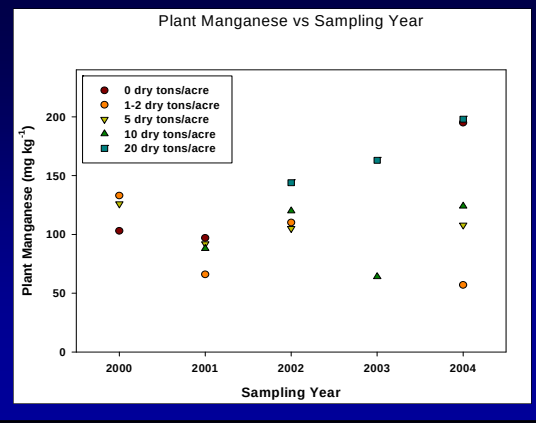


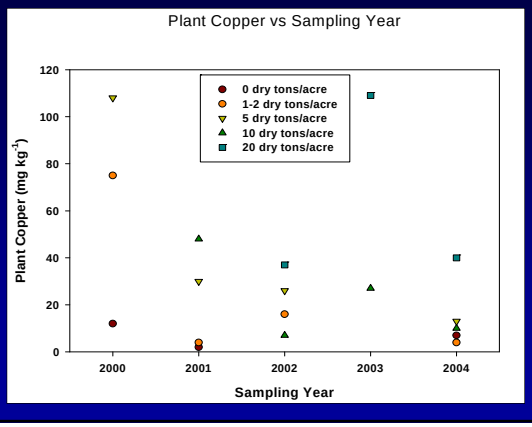


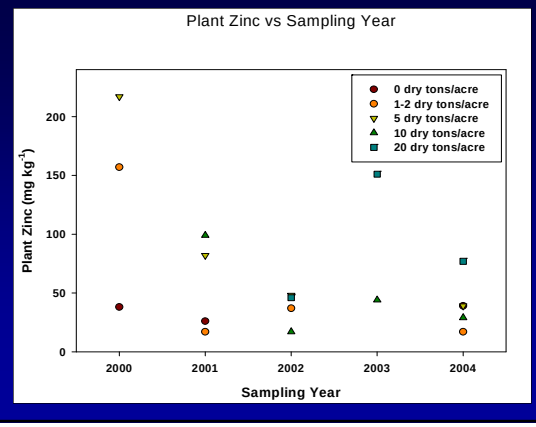












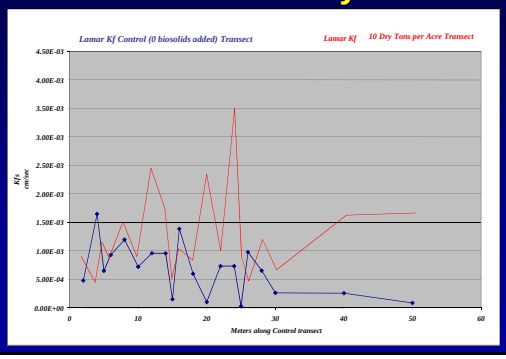
RESULTS

SOILS

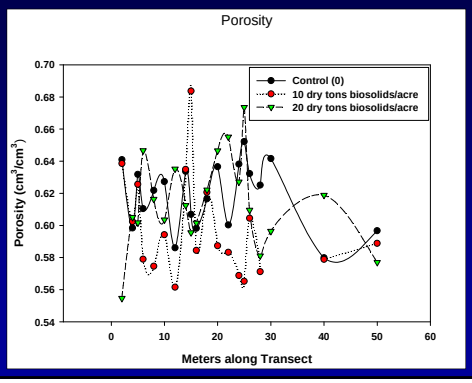
AB-DTPA

- Extractable metal concentrations all were near or below detection limits.

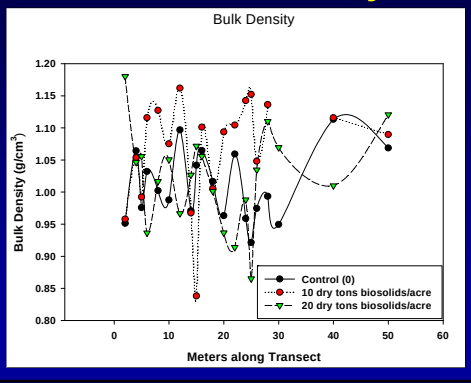
Field Saturated Hydraulic Conductivity



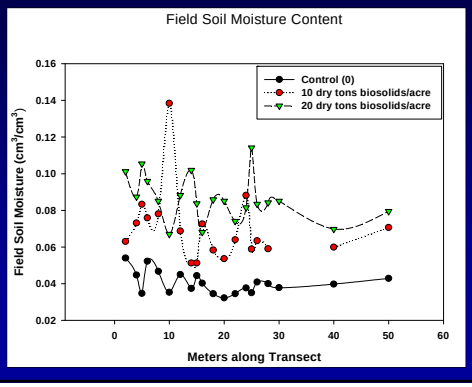
Soil Porosity



Soil Bulk Density



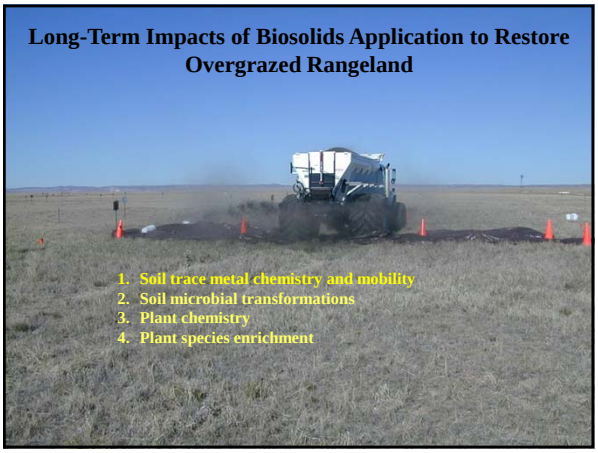
Field Soil Moisture Content



Conclusions

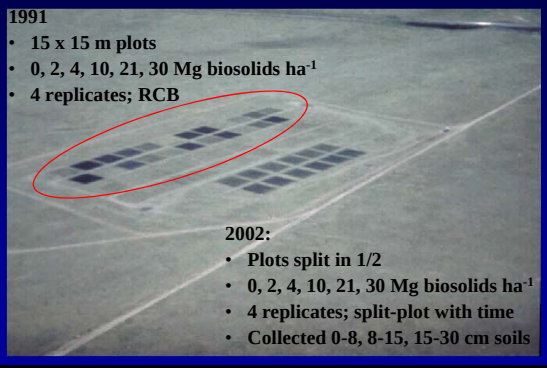
- Biosolids land application at rates of up to 20 dry tons acre^{-1}:
  - Increased biomass production
  - Increased species diversity
  - Improved plant nutritive status
  - Improved soil quality by increasing:
    - Hydraulic conductivity
    - water holding capacity
- All contributing to improved rangeland sustainability.

Long-Term Impacts of Biosolids Application to Restore Overgrazed Rangeland



1. Soil trace metal chemistry and mobility
2. Soil microbial transformations
3. Plant chemistry
4. Plant species enrichment

Materials and Methods



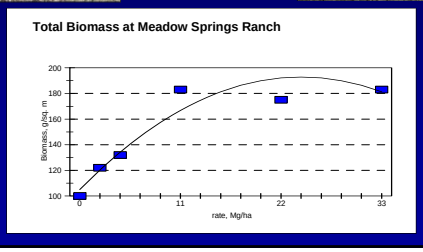
1991

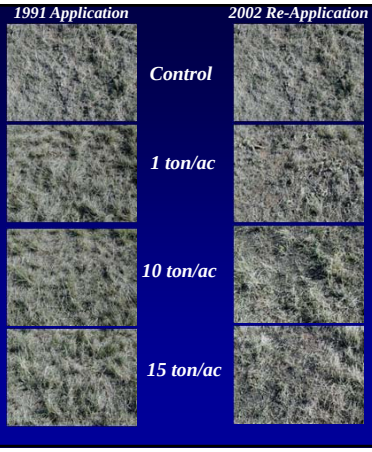
- **15 x 15 m plots**
- **0, 2, 4, 10, 21, 30 Mg biosolids ha^{-1}**
- **4 replicates; RCB**

2002:

- **Plots split in 1/2**
- **0, 2, 4, 10, 21, 30 Mg biosolids ha^{-1}**
- **4 replicates; split-plot with time**
- **Collected 0-8, 8-15, 15-30 cm soils**

Early Findings





Sequential Trace Metal Extraction

- **Soluble and exchangeable,**
- **Specifically adsorbed,**
- **Easily reducible Fe/Mn oxides**
- **Fe/Mn oxides and acid replaceable (organically complexed),**
- **Residual Organic,**
- **Residual Inorganic.**

- **The above sequence follows more to less available metal forms present in soils.**

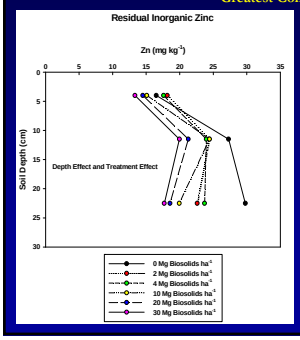
Unique Phase Shifts for:

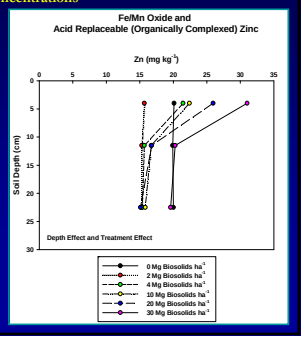
- **Cu**
- **Ni**
- **Zn**

Zinc

Single Application (1991) Dominant Fractions

Greatest Concentrations

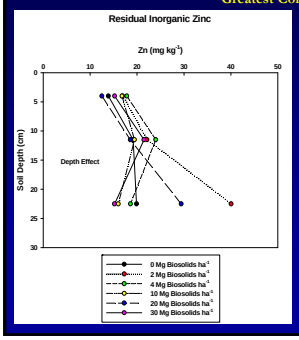


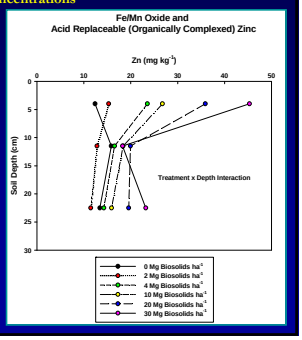


Zinc

Repeated Application (2002) Dominant Fractions

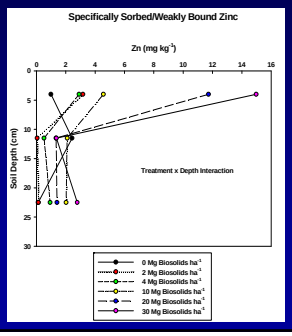
Greatest Concentrations





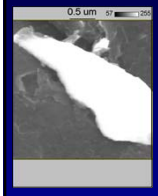
Zinc

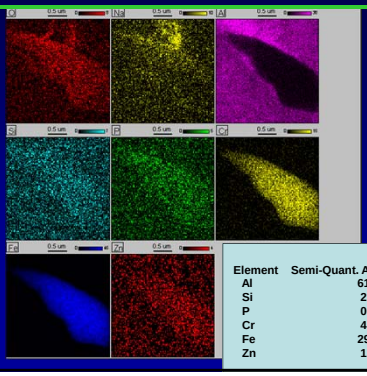
Repeated Application (2002) *UNIQUE* Dominant Fraction



SEM-EDS

30 Mg ha^{-1} repeated application, 0-8 cm



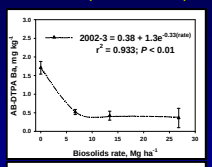


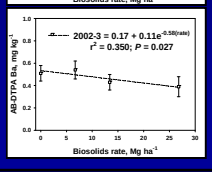
Element	Semi-Quant. Atom %
Al	61.54
Si	2.56
P	0.57
Cr	4.59
Fe	29.41
Zn	1.33

Supports wet chemistry Findings

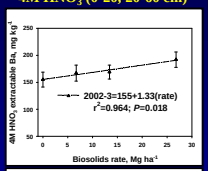
Biosolids Affect Soil Barium in a Dryland Wheat Agroecosystem

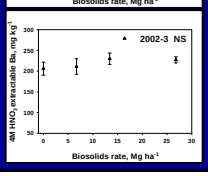
AB-DTPA (0-20, 20-60 cm)

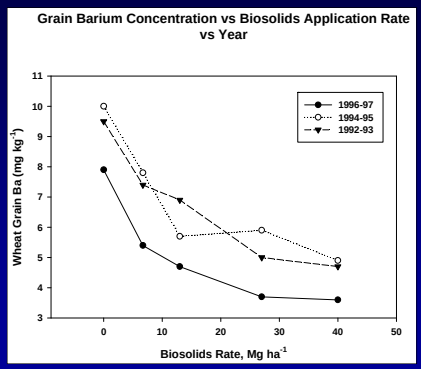




4M HNO_3 (0-20, 20-60 cm)

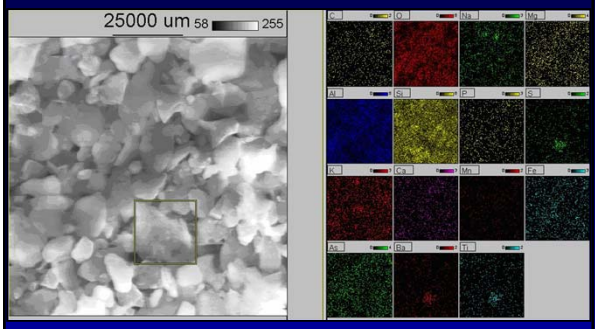


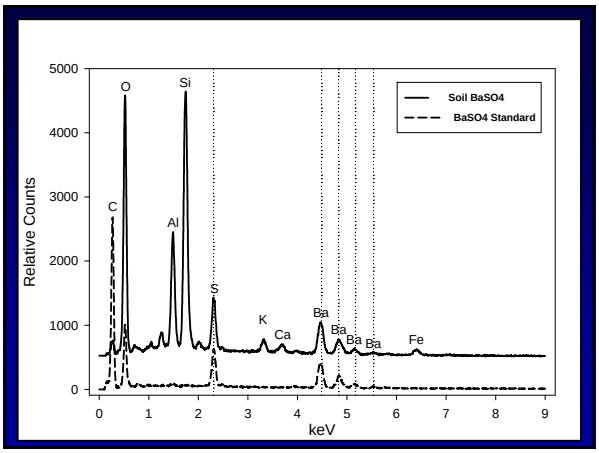




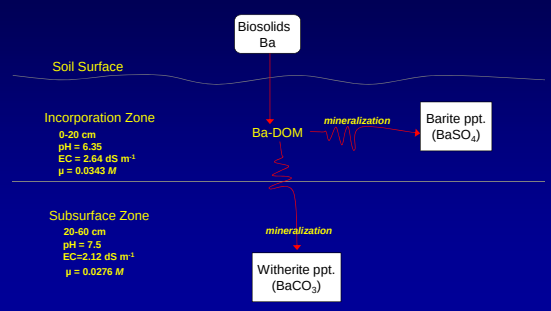
Scanning Electron Microscopy

27 Mg ha^{-1} soil, 0-20 cm, 2002-2003

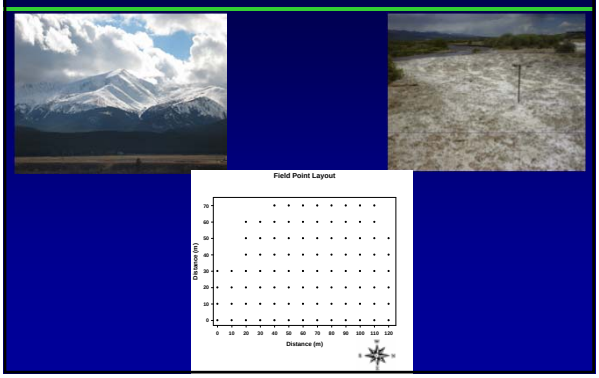


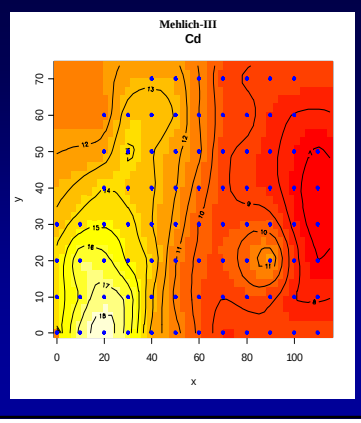


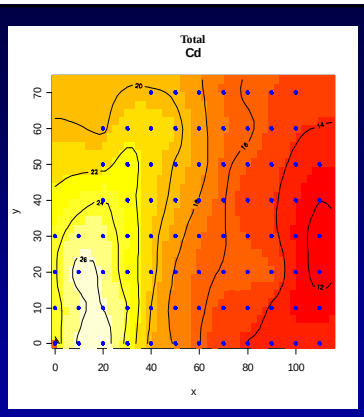
Soil Barium Concept

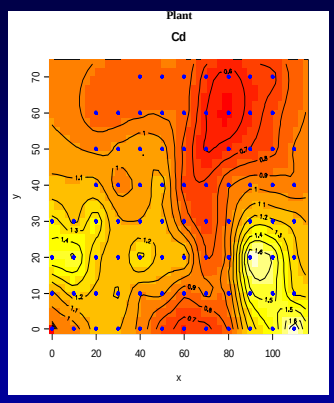


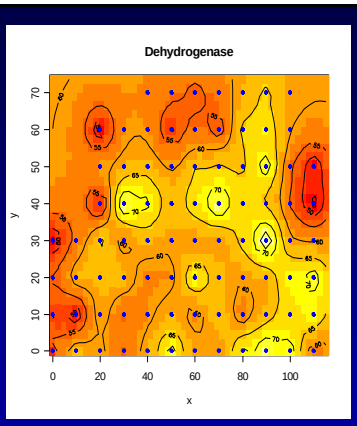
Biosolids for Mine Land Reclamation





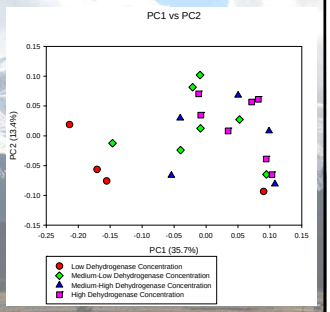






Microorganisms

- Communities with low dehydrogenase activity found primarily on negative side of PC1
  - High metal concentration
- Communities with medium-high and high dehydrogenase activity were found primarily on positive side of PC1



Plant and Soil Responses to Biosolids Application Following a Forest Fire

Questions