BENEFICIAL REUSE OF FGD GYPSUM IN AGRICULTURAL APPLICATIONS

November 11, 2009

1:00 – 1:10	Introductions, Agenda Review	Bob Spoerri & Eric Schaeffer
1:10-1:20	What is FGD Gypsum?	Dave Goss
1:20-1:40	FGD Gypsum impact on metals in soils and plants	Dr. Malcolm Sumner
1:40-2:00	FGD Gypsum, Soil Erosion & Water Quality	Dr. L. Darrell Norton
2:00-2:10	A Farmer's Perspective on FGD Gypsum	Jack Maloney
2:10-2:30	Use of FGD Gypsum in Agriculture	Dr. Warren Dick
2:30-2:50	Risk Assessment for use of FGD Gypsum in Agriculture	Dr. Rufus L. Chaney
2:50-3:05	Break	
3:05- 3:15	Market Factors	Dave Goss
3:15-3:25	Implementing an FGD Gypsum agricultural program	Bob Spoerri & Ron Chamberlain
3:25-3:55	Open Discussion	John Andersen, Moderator
3:55-4:00	Next Steps and Close	Bob Spoerri & Eric Schaeffer

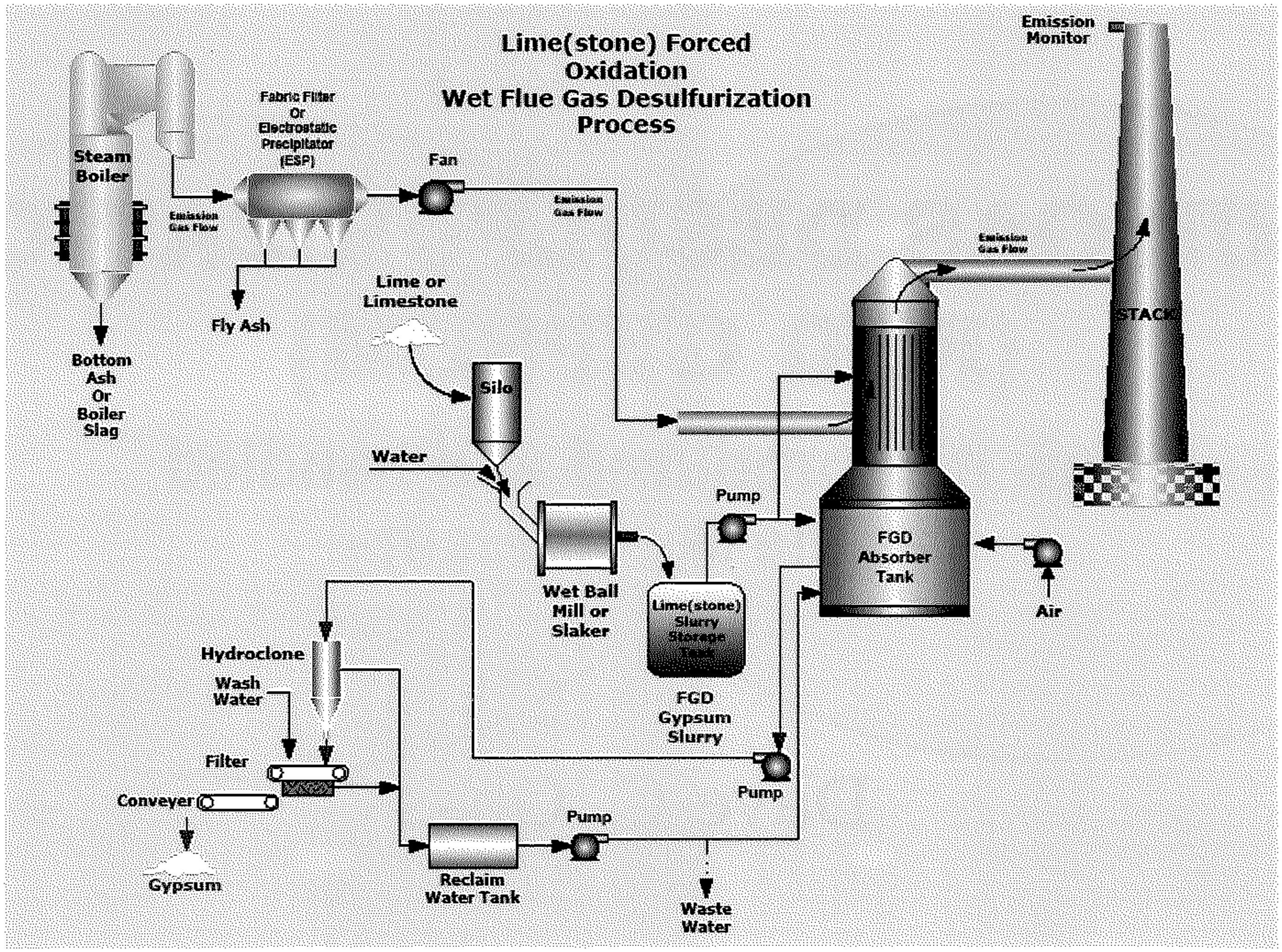
Agenda

FLUE GAS DESULFURIZATION (FGD GYPSUM)

How it is produced and handled at the Power Plant

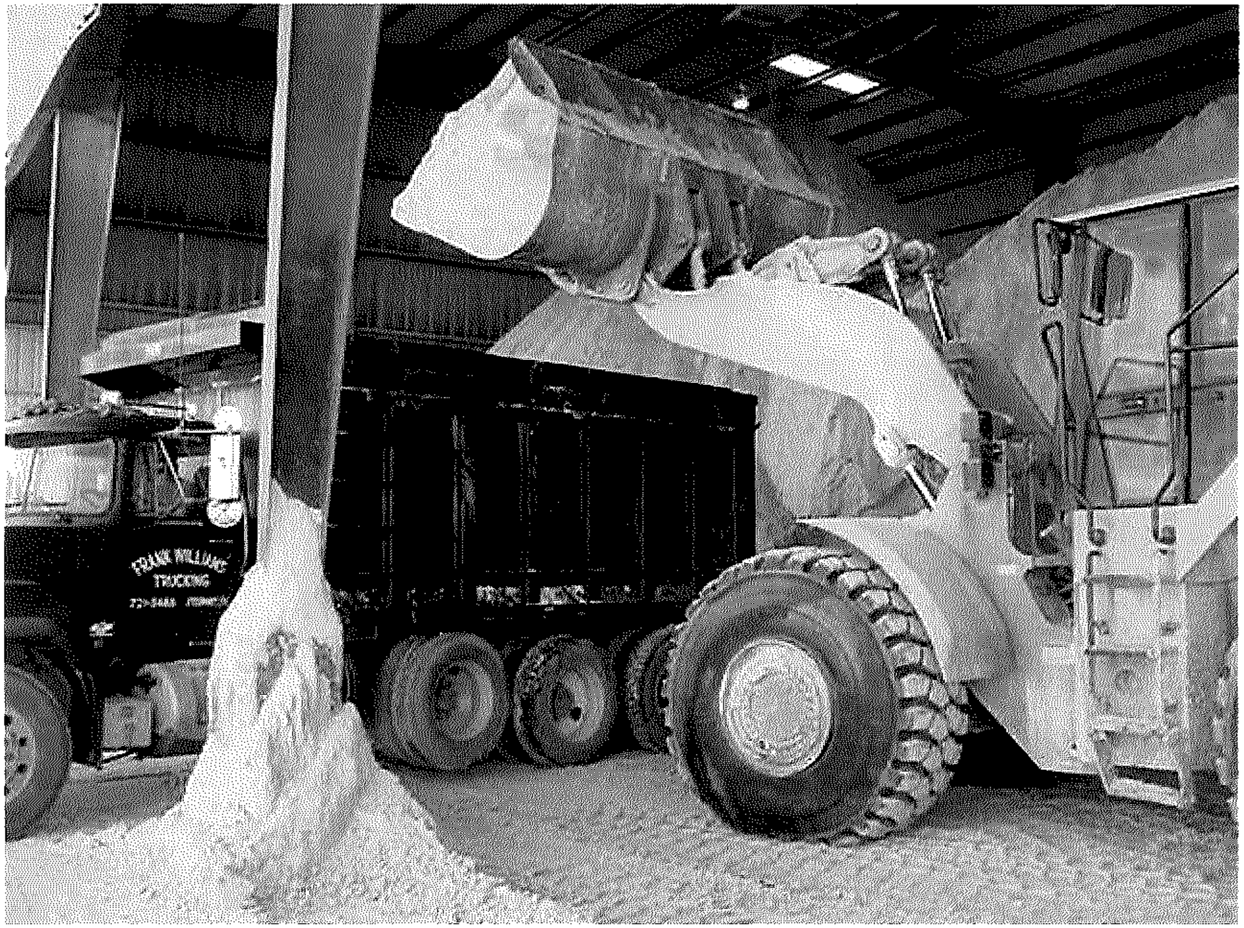
Dave C. Goss

Limestone Forced Oxidation Process



Removing Dried Gypsum from Drying Area using Earthmoving Equipment

Loading Trucks with Gypsum inside Covered Storage Shed



Loading Barge

FGD Gypsum:

- Is calcium sulfate dihydrate – $CaSO_4$-$2H_20$

- Exhibits essentially the same chemical characteristics of mined ore gypsum

  – White Sands National Monument contains 275 square miles of calcium sulfate dihydrate or gypsum in the form of sand particles

- Is ONLY produced from forced oxidation scrubber systems at power plants

FGD Gypsum is NOT:

- Coal ash or derived from coal in any manner
- Phosphogypsum (from the manufacture of fertilizers from phosphate ore using sulfuric acid)
- Titano-gypsum (from the production of titanium oxide for paints)
- Citro-gypsum (from the production of citric acid)

EFFECT OF FLUE GAS DESULFURIZATION GYPSUM ON METALS IN SOILS AND PLANTS

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Why Do We Apply Gypsum to Soils?

- To improve chemical and physical conditions
  - Reclaim sodium affected (sodic) soils
  - Increase yields on many soils
  - Reduce runoff and erosion
  - Reduce nitrogen volatilization
  - Reduce phosphorus in runoff

Examples of Yield Increases

Crop	# of sites	Yield increase due to gypsum %
Alfalfa	10	24
Bell pepper	1	49
Cantaloupe	2	32
Cotton	8	20
Cucumber	1	42
Oats	1	15
Peanuts	90	13
Sorghum	1	57
Soybean	1	51
Squash	2	39
Sugarcane	1	24
Tomatoes	12	25
Watermelon	4	51

Outcome

- FGD gypsum
  - Valuable resource for crop production
  - Increases yields and quality of crops
  - Highly economic soil amendment

COMPARISON OF CONTAMINANTS IN VARIOUS GYPSUM MATERIALS

Element	Mined Gypsum			FGD Gypsum		
	# of samples	Range	Mean	# of samples	Range	Mean
		mg/kg			mg/kg	
As	20	nd-2.53	0.84	30	nd-6.93	2.06
Be	19	nd-0.07	0.03	29	nd-0.18	0.07
Cd	19	nd-0.52	0.08	30	nd-0.90	0.16
Cr	20	nd-4.20	1.57	31	0.26-6.77	2.90
Co	12	0.01-4.39	1.37	27	0.17-1.38	0.55
Cu	20	nd-8.20	1.42	31	0.23-3.71	1.42
Hg	20	0.02-0.07	0.02	28	0.05-1.12	0.30
Ni	20	nd-10.96	2.65	31	nd-14.60	3.56
Pb	20	0.28-21.6	3.39	31	0.07-9.00	1.21
Se	19	nd-1.14	0.31	28	nd-12.05	4.61
Te	15	nd-0.43	0.04	16	nd-1.40	0.09
Tl	17	nd-0.51	0.10	26	nd-0.13	0.04
Va	20	nd-42.70	4.85	28	nd-35.00	3.73
Zn	20	nd-78.00	10.57	31	0.96-28.80	8.93

nd = not detected

Gypsum vs US-EPA 503 Pollutant Concentration Limits (PCL) (EPA3052)

Element	EPA 503	FGD gypsum*	Mined gypsum**
	mg/kg		
As	41	2.06	0.84
Cd	39	0.16	0.08
Cr	1200	2.90	1.57
Cu	1500	1.42	1.42
Pb	300	1.21	3.39
Hg	17	0.30	0.02
Ni	420	3.56	2.65
Se	36	4.61	0.31
Zn	2800	9.83	10.57

*** Mean of ~25 samples ** Mean of ~ 20 samples**

Comparison of Phospho- and FGD Gypsum

Pollutant	Phosphogypsum (FL)	FGD Gypsum*
	kg/ha (~lb/ac)	
As	2.5	2.06
Cd	4	0.16
Cu	9	1.42
Pb	15	1.21
Hg	0.35	0.30
Ni	10	3.56
Se	1.5	4.61

- *Mean of ~ 25 samples

Loading Limits for Biosolids & Maximum FGD Gypsum Application Rates

Pollutant	Annual pollutant loading rate for biosolids (503)	Maximum annual application rate for FGD gypsum*
	kg/ha (~lb/ac)	
As	2.0	0.0206
Cd	1.9	0.0016
Cu	75	0.0142
Pb	15	0.0121
Hg	0.85	0.0030
Ni	21	0.0356
Se	5.0	0.0461
Zn	140	0.0983

*** Assuming an application rate of 10 T/ha using mean element concentrations**

Outcome

- **Elements of environmental concern**
  - **As, Cr, Cd, Hg, Ni & Se slightly higher than in mined gypsum**
  - **As, Cr, Cd, Hg, Se & Ni lower than in phosphogypsum**
  - **All far below EPA 503 regulations for biosolids**
  - **Annual loading limits for FGD gypsum far below those for biosolids**

Comparison of Saturated Solutions of FGD & Mined Gypsum

- **Gypsum solubility**
  - **2.2 g/L**
- **Gypsum dissolved in**
  - **Distilled water**
- **Or**
  - **Conc HNO_3 before dilution**

Gypsum Vs Drinking Water

Element	MCL	FGD Gypsum		Mined gypsum	
		Total*	Water*	Total	Water
	µg/L				
As	10	5.3	1	1.3	0.15
Ba	2000	134	18.5	130	5.5
Be	4	0.2	0.04	0.05	0.05
Cd	5	0.12	0.12	0.5	0.06
Cr	100	6.4	3.5	4.4	1.1
Cu	1300	2.9	0.11	5	2.9
Pb	15	1	0.03	0.84	0.11
Hg	2	0.62	0.08	0.03	0.02
Se	50	22	9.1	0.52	0.32
Tl	2	0.01	0.01	0.01	0.00
Zn		15	1.1	19.1	6.7

* 2.2 g gypsum/L
- Dissolved in conc HNO_3 or water

Outcome

- **Saturated solution of FGD gypsum**
  - **Easily meets US Drinking Water Standard**
    - **For all elements of environmental concern**

Various Grains

- **Data of Arnold (1997)**
- **Gypsum application rate**
  - **4.5 T FGD Gypsum/ac (10 T/ha) applied once**

Element	Treatment	Soybean			Corn			Wheat		
		# Obs	Range	Mean	# Obs	Range	Mean	# Obs	Range	Mean
			mg/kg			mg/kg			mg/kg	
As	Control	5	0.005-0.005	0.00	2	0.005-0.005	0.00	2	0.005-0.006	0.01
	Gypsum	5	0.005-0.107	0.03	2	0.005-0.009	0.01	2	0.005-0.008	0.01
Cu	Control	5	19.19-20.3	19.60	2	1.39-5.01	3.20	2	1.59-4.99	3.29
	Gypsum	5	19.43-20.39	19.70	2	1.69-5.00	3.35	2	1.67-4.76	3.21
Mo	Control	5	0.144-0.443	0.22	2	0.145-0.185	0.17	2	0.158-0.43	0.29
	Gypsum	5	0.146-0.445	0.22	2	0.146-0.187	0.17	2	0.335-0.395	0.37
Ni	Control	5	0.221-0.377	0.26	2	0.34-0.361	0.35	2	0.196-0.367	0.28
	Gypsum	5	0.221-0.385	0.22	2	0.338-0.361	0.35	2	0.207-0.397	0.30
Pb	Control	5	0.238-0.404	0.30	2	0.241-0.30	0.27	2	0.116-0.129	0.12
	Gypsum	5	0.238-0.421	0.31	2	0.243-.0298	0.27	2	0.119-0.128	0.12
Se	Control	5	0.049-0.544	0.15	2	0.042-0.087	0.06	2	0.040-0.42	0.04
	Gypsum	5	0.05-0.549	0.15	2	0.064-0.088	0.07	2	0.040-0.046	0.04
Zn	Control	5	40.25-45.84	43.04	2	10.52-17.14	13.83	2	12.29-20.01	16.15
	Gypsum	5	40.29-46.21	42.96	2	10.5-15.69	13.10	2	10.26-20.46	15.36

Cotton

- **Gypsum application rate**
  - **4.5 T FGD Gypsum/ac (10 T/ha) applied once**

Element	Treatment	Leaf			Soil			Seed		
		# Obs	Range	Mean	# Obs	Range	Mean	# Obs	Range	Mean
			mg/kg			mg/kg			mg/kg	
As	Control	4	0.99-1.94	1.88	6	0.76-9.64	5.12	3	0.16-0.33	0.24
	Gypsum	4	0.75-2.41	1.73	6	0.78-8.47	4.91	3	0.16-0.26	0.22
Cu	Control	4	5.4-10.7	7.43	5	3.42-12.2	8.25	3	3.71-6.52	5.11
	Gypsum	4	5.4-10.9	7.80	5	3.54-14.4	7.55	3	3.73-6.86	5.23
Cd	Control	4	0.10-0.14	0.12	6	0.05-0.13	0.10	3	0.02-0.07	0.04
	Gypsum	4	0.11-0.23	0.16	6	0.05-0.13	0.10	3	0.02-0.06	0.04
Cr	Control	4	2.00-7.24	5.02	6	2.30-14.8	9.96	3	0.08-1.94	1.18
	Gypsum	4	2.40-25.9	9.77	6	2.65-16.2	9.29	3	0.17-1.91	1.22
Pb	Control	4	0.20-0.50	0.34	6	1.59-21.6	11.42	3	0.06-0.66	0.28
	Gypsum	4	0.20-0.50	0.31	6	1.44-14.1	9.64	3	0.02-1.05	0.38
Mn	Control	4	87-155	129.00	6	115-1036	466.00	2	15.7-29.4	22.50
	Gypsum	4	118-294	197.00	6	202-508	363.00	2	17.0-31.0	24.00
Hg	Control	4	0.03-0.11	0.08	6	0.03-0.10	0.07	3	0.01-0.03	0.02
	Gypsum	4	0.03-0.10	0.08	6	0.03-0.10	0.07	3	0.00-0.02	0.01
Mo	Control	4	0.25-1.07	0.53	6	0.10-2.32	0.79	3	0.00-0.15	0.06
	Gypsum	4	0.21-0.75	0.38	6	0.11-0.78	0.47	3	0.00-0.16	0.07
Ni	Control	4	0.80-2.57	1.83	6	1.05-3.96	2.71	3	0.50-0.76	0.65
	Gypsum	4	1.08-8.59	3.55	6	1.21-4.29	2.71	3	0.37-0.80	0.45
Se	Control	4	0.41-0.74	0.60	6	0.15-1.21	0.46	3	0.05-0.72	0.30
	Gypsum	4	0.49-0.72	0.64	6	0.15-1.38	0.52	3	0.05-1.09	0.43
Zn	Control	4	28.9-53.0	39.50	6	2.13-31.4	18.59	3	16.9-37.4	23.92
	Gypsum	4	28.6-51.7	39.90	6	2.49-34.4	19.26	3	14.6-37.4	22.53

Yellow Squash

- **Gypsum application rate**
  - **2T FDG Gypsum/ac (5 T/ha) applied annually**

Element	Treatment	Leaf			Soil			Fruit		
		# Obs	Range	Mean	# Obs	Range	Mean	# Obs	Range	Mean
			mg/kg			mg/kg			mg/kg	
As	Control	2	0.12-0.53	0.33	2	1.47-3.25	2.36	2	0.34-0.51	0.43
	Gypsum	2	0.34-0.58	0.46	2	1.27-3.10	2.18	2	0.39-0.40	0.40
Cu	Control	2	6.84-17.7	12.27	2	4.71-13.2	8.95	2	7.97-17.4	12.68
	Gypsum	2	6.94-13.4	10.17	2	4.83-12.4	8.62	2	9.43-11.6	10.51
Cd	Control	2	0.25-0.26	0.26	2	0.05-0.12	0.08	2	0.06-0.07	0.07
	Gypsum	2	0.34-0.46	0.40	2	0.06-0.15	0.11	2	0.06-0.07	0.07
Cr	Control	2	1.38-4.39	2.88	2	8.38-8.52	8.45	2	5.52-9.09	7.31
	Gypsum	2	1.92-4.18	3.05	2	6.70-76.2	41.45	2	1.68-4.11	2.90
Pb	Control	2	0.24-0.42	0.33	2	7.15-11.0	9.07	2	0.13-0.14	0.14
	Gypsum	2	0.18-0.45	0.32	2	7.28-26.6	16.95	2	0.07-0.14	0.11
Mn	Control	2	295-972	634.00	2	157-693	425.00	2	74.9-112	93.45
	Gypsum	2	236-444	340.00	2	221-890	555.50	2	46.7-113	79.85
Hg	Control	2	0.07-0.29	0.18	2	0.05-0.06	0.06	2	0.07-0.44	0.26
	Gypsum	2	0.06-0.07	0.07	2	0.05-0.06	0.06	2	0.06-0.07	0.07
Mo	Control	2	0.56-1.97	1.27	2	0.42-0.46	0.44	2	0.21-1.96	1.09
	Gypsum	2	0.45-1.16	0.81	2	0.25-0.44	0.35	2	0.22-1.23	0.73
Ni	Control	2	1.16-2.96	2.06	2	3.96-8.86	6.41	2	2.45-7.55	5.00
	Gypsum	2	1.08-2.60	1.84	2	3.45-8.64	6.04	2	1.41-2.06	1.74
Se	Control	2	0.49-0.56	0.53	2	0.59-0.64	0.62	2	0.35-0.39	0.37
	Gypsum	2	0.50-0.58	0.54	2	0.51-0.73	0.62	2	0.38-0.44	0.41
Zn	Control	2	172-191	181.50	2	10.6-115	62.80	2	61.8-73.6	67.70
	Gypsum	2	170-411	290.50	2	11.0-71.6	41.32	2	50.1-83.2	66.70

Tomato

- **Gypsum application rate**
  - **2T FGD Gypsum/ac (5 T/ha) applied annually**

Element	Treatment	Leaf			Soil			Fruit		
		# Obs	Range	Mean	# Obs	Range	Mean	# Obs	Range	Mean
			mg/kg			mg/kg			mg/kg	
As	Control	6	0.55-3.67	1.79	6	1.70-4.66	3.07	4	0.24-1.63	0.72
	Gypsum	6	0.61-2.83	1.46	6	1.89-4.73	2.97	4	0.35-0.94	0.62
Cu	Control	6	233-760	457.00	6	0.42-16.2	10.64	4	7.24-15.6	10.75
	Gypsum	6	135-871	445.50	6	0.76-16.0	9.08	4	9.34-15.1	12.05
Cd	Control	6	0.39-0.97	0.70	6	0.04-0.11	0.08	4	0.06-0.16	0.12
	Gypsum	6	0.37-1.40	0.94	6	0.04-0.27	0.12	4	0.11-0.23	0.18
Cr	Control	6	1.57-14.6	5.45	6	4.03-21.9	12.12	4	0.64-8.12	3.48
	Gypsum	6	1.52-11.0	5.41	6	4.29-14.7	9.77	4	0.66-8.19	4.74
Pb	Control	6	0.06-0.68	0.31	6	0.17-12.1	7.48	4	0.05-0.32	0.12
	Gypsum	6	0.06-0.79	0.32	6	0.17-9.53	7.10	4	0.05-0.72	0.31
Mn	Control	5	320-640	491.00	5	98-232	161.20	2	14.3-15.8	15.03
	Gypsum	5	257-726	447.60	5	67-246	136.80	2	18.3-19.9	19.10
Hg	Control	6	0.02-0.10	0.05	6	0.04-0.10	0.06	4	0.01-0.10	0.04
	Gypsum	6	0.02-0.10	0.05	6	0.02-0.10	0.06	4	0.01-0.10	0.04
Mo	Control	6	0.28-1.16	0.71	6	0.26-0.38	0.32	4	0.35-0.87	0.54
	Gypsum	6	0.18-1.18	0.62	6	0.20-0.41	0.27	4	0.18-0.74	0.48
Ni	Control	4	1.72-5.63	3.79	6	0.23-11.5	5.42	2	0.43-2.81	1.62
	Gypsum	4	1.86-3.43	2.76	6	0.58-9.89	5.47	2	0.39-0.51	0.45
Se	Control	6	0.12-6.34	3.01	6	0.32-0.87	0.53	4	0.11-7.35	2.06
	Gypsum	6	0.79-7.90	3.62	6	0.29-0.71	0.45	4	0.27-6.56	1.98
Zn	Control	6	28.1-51.5	41.80	6	27.4-41.6	33.24	4	18.7-28.2	22.35
	Gypsum	6	28.2-47.7	38.86	6	28.2-47.7	34.25	4	26.5-47.7	32.41

Peanuts

- **Gypsum application rate**
  - **0.5 T/ha (1.25 T/ha) applied annually**

Element	Treatment	Leaf			Soil			Seed		
		# Obs	Range	Mean	# Obs	Range	Mean	# Obs	Range	Mean
			mg/kg			mg/kg			mg/kg	
As	Control	15	0.16-2.24	1.56	22	1.40-53	6.81	9	0.16-1.12	0.54
	Gypsum	15	0.10-2.38	1.48	22	1.21-8.47	4.21	9	0.05-1.12	0.78
Cu	Control	15	3.30-19.69	7.90	22	0.31-13.86	6.65	9	0.67-9.33	3.19
	Gypsum	15	4.33-10.92	7.13	22	0.41-14.35	6.68	9	0.32-11.08	2.83
Cd	Control	15	0.08-0.27	0.14	22	0.03-0.30	0.10	9	0.03-0.08	0.06
	Gypsum	15	0.03-0.18	0.11	22	0.04-0.19	0.11	9	0.03-0.10	0.08
Cr	Control	15	1.40-10.96	4.36	22	1.94-27.4	8.05	9	1.94-8.94	3.65
	Gypsum	15	1.58-6.66	3.60	22	1.68-27.65	7.06	9	0.91-8.24	4.49
Pb	Control	15	0.06-1.58	0.36	22	1.00-17.3	6.45	9	0.05-0.50	0.17
	Gypsum	15	0.06-1.51	0.31	22	0.24-14.08	5.09	9	0.03-0.50	0.17
Mn	Control	9	56-289	141.00	12	18.3-1625	425.00	2	15.6-20.0	17.80
	Gypsum	9	23-267	120.00	12	20.2-1365	276.00	2	17.0-19.5	18.25
Hg	Control	15	0.03-0.10	0.04	22	0.02-0.10	0.05	9	0.03-0.05	0.04
	Gypsum	15	0.03-0.10	0.04	22	0.02-0.10	0.05	9	0.00-0.06	0.03
Mo	Control	15	0.03-0.72	0.15	22	0.13-2.94	0.47	9	0.04-0.44	0.28
	Gypsum	15	0.06-0.65	0.17	22	0.13-2.11	0.45	9	0.07-0.89	0.40
Ni	Control	9	0.77-2.32	1.34	18	0.25-11.94	1.98	9	0.50-5.38	1.22
	Gypsum	9	0.45-2.17	1.38	18	0.32-6.37	1.64	9	0.68-3.41	0.98
Se	Control	15	0.25-6.14	1.60	22	0.22-0.72	0.30	9	0.05-1.00	0.33
	Gypsum	15	0.25-3.82	1.25	22	0.19-0.75	0.30	9	0.02-1.00	0.33
Ag	Control	9	0.05-0.15	0.10	18	0.10-0.50	0.25	7	0.01-0.25	0.18
	Gypsum	9	0.01-0.15	0.09	18	0.10-0.50	0,23	7	0.01-0.25	0.16
Zn	Control	15	16.3-101	44.80	22	13.8-127	28.90	9	16.9-41.4	30.90
	Gypsum	15	17.7-98.5	39.30	22	10.9-170	21.90	9	5.75-40.8	29.40

Cantaloupe

- **Gypsum application rate**
  - **2 T/ac (5 T/ha) applied annually**

Element	Treatment	Leaf			Soil			Fruit		
		# Obs	Range	Mean	# Obs	Range	Mean	# Obs	Range	Mean
			mg/kg			mg/kg			mg/kg	
As	Control	6	0.31-0.44	0.35	2	1.34-3.90	2.63	5	0.10-0.71	0.51
	Gypsum	6	0.20-0.57	0.35	2	1.66-5.44	3.55	5	0.17-0.93	0.66
Cu	Control	6	7.26-11.40	10.22	2	3.93-4.85	4.39	5	4.88-9.89	6.33
	Gypsum	6	7.03-12.72	9.87	2	4.09-5.11	4.60	5	5.10-9.16	6.31
Cd	Control	6	0.13-1.05	0.53	2	0.05-0.12	0.08	5	0.06-0.09	0.07
	Gypsum	6	0.23-0.72	0.48	2	0.05-0.09	0.07	5	0.05-0.11	0.08
Cr	Control	6	0.63-6.05	4.70	2	7.81-10.64	9.23	5	1.70-3.50	2.81
	Gypsum	6	2,12-5.05	4.00	2	9.71-24.81	17.30	5	0.90-3.11	2.56
Pb	Control	6	0.30-0.84	0.54	2	5.35-7.41	6.38	5	0.05-0.37	0.25
	Gypsum	6	0.21-1.13	0.62	2	6.14-9.60	7.87	5	0.06-0.36	0.24
Mn	Control	6	80-513	243.00	2	68.0-79.4	68.70	5	21.0-50.5	34.70
	Gypsum	6	165-278	225.00	2	43.1-84.2	63.30	5	26.3-80.2	42.73
Hg	Control	6	0.02-0.05	0.03	2	0.03-0.05	0.04	5	0.01-0.20	0.06
	Gypsum	6	0.02-0.05	0.03	2	0.03-0.05	0.04	5	0.01-0.03	0.02
Mo	Control	6	0.07-0.25	0.15	2	0.21-0.41	0.31	5	0.07-0.13	0.11
	Gypsum	6	0.05-0.25	0.12	2	0.22-0.73	0.48	5	0.09-0.22	0.17
Ni	Control	6	2.23-4.58	2.88	2	1.76-4.95	3.36	5	0.62-1.70	1.35
	Gypsum	6	1.77-2.87	2.16	2	2.03-5.07	3.55	5	0.60-1.93	1.58
Se	Control	6	0.18-0.79	0.56	2	0.33-0.66	0.50	5	0.41-0.73	0.44
	Gypsum	6	0.13-0.88	0.63	2	0.36-0.74	0.55	5	0.39-0.56	0.35
Ag	Control	6	0.05-0.08	0.07	2	0.05-0.10	0.08	5	0.05-0.20	0.15
	Gypsum	6	0.05-0.08	0.07	2	0.06-0.10	0.08	5	0.06-0.20	0.16
Zn	Control	6	51.7-70.4	57.60	2	18.14-56.1	37.00	5	26.2-35.5	29.67
	Gypsum	6	41.8-85.1	54.40	2	7.47-19.05	13.26	5	24.5-38.8	30.00

Outcome

- Levels of all elements of environmental concern
  - VERY LOW in soil, tissue, fruit and seeds
  - Alfalfa and tomato tissue sometimes high in Se
    - Not due to FGD gypsum
    - Environmental heterogeniety likely responsible
- No consistent trends from gypsum application
  - In soils, tissue, fruits or grains
  - Variations probably due to heterogeniety

COMPARISON OF VARIOUS SOIL HEAVY METAL DATA BASES

Element	Treatment	Sumner			Alloway		Adriano	
							World	US
		# Obs	Range	Mean	Range	Mean	Mean	Mean
			mg/kg					
As	Control	40	0.76-53	5.46	0.5-15	10		
	Gypsum	40	0.78-8.47	4.05				
Cu	Control	39	0.31-16.2	7.42	1-150		20	25
	Gypsum	39	0.41-16.0	7.24				
Cd	Control	40	0.03-0.30	0.09	0.3-11	1	0.3	0.5
	Gypsum	40	0.04-0.27	0.11				
Cr	Control	40	1.95-27.4	9.27	0.2-837		200	53
	Gypsum	40	1.68-76.2	10.44				
Pb	Control	40	0.17-21.6	7.51		13	10	20
	Gypsum	40	0.17-26.6	6.99				
Mn	Control	29	18-1036	337.54	50-11500		850	560
	Gypsum	29	20-1365	259.81				
Hg	Control	40	0.02-0.10	0.05	0.001-0.46	0.11		
	Gypsum	40	0.02-0.10	0.05				
Mo	Control	40	0.10-2.94	0.49				
	Gypsum	40	0.11-2.11	0.43				
Ni	Control	36	0.23-11.94	3.23	0.8-439		40	20
	Gypsum	36	0.32-9.89	3.06				
Se	Control	40	0.15-1.21	0.38	0.6-1.6	1.5		
	Gypsum	40	0.15-1.38	0.39				
Zn	Control	40	2.13-127	29.83	0.7-987	50	50	54
	Gypsum	40	2.49-170	24.05				

Outcome

- **Levels of all elements of environmental concern**
  - **Well within normal ranges for soils**

Conclusions

- In FGD gypsum applications to soils
  - Levels of elements of environmental concern
    - Well within normal ranges for soils
    - No consistent variations in heavy metals due to FGD gypsum
      - In soil
      - In tissue
      - In fruits or seeds
    - Pose no threat to the environment or food chain

THANK YOU FOR YOUR ATTENTION

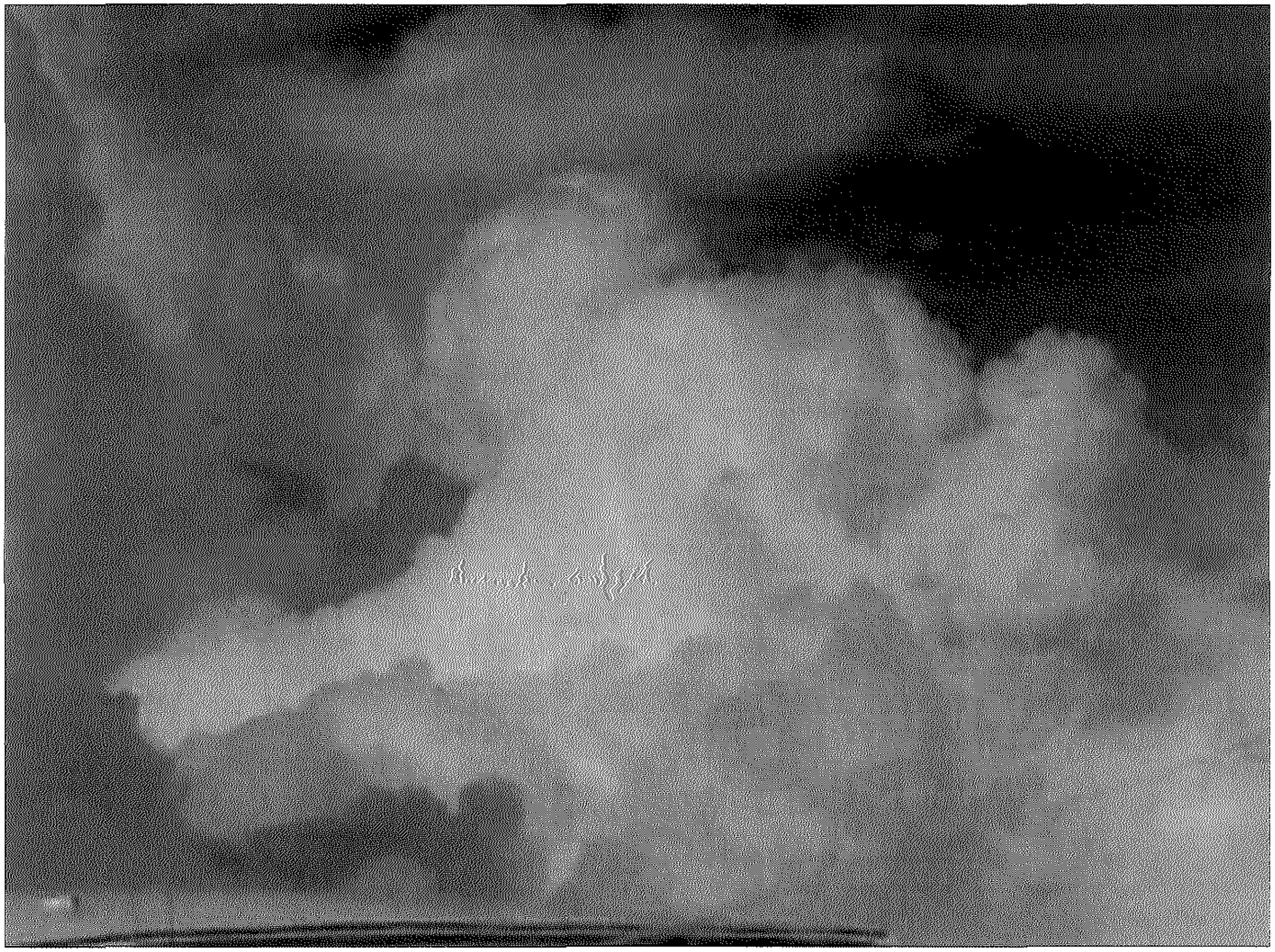
University of Georgia

First Public Funded University in the United States

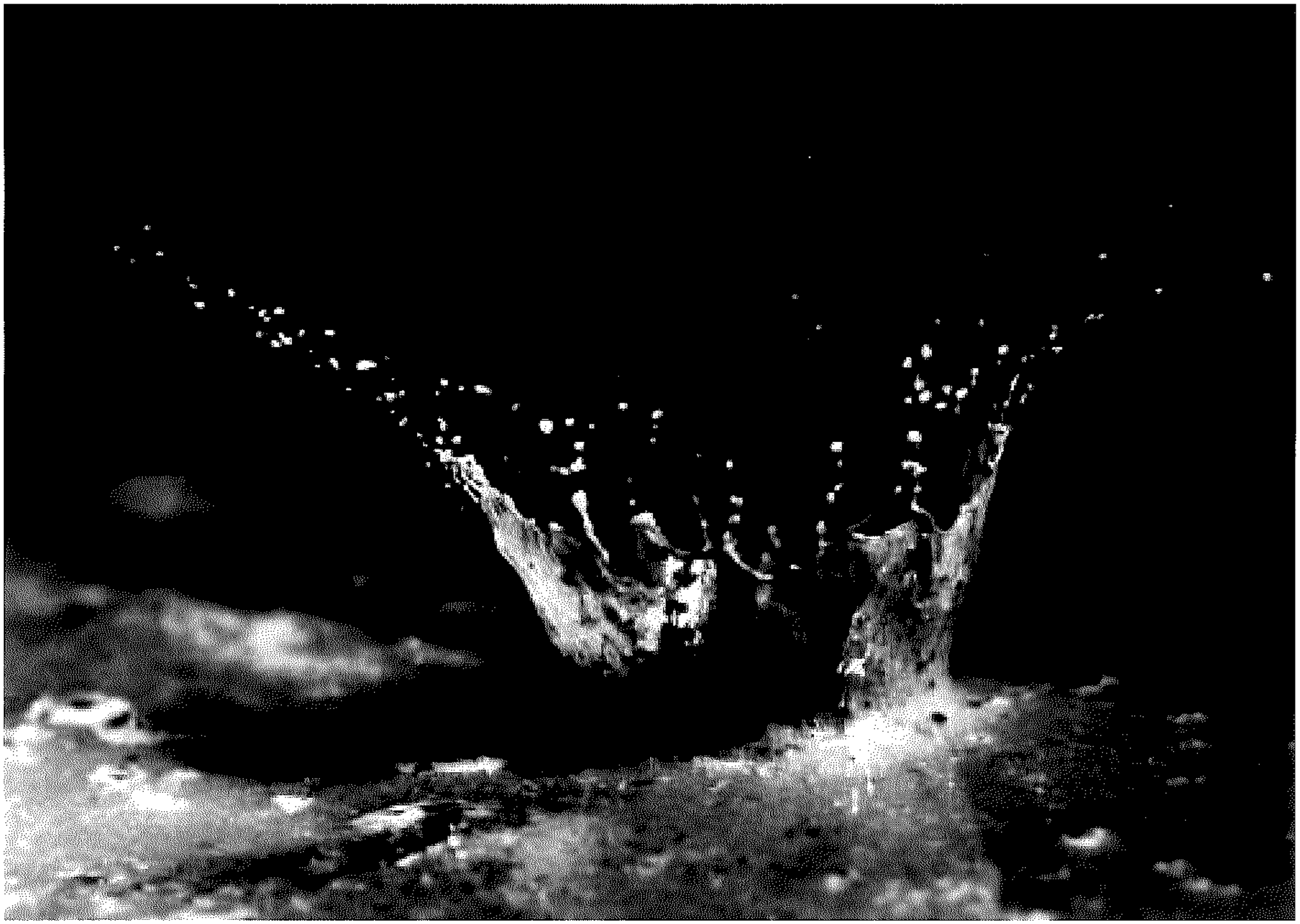
USING GYPSUM TO AFFECT SOIL EROSION PROCESSES AND WATER QUALITY

Dr. L Darrell Norton, Research Soil Scientist USDA-ARS National Soil Erosion Research Laboratory, Purdue University, West Lafayette, IN

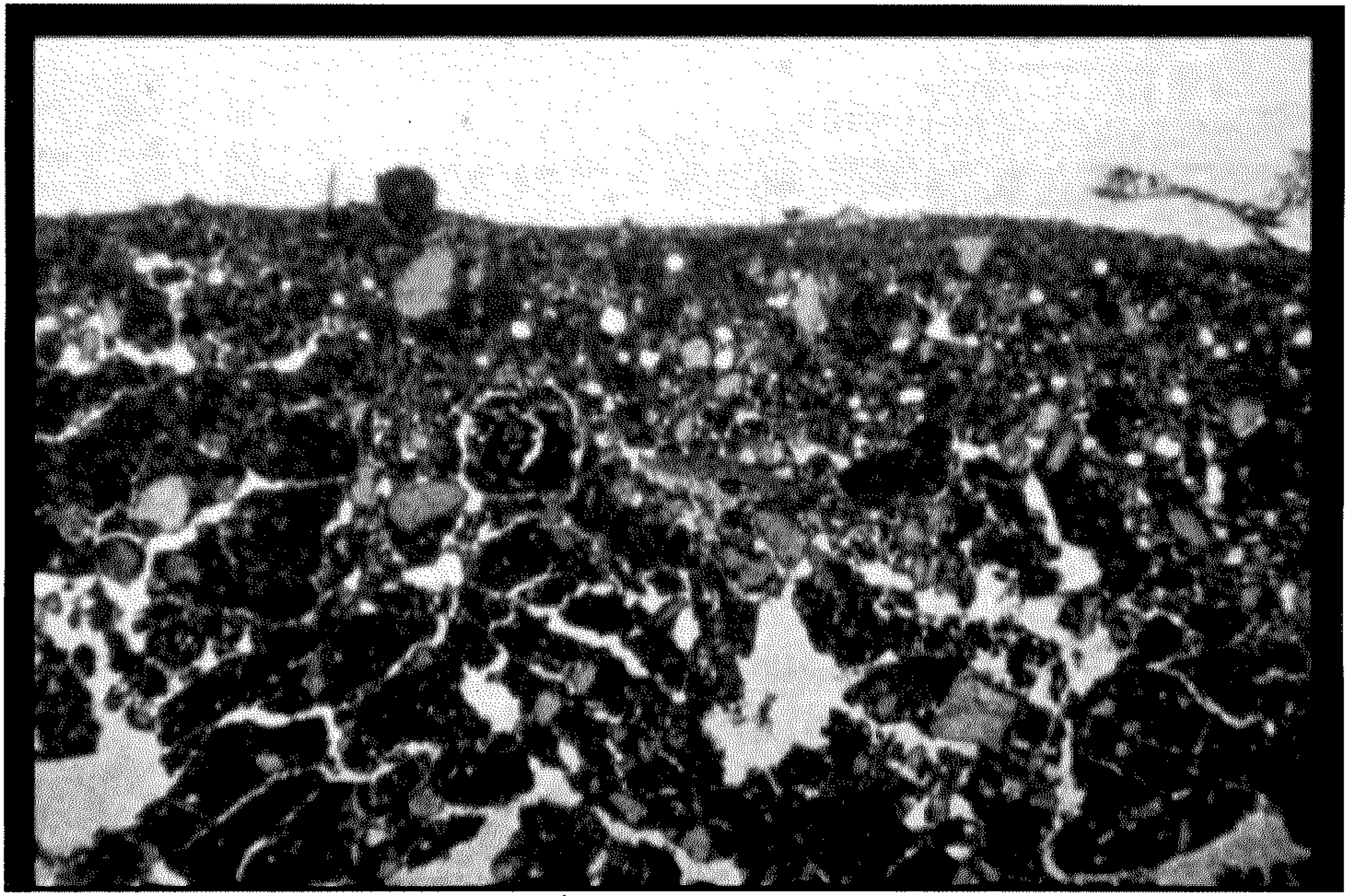
Rainwater is Natural Distilled and Low in Electrolytes



Both Physical and Chemical Processes Occur at the Time Scale of Raindrop Impact

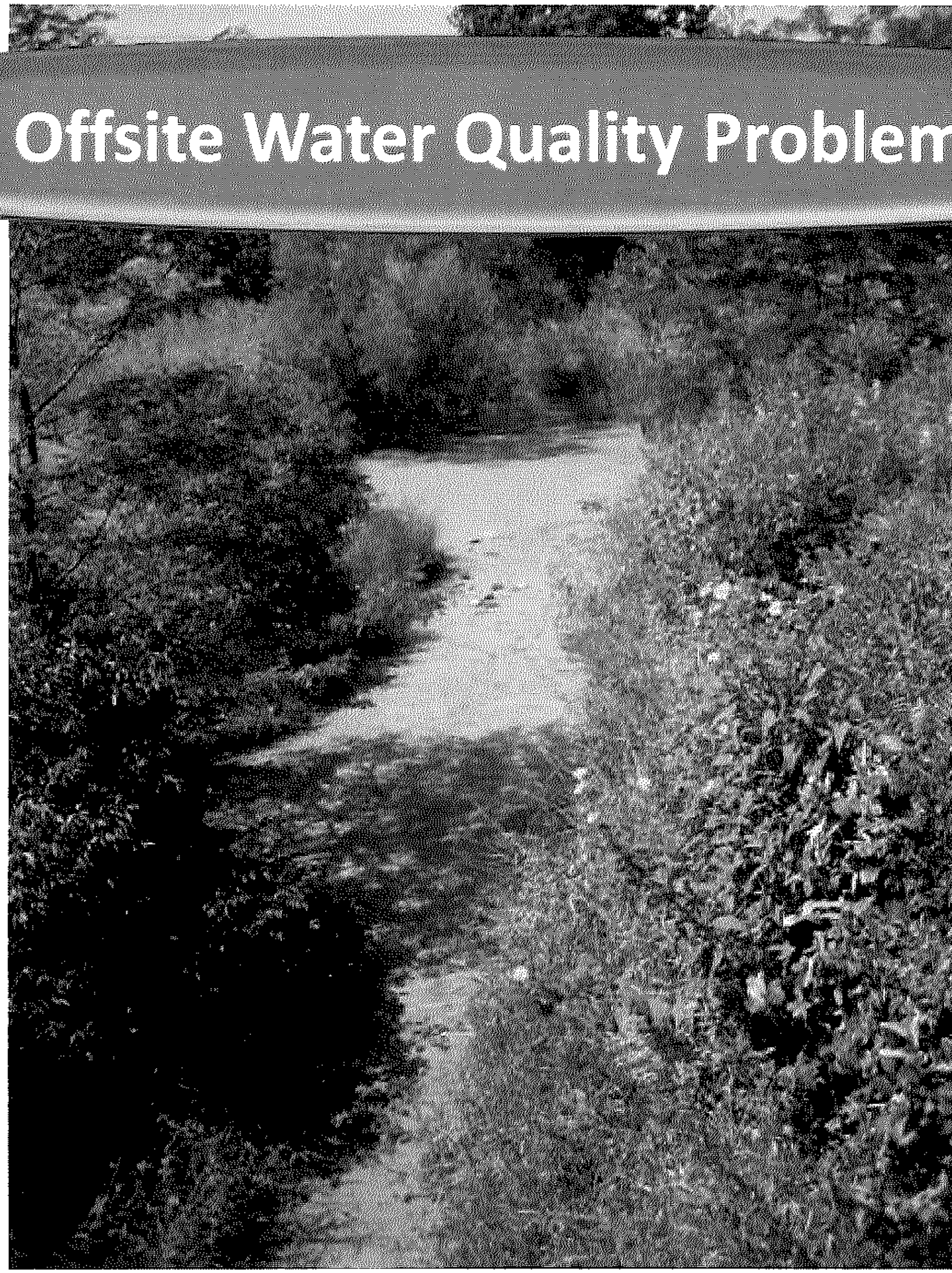


This Leads to Surface Sealing



Runoff Causing Soil Erosion and Removal of Chemicals

Offsite Water Quality Problems

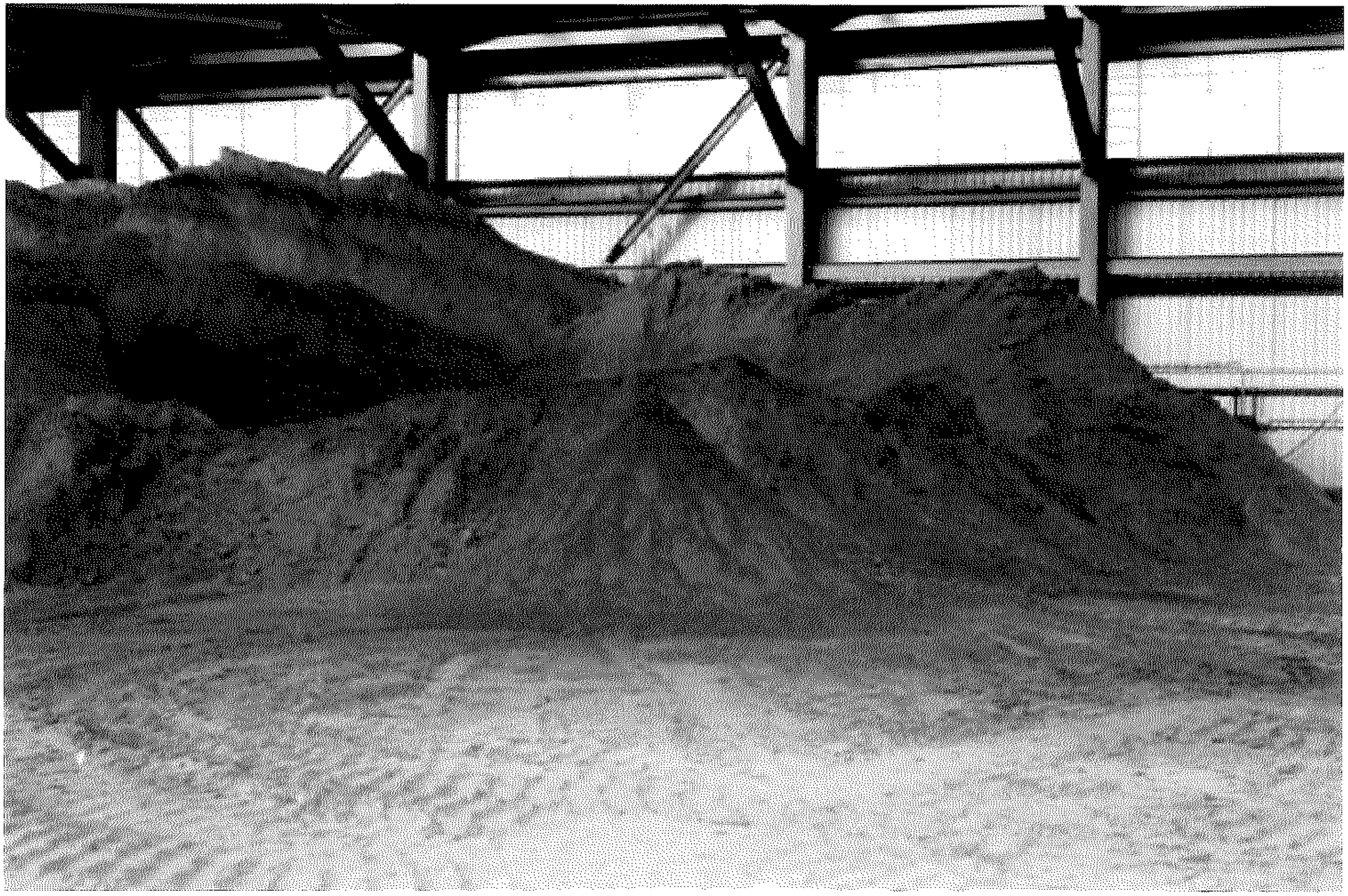


This Leads to Surface Sealing

Natural Occurring Geologic Deposits

Synthetic Production from Clean Air Regulations

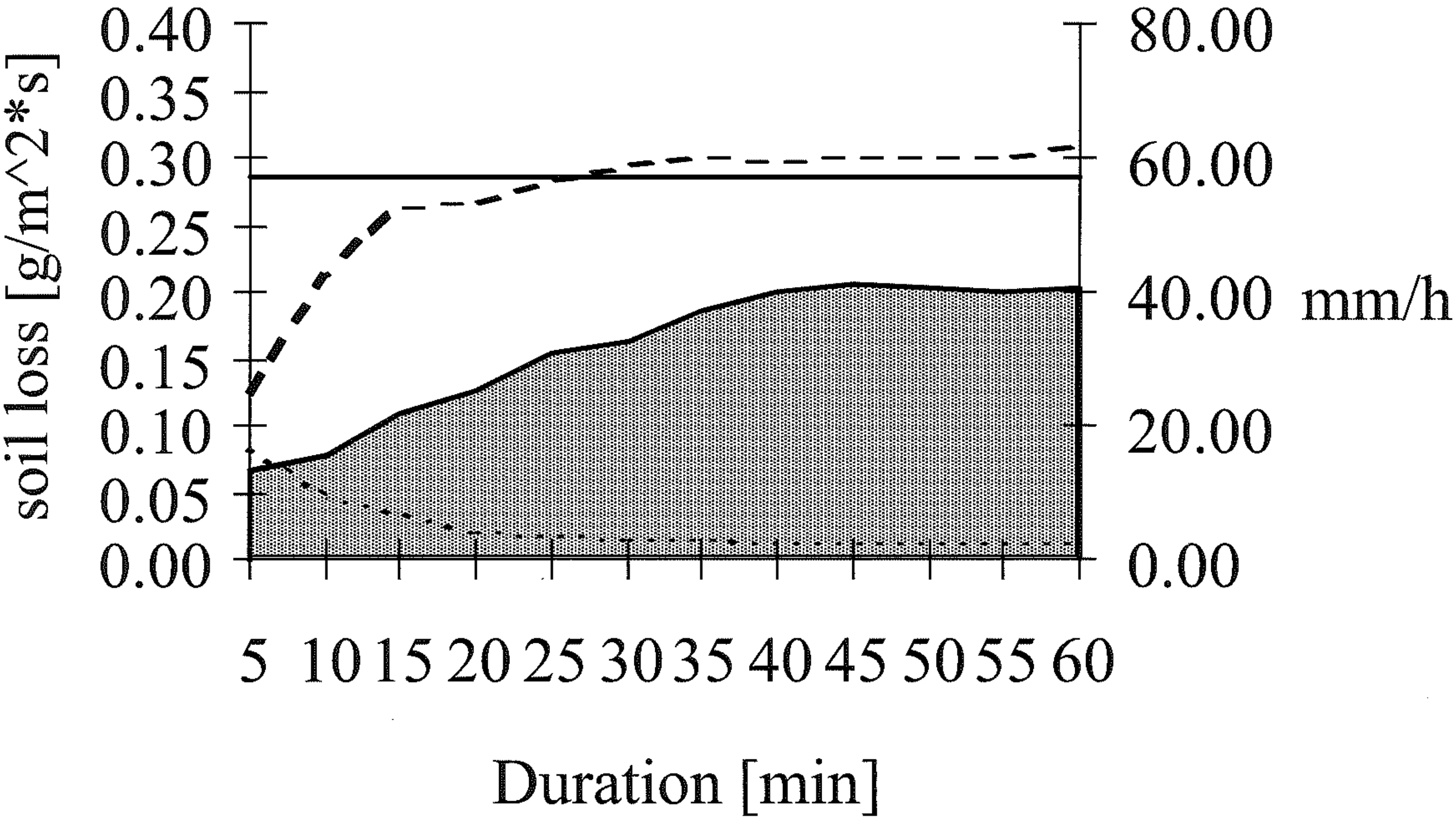
Synthetic Gypsum as a Soil Amendment



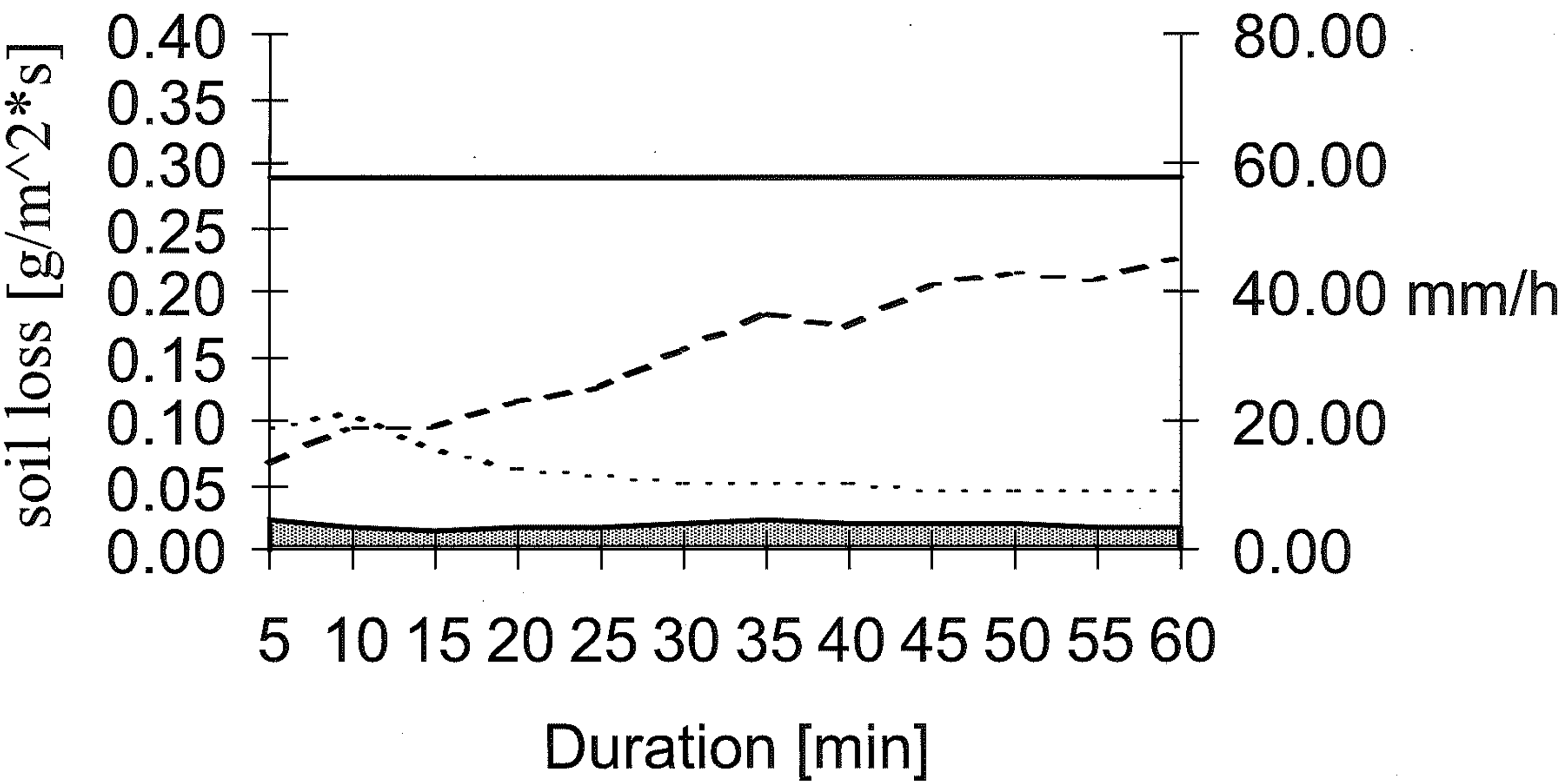
Gypsum Use in USA
Source USGS, 2004

• Total use	39,000,000
• Mined	18,000,000
• Synthetic	11,000,000
• Imports	10,400,000
• Cement	4,700,000
• Agriculture	1,000,000

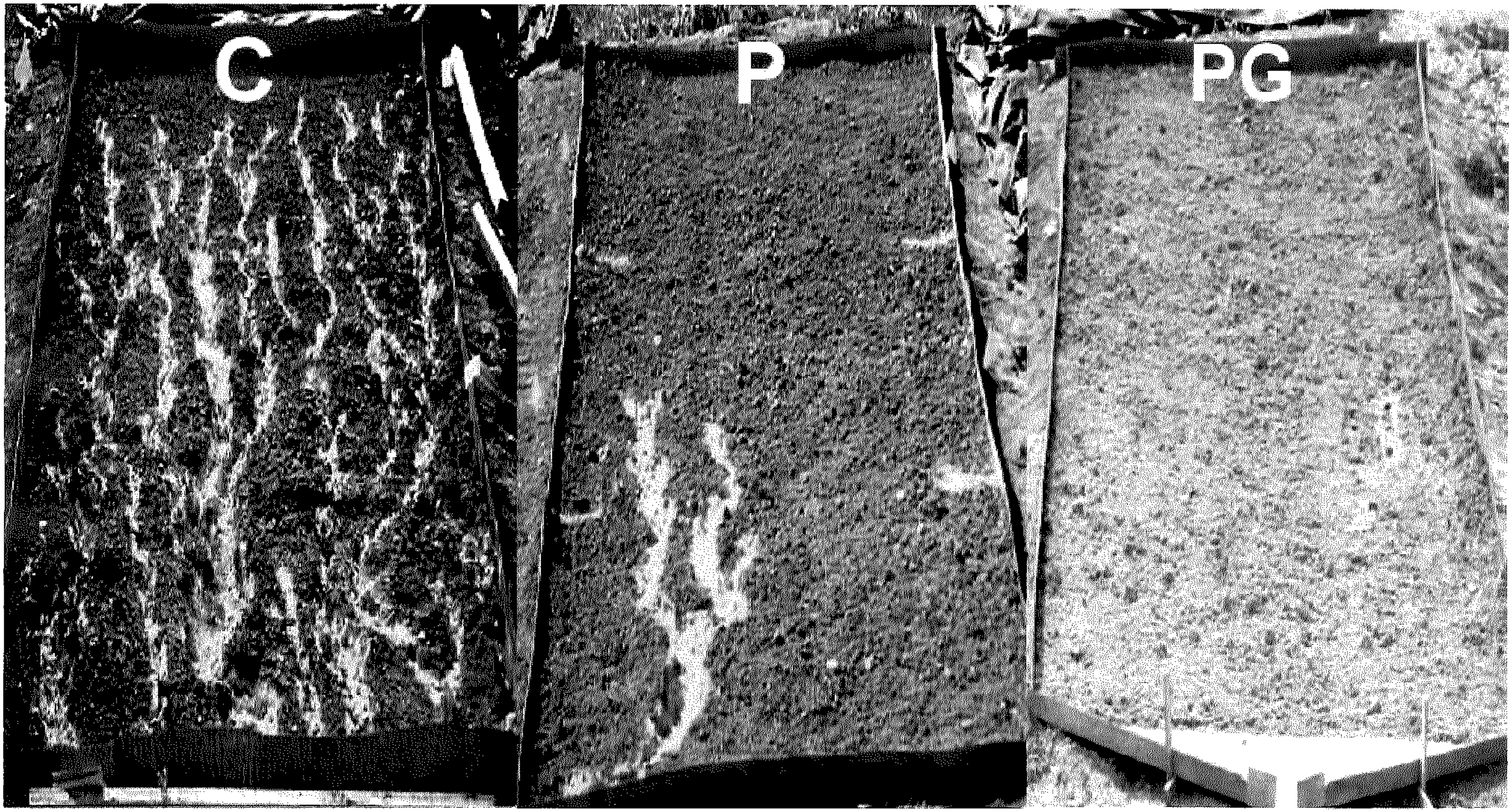
DeWitt, Iowa Site
Fayette silty clay loam



Fayette PAM+FBCBA Treatment

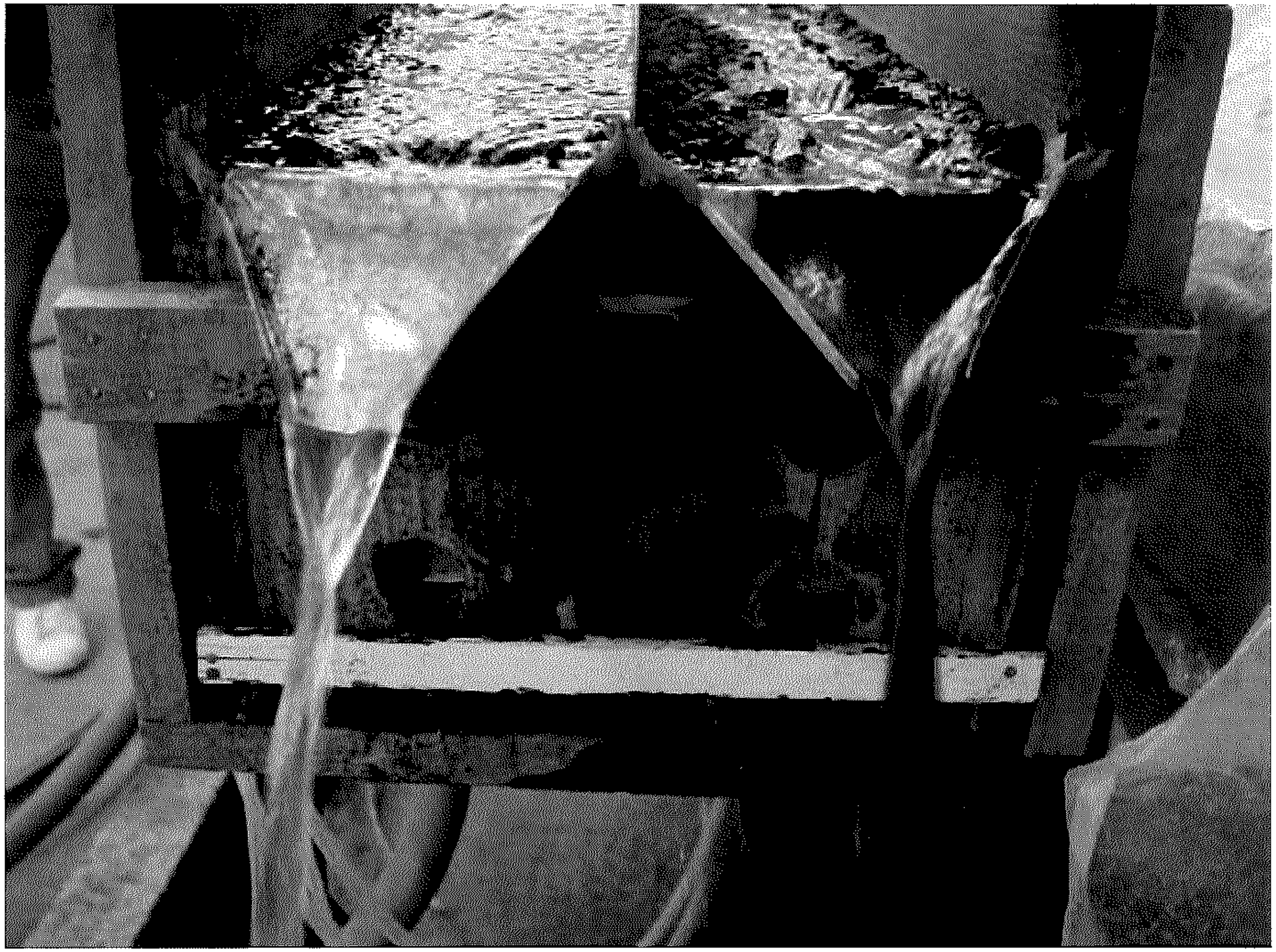


Effect of Gypsum and PAM on Soil Erosion by Concentrated flow on Steep Road Construction Slopes

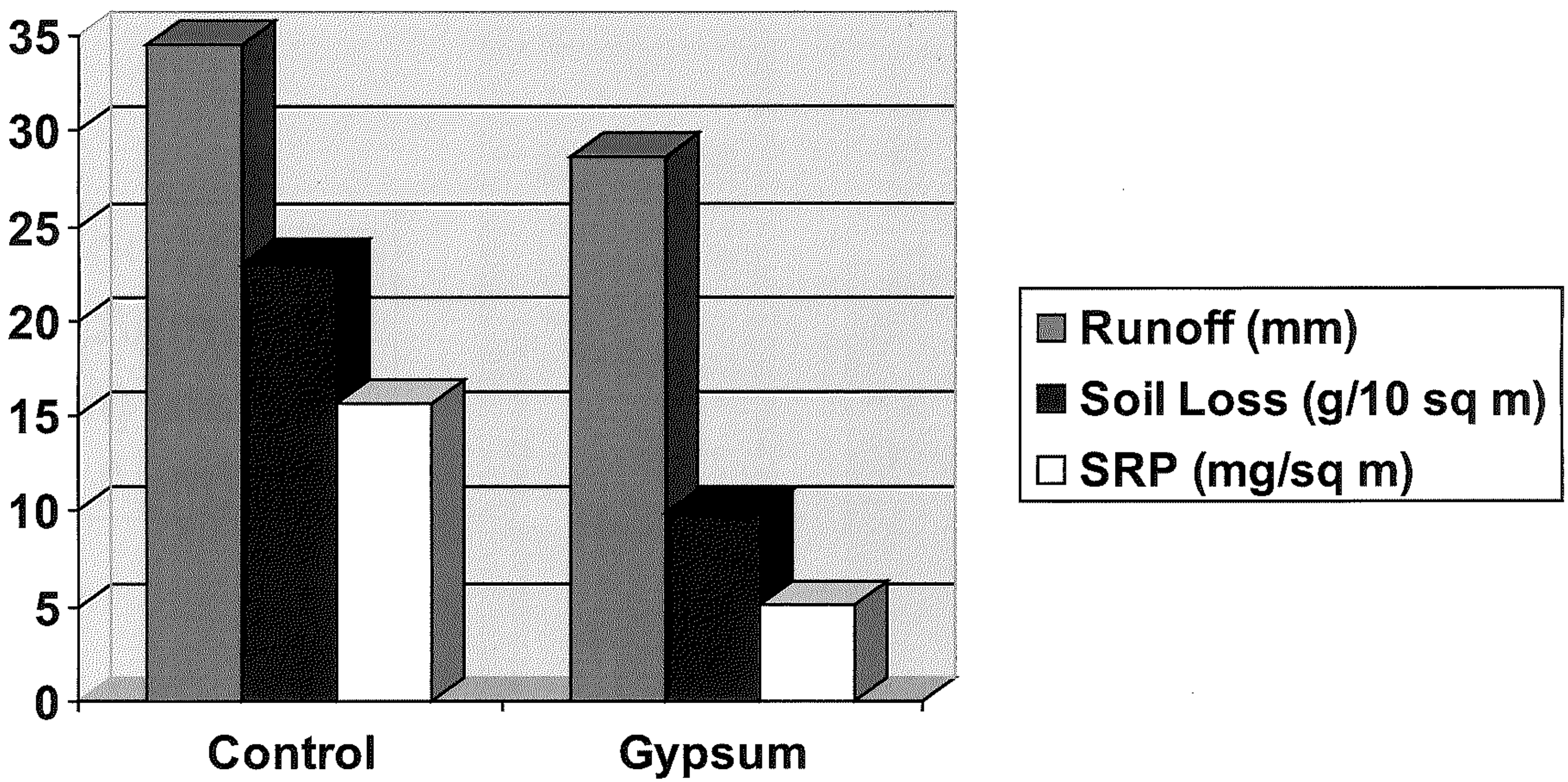


Soil Structural Differences (Control left Gypsum on right)

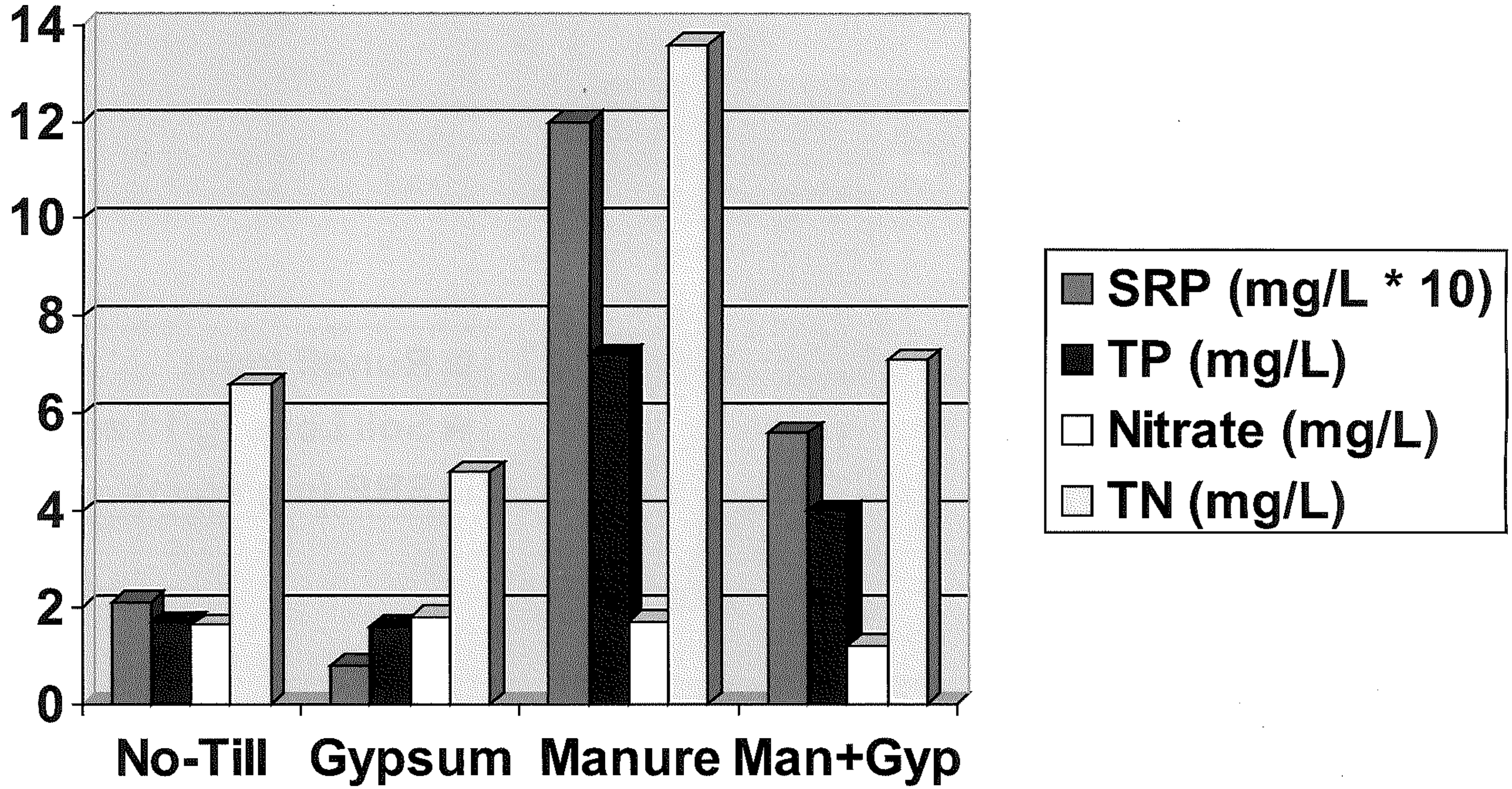
Detachment by Flow reduced by Gypsum+PAM



Effect of Gypsum on Erosion



Gypsum Effect on N and P



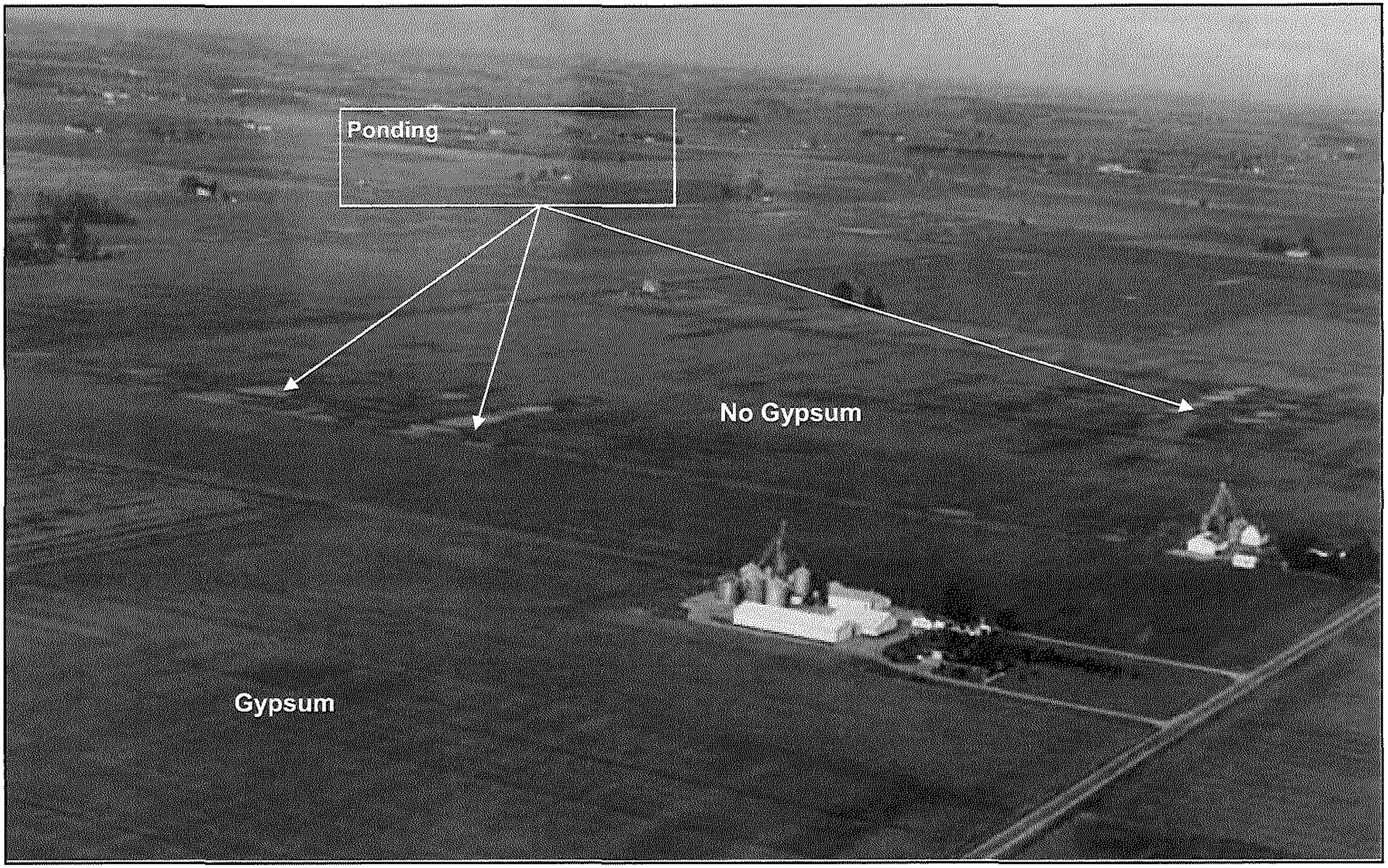
Conventional No-tillage on Vertisol in Villadiego, MX

No-Till System with Gypsum on Vertisol in Villadiego, MX

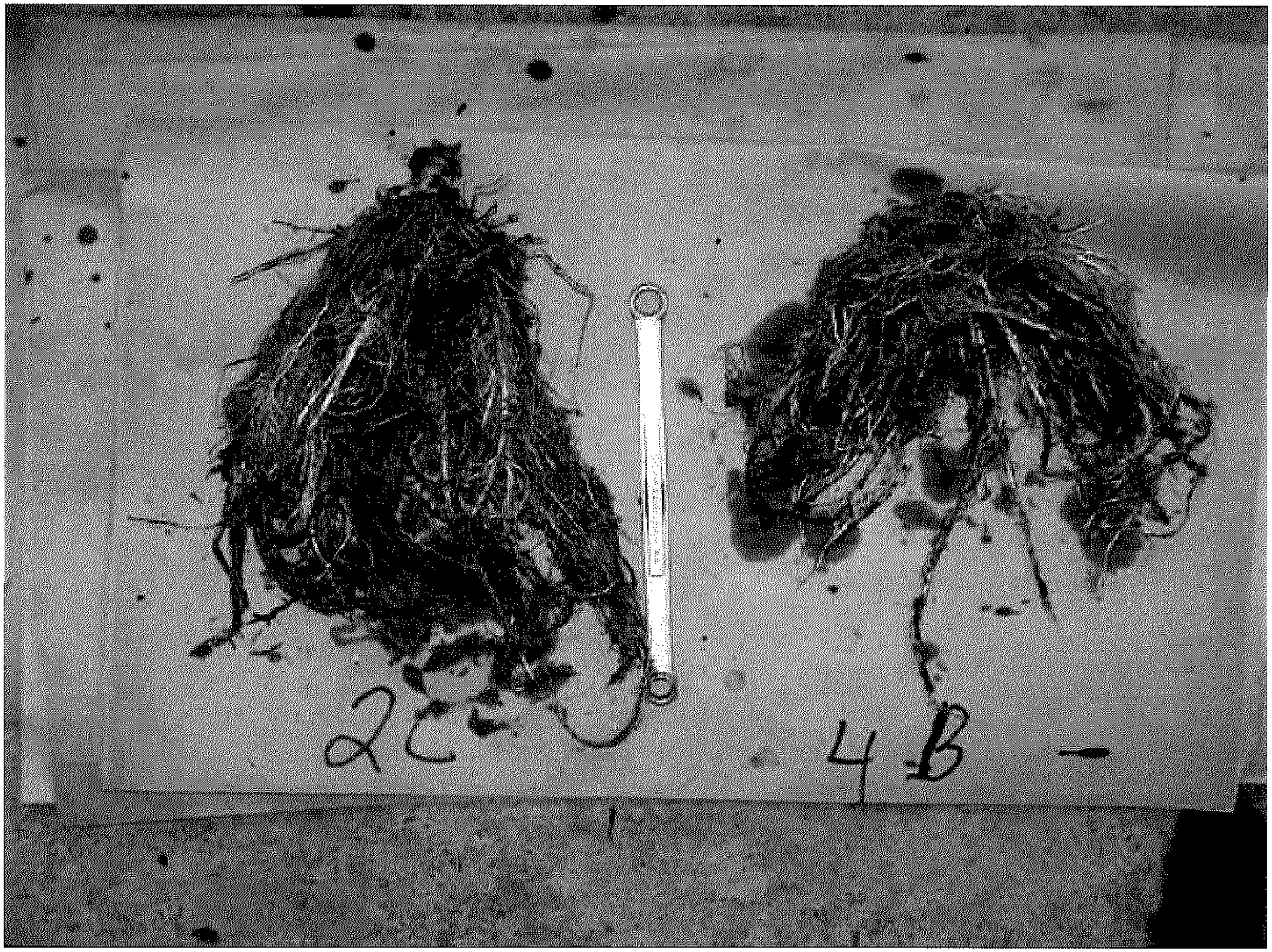
Vertisol with Severe Cracking (Control)

Vertisol Amended with Gypsum

Effect of Gypsum on infiltration/drainage on a Paulding clay



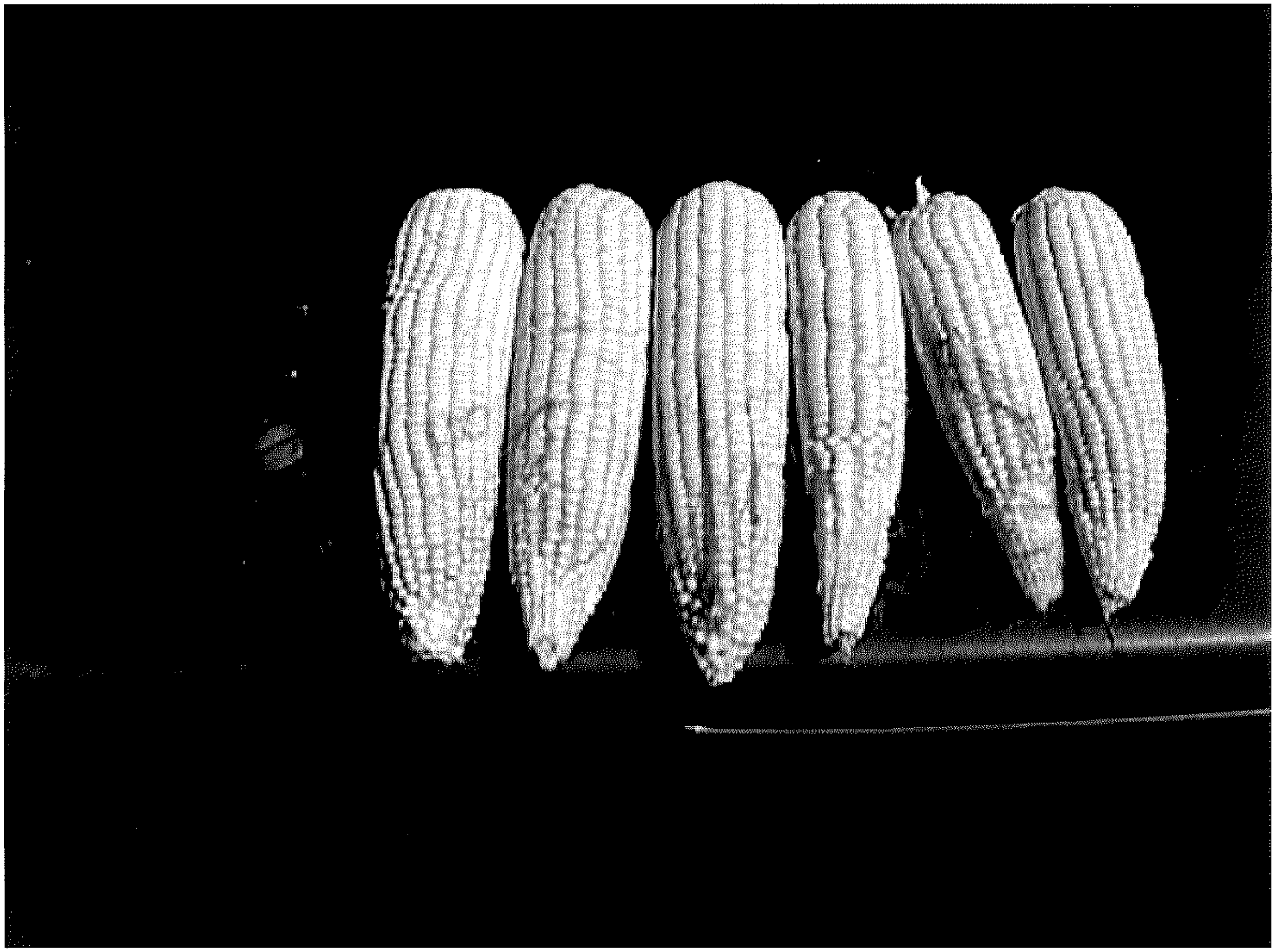
Root Biomass Increased



Gypsum Application on Left w/o on Right

Water Stress Reduced with Gypsum and PAM

Random Corn Ears Amended with Gypsum on Left and Control, Colorado



RCRA Total Elements in Materials Added (USEPA 3051)

Material	As	Ba	Cd	Cr	Hg	Pb	Se
	ppm	ppm	ppm	ppm	ppb	ppm	ppm
FGD #1	<1.3	22.2	0.39	7.2	0.1635	<0.77	3.5
FGD #3	1.4	20.4	0.55	6.8	0.2320	<0.77	<2.3
Mined Gypsum	<1.3	46.6	0.11	2.2	0.0001	<0.77	<2.3
Soil	9.4	170.8	1.47	30.3	0.0261	16.06	3.5

Hg in Plant Corn Tissue Kingman, 2008

Type	Trt	Hg (ppb)	S (ppm)	N(%)	C (%)
Ear Leaf	None	4.88	2245	2.99	44.20
Ear Leaf	2000 FGD	6.30	2855	2.84	43.16
Ear Leaf	2000 PG	4.51	2575	2.92	43.29
Stover	None	6.29	1159	0.73	44.15
Stover	2000 FGD	6.20	927	0.70	36.03
Stover	2000 PG	6.52	1185	0.73	44.21
Grain	None	2.31	1095	1.37	44.34
Grain	2000 FGD	3.22	1135	1.36	44.24
Grain	2000 PG	3.28	1129	1.33	44.06

Kingman, IN Hg in Water -60cm 2008

Date	Rate (lbs)	Product	pH	ppt Hg
7/18/2008	2000	FGD	7.11	17.09
7/23/2008	2000	FGD	7.53	19.54
7/18/2008	0	None	7.41	28.37
7/23/2008	0	None	7.8	67.98
7/18/2008	2000	Mined	7.29	65.32
7/23/2008	2000	Mined	6.8	18.96

Hg in Runoff Water Kingman, IN 2009

Plot	Trt	Hg Conc. ppt	Average
6	Control	18.6	12.24
10	Control	6.4	
15	Control	11.8	
1	6000 lb/ac Fly Ash	11.7	9.88
7	6000 lb/ac Fly Ash	10.2	
14	6000 lb/ac Fly Ash	7.8	
8	6000 lb/ac FGD	25.1	24.08
9	6000 lb/ac FGD	18.4	
11	6000 lb/ac FGD	28.7	

Hg uptake in Corn Shoots 6 after six weeks subjected to perched water table

Drainage condition	Treatment		Hg ppb	
Freely Drained	Control		4.57	a
	FGD Gypsum		3.75	a
	Glyphosate		6.43	a
	FGD Gyp.+Glyph.		4.13	a
Perched water table (-5cm)	Control		55.92	b
	FGD Gypsum		61.88	b
	Glyphosate		61.98	b
	FGD Gyp.+Glyph.		64.54	b

Conclusions

- FGD gypsum has a multitude of uses in agriculture
- Reduced soil erosion and runoff
- Improvement of physical properties
- Ca and S Fertility
- Improved water quality
- Potential for improved N and P efficiency
- FGD Gypsum has no significant uptake in corn on adverse potential to water quality for a poorly drained midwestern soil.
- Improved yields and sustainability of agriculture

Questions?

A FARMER'S PERSPECTIVE ON FGD GYPSUM

Jack Maloney

Beneficial Reuse of FGD Gypsum in Agriculture Applications

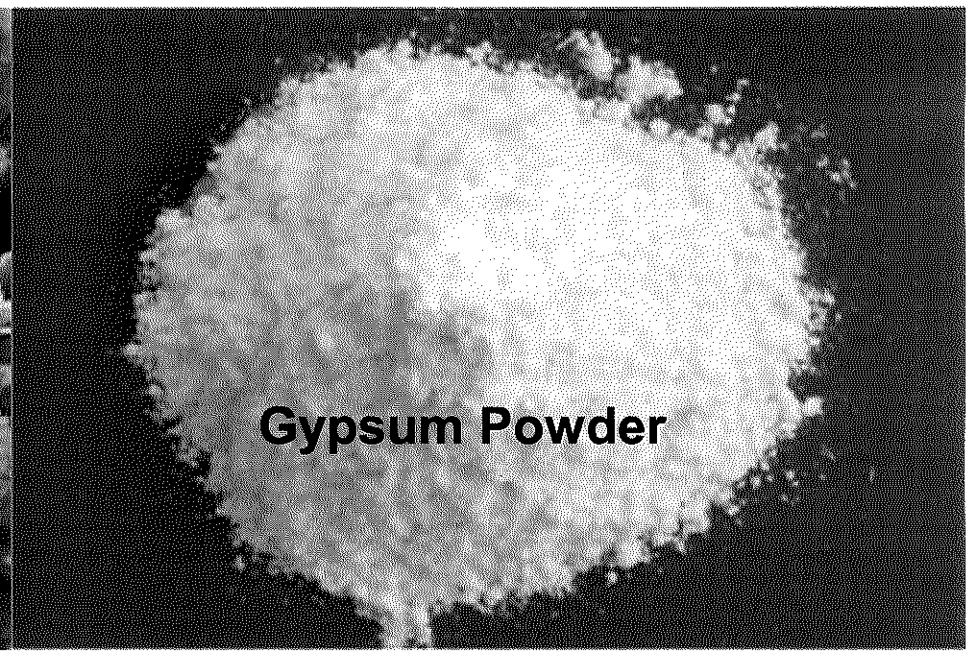
Questions?

SYNTHETIC GYPSUM AND AGRICULTURAL APPLICATIONS

Warren Dick and Dave Kost
School of Environment and Natural Resources
The Ohio State University, Wooster, OH

What is Gypsum?

Gypsum is a very soft mineral composed of calcium sulfate dihydrate, with the chemical formula $CaSO_4 \cdot 2H_2O$. The word gypsum is derived from a Greek word meaning "chalk" or "plaster". Because the gypsum from the quarries of the Montmartre district of Paris has long furnished burnt gypsum, this material has often been called plaster of Paris. Gypsum is water-soluble. The source of gypsum is both mined and synthetic.



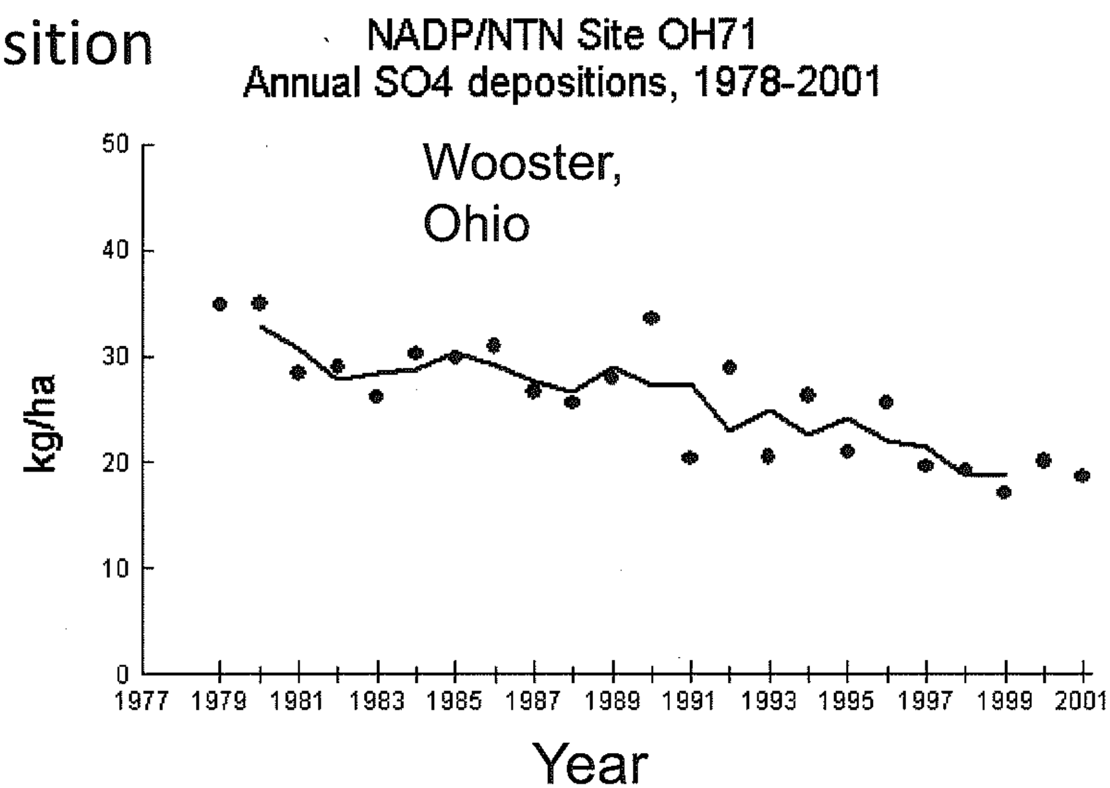
Summary of Gypsum and Benefits in Agriculture

- ❑Ca and S source for plant nutrition
- ❑Source of S and exchangeable Ca to ameliorate subsoil acidity and Al^{3+} toxicity
- ❑Flocculate clays to improve soil structure and reclaim sodic and high magnesium soils

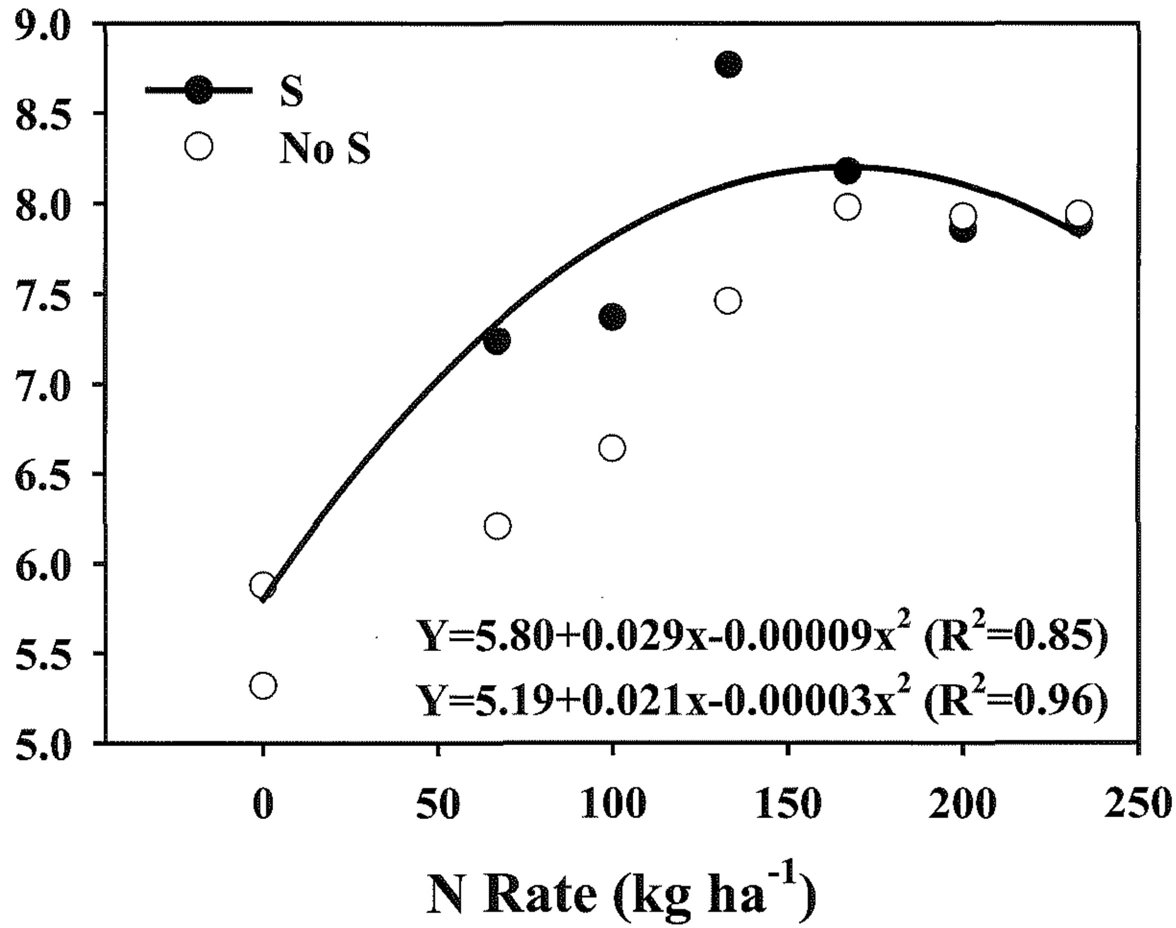
(Also as growth media component for mushroom production - approximately 60 kg/ton compost)

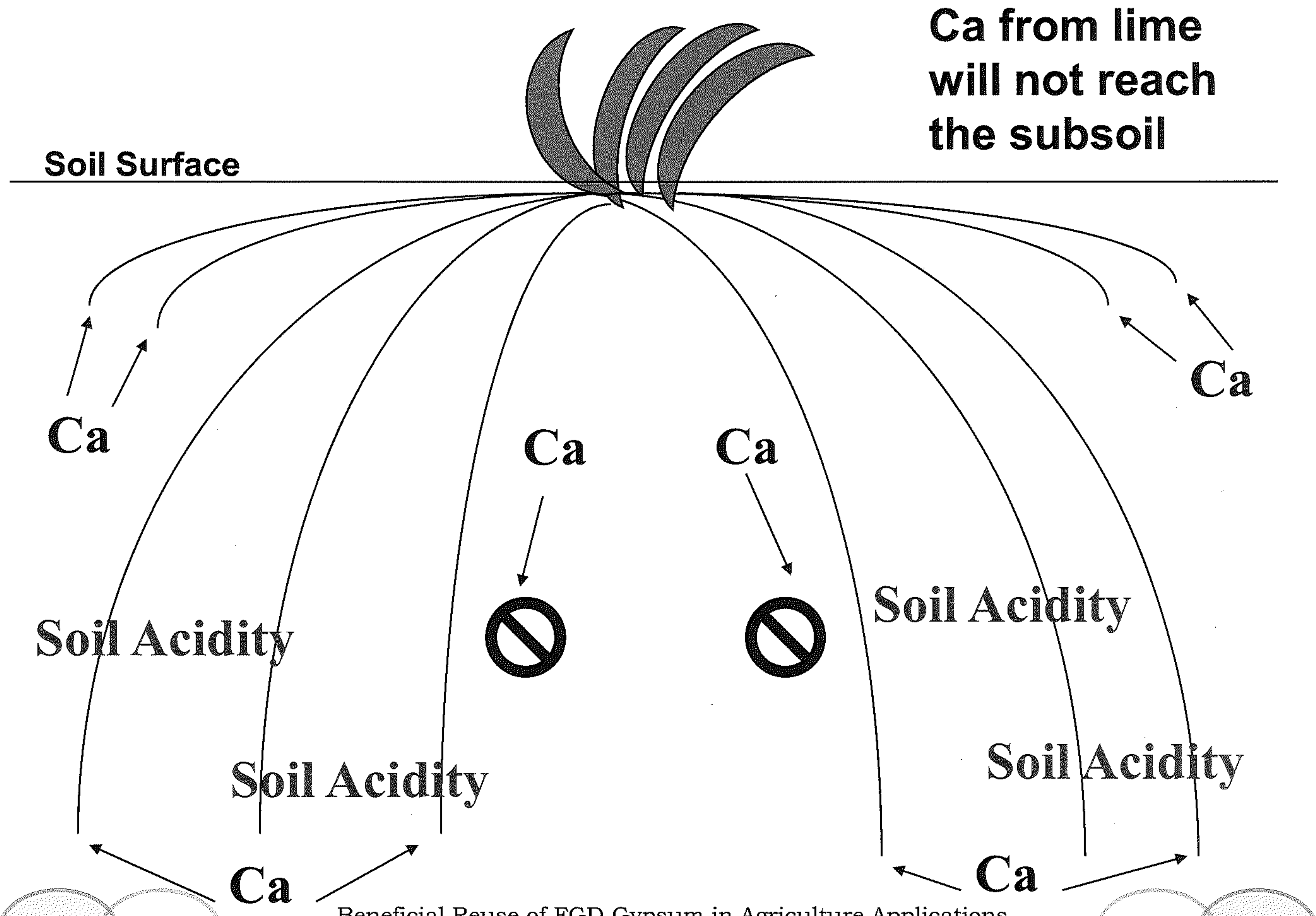
Reduction in Atmospheric S Deposition

- Increasing in importance as cause for crop S deficiencies
- Loss of soil organic matter
- Reduced annual S deposition
  - 34 kg/ha in 1971
  - 19 kg/ha in 2002

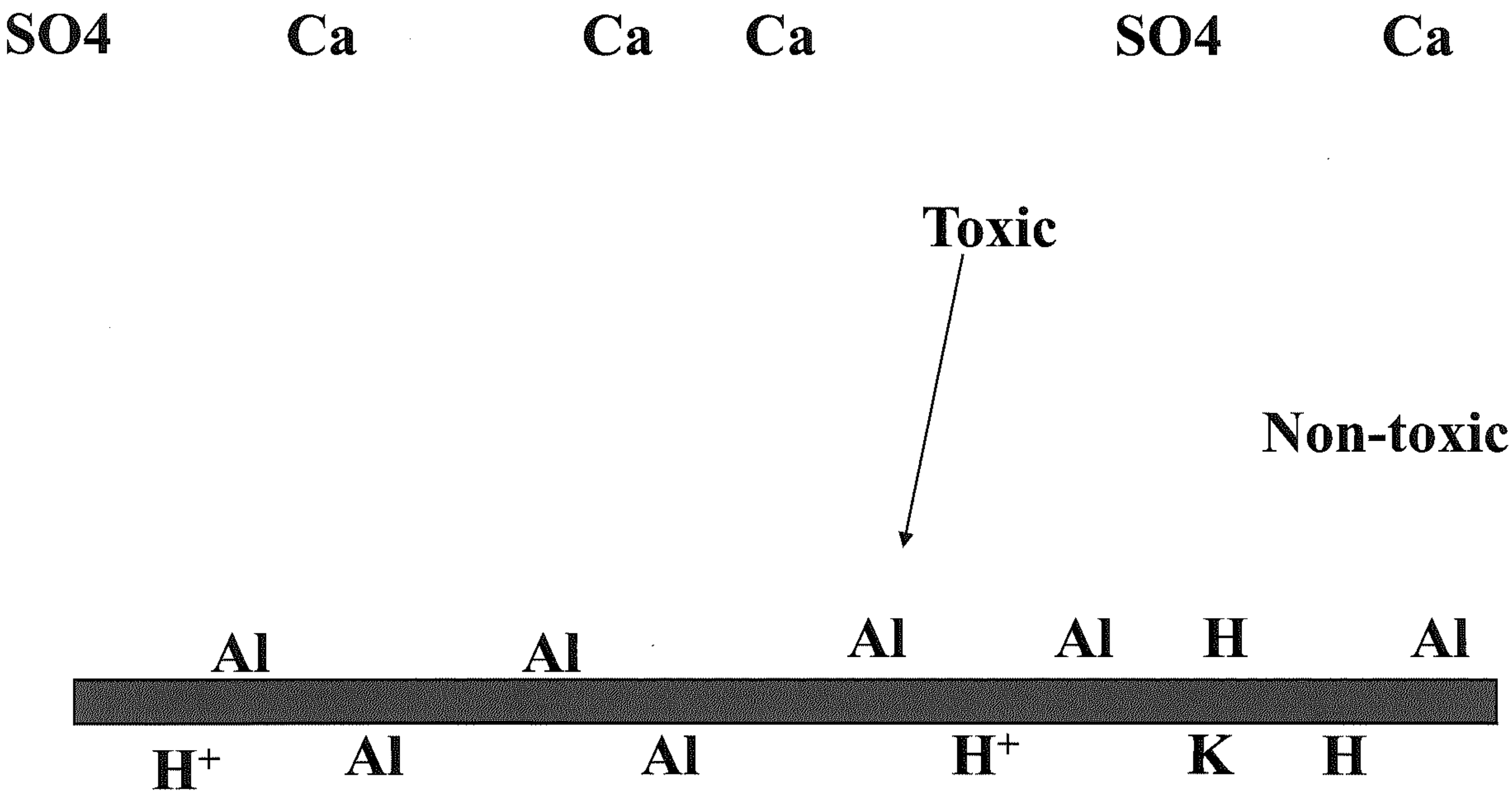


Average Corn Yields from 2002 to 2005 (Ohio, USA)



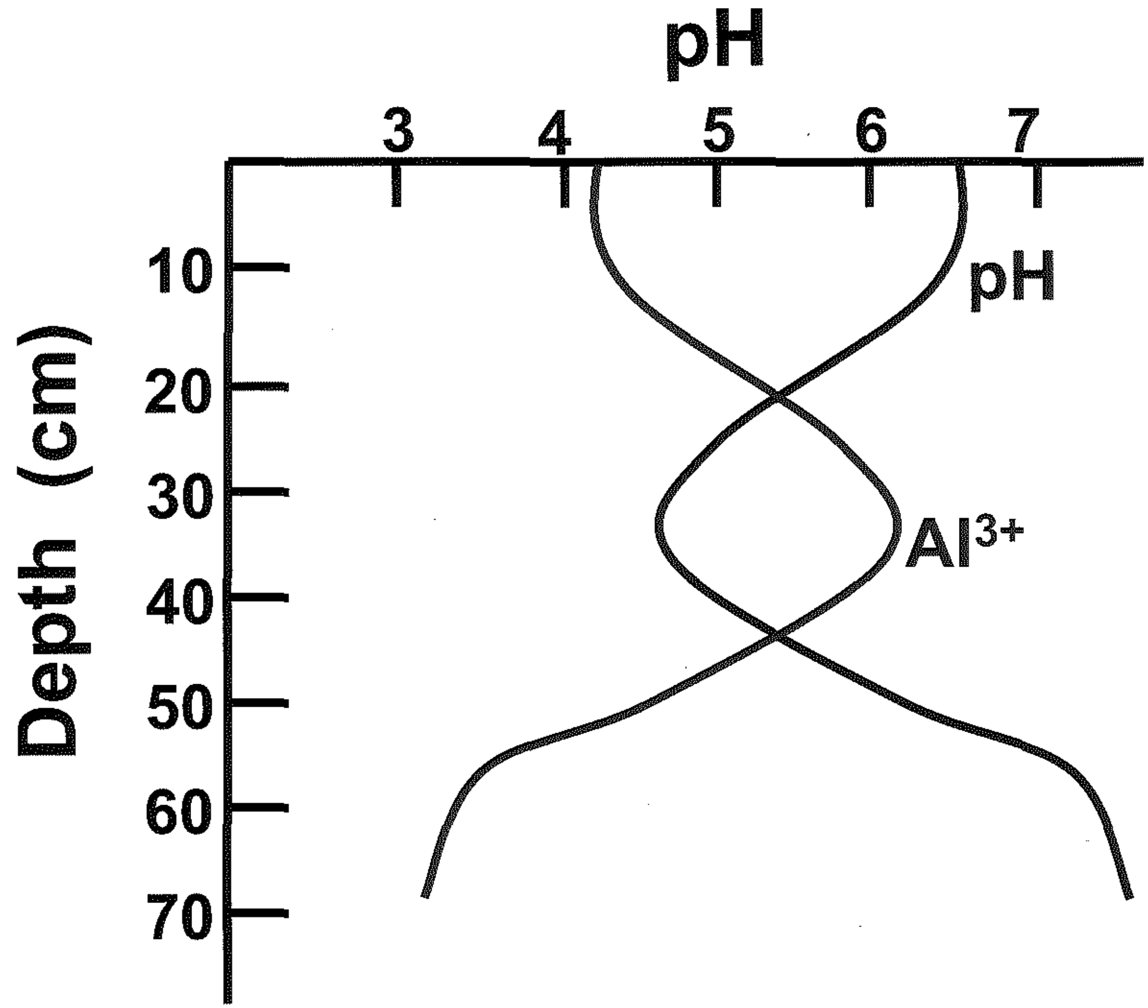

Ca from lime
will not reach
the subsoil
Soil Surface
Ca
Ca
Ca
Ca
Soil Acidity
Soil Acidity
Soil Acidity
Soil Acidity
Ca
Ca

Gypsum applied to surface of soil with acidic subsoil



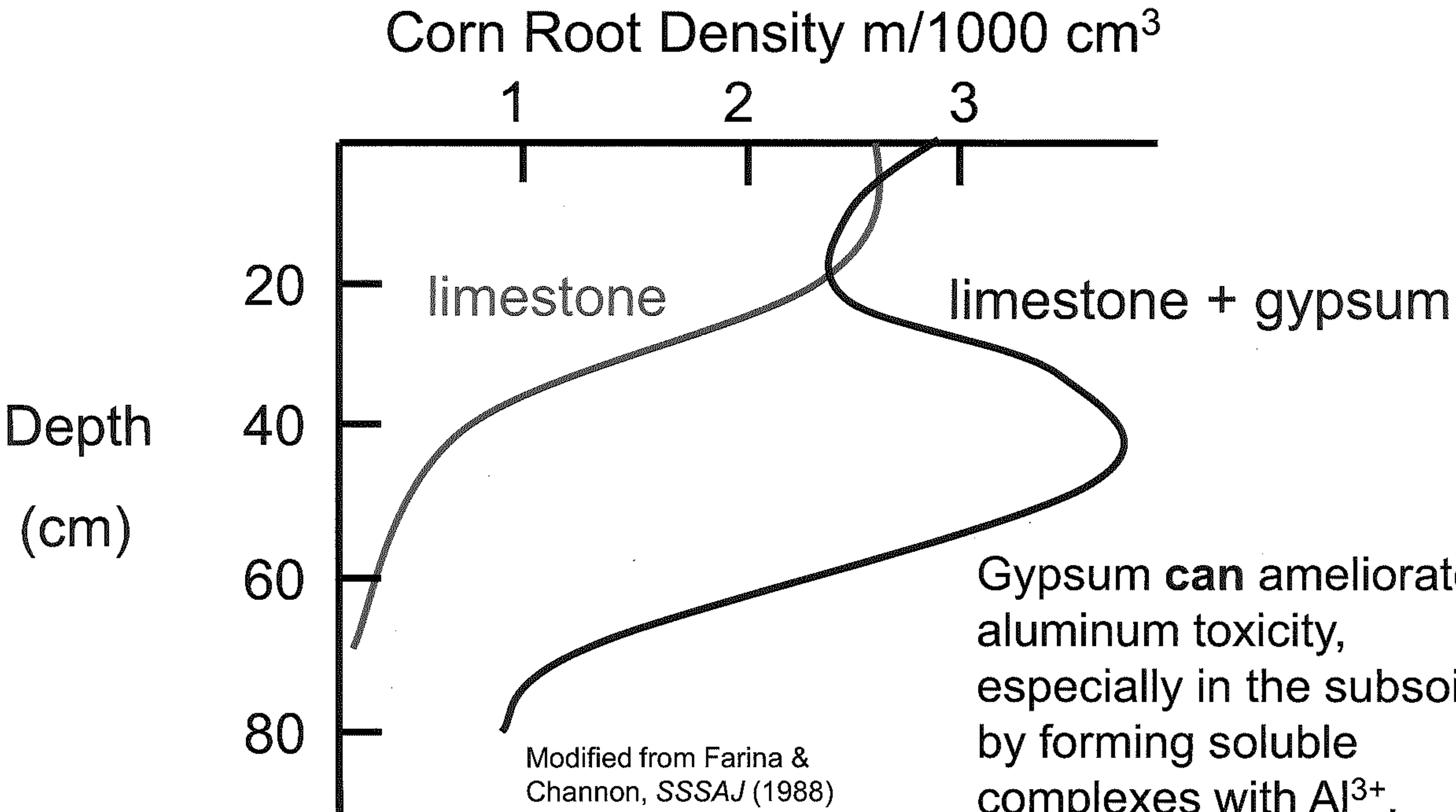
Clay platelet in subsoil

Typical pH profile for a Blount soil



$$CaSO_4 + Al^{3+} \longrightarrow Al(SO_4)^{+} + Ca^{2+}$$

(toxic) (non-toxic)



Modified from Farina & Channon, *SSSAJ* (1988)

Gypsum **can** ameliorate aluminum toxicity, especially in the subsoil, by forming soluble complexes with Al^{3+}.

Gypsum and Sodic Soil Reclamation in China

Comparison of field with (background) and without (foreground) FGD by-product gypsum

Development of Network for FGD Gypsum Use in Agriculture

Workshop

Research and Demonstration of Agricultural Uses of Gypsum and Other FGD Materials

November 17-19, 2009
Indianapolis, IN

http://www.oardc.ohio-state.edu/agriculturalfgdnetwork

Workshop sponsored by:

Combustion ByProducts Recycling Consortium (CBRC)

Electric Power Research Institute (EPRI)

The Ohio State University

U.S. Department of Energy/National Energy Technology Laboratory

November 4 (afternoon), Pittsburgh, PA
https://www.acsmeetings.org/

Development of Network for FGD Gypsum Use in Agriculture

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Agricultural Uses of Gypsum and Other Products from Flue Gas Desulfurization (FGD) Systems

Many crops can benefit from the addition of gypsum to the soil

- Demonstration of the agronomic value and environmental acceptability of FGD products in each participant's geographic area
- Development of the agricultural market for high volumes of FGD gypsum to complement the wallboard market
- Direct interaction with a wide range of interested parties--researchers, utilities, marketers, regulators, and agricultural specialists

Development of Network for FGD Gypsum Use in Agriculture

Deliverables

The following deliverables will be produced during this project.

- **On-site Research.** Site-specific research activities and reports. Network members are on the project steering committee.
- **Database.** All of the data collected will be maintained in a central database. Network members will have access to data via an OSU website.
- **Website.** OSU will maintain a website throughout the project to disseminate information to network members in a timely manner, supplemented by webcasts and conference calls.
- **Progress Reports.** Annual reports will detail progress and significant results. A comprehensive final report will detail all aspects and results from the project.
- **Specialty Reports.** Various reports on special interest topics (e.g., sulfur deficiency in soils, mined vs. natural gypsum) will be prepared throughout the project at the direction of the steering committee.
- **Workshops.** One workshop will be held each year to discuss project progress and technical topics.


Washington
Montana
North Dakota
Minnesota
Oregon
Idaho
Wyoming
South Dakota
Wisconsin
Michigan
Vermont
Maine
New Hampshire
New York
Massachusetts
Connecticut
Rhode Island
Nevada
Utah
Colorado
Nebraska
Iowa
Illinois
Indiana
Ohio
Pennsylvania
New Jersey
Delaware
Maryland
California
Kansas
Missouri
Kentucky
West Virginia
Virginia
Arizona
New Mexico
Oklahoma
Arkansas
Tennessee
North Carolina
South Carolina
Mississippi
Alabama
Georgia
Texas
Louisiana
Florida

Development of Network for FGD Gypsum Use in Agriculture

National Research and Demonstration Network of FGD Products in Agriculture

School of Environment and Natural Resources,
The Ohio State University Agricultural Research
& Development Center
Wooster, Ohio 44691-4096
Phone: (330) 263-3877
Fax: (330) 263-3788
e-mail:dick.5@osu.edu

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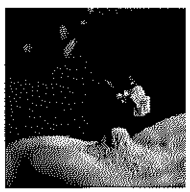
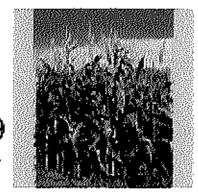
Long-term Gypsum Effects on Crop Yield



Gypsum application may increase crop yields for an extended time. Corn grain yields were increased by 29 to 50% and alfalfa yields by 70% in the 16th year after gypsum was applied a to coarse sandy loam soil in Georgia. The long-lasting beneficial effects of gypsum on crop yield enabled the expense of gypsum application to be amortized during an extended period of time. Soil Science Society of America Journal 63:891-895, July-August 1999.

No-tillage and Gypsum



Gypsum applications may promote the expansion of no-tillage crop production systems onto clay soils that have usually not been no-tilled because of compaction and aeration problems. Gypsum can increase water penetration and improve internal soil drainage because it dissolves quickly to release calcium that promotes the aggregation of soil clay particles.

http://www.oardc.ohio-state.edu/agriculturalfgdnetwork/

Development of Network for FGD Gypsum Use in Agriculture

Great River Energy - North Dakota

Public Service of New Mexico San Juan Generating Plant

Cinergy Cayuga Plant - Indiana

Entergy White Bluff Plant - Arkansas

TVA Widows Creek Fossil Plant - Alabama

Buckeye Power Cardinal Plant - Ohio

We Energies Pleasant Prairie Plant - Wisconsin

Great River Energy - North Dakota

North Dakota Study Description

2007 Wheat Yield Gary site

2007 Wheat Yield Wayne site

2007 Wheat Grain Chemistry Gary site

2007 Wheat Grain Chemistry Wayne site

2007 Soil Chemistry Gary site

2007 Soil Chemistry Wayne site

2007 Gypsum Chemistry

2008 Wheat Yield Gary site

2008 Wheat Yield Wayne site

2008 Wheat Grain Chemistry Gary site

2008 Wheat Grain Chemistry Wayne site

2008 Soil Chemistry Gary Site

2008 Soil Chemistry Wayne Site

Development of Network for FGD Gypsum Use in Agriculture

NORTH DAKOTA

Coal Creek Generating Station – Great River Energy

The Coal Creek Generating Station of Great River Energy (headquarters in Elk River, MN) is located near Underwood, ND. It is supporting research at two sites located about 8 miles south of Dickinson, ND. The soil at #1 (wayne) is classified as Lawther silty clay from the White River formation. This site has a slope of 0 to 2 percent and has been in wheat-fallow for greater than 20 years. The soil at #2 (gary) is classified as a Belfield-Daglum silt loam from the Golden Valley formation. This site has a slope of 0 to 2 percent and has been in a wheat-fallow rotation for greater than 10 years. Wheat crops were grown at both sites in 2007 and 2008 using no-till management. Yields, and soil and grain samples for chemical quality measurements were collected each year. Gypsum rates for both FGD gypsum and commercial gypsum were 0, 1, 5, and 10 tons/acre (0, 2.24. 11.2, and 22.4 Mg/ha).

Development of Network for FGD Gypsum Use in Agriculture

Great River Energy, North Dakota
Gary Site
2007 Wheat Grain Chemistry

Rep	Sample ID	Treatment tons/A	P µg/g	K µg/g	Ca µg/g	Mg µg/g	S µg/g
1	FGD 55	Check0	4113.3	4253.8	339.4	1691.6	1498.3
2	FGD 57	Check0	3943.9	4281.1	368.8	1681.7	1550.3
3	FGD 62	Check0	4440.8	4356.9	367.4	1856.8	1564.5
4	FGD 63	Check0	4178.1	4524.6	373.9	1856.4	1546.0
1	FGD 54	FGDGyp10	3585.9	3877.8	372.8	1593.0	1665.3
2	FGD 59	FGDGyp10	3978.7	4176.0	413.4	1761.4	1831.4
3	FGD 61	FGDGyp10	4102.5	4054.1	362.2	1836.8	1709.2
4	FGD 64	FGDGyp10	3450.6	3735.2	352.0	1611.8	1676.7
1	FGD 56	CommGyp10	3575.0	3857.3	388.9	1610.3	1791.0
2	FGD 58	CommGyp10	3686.6	4033.9	402.0	1676.2	1851.4
3	FGD 60	CommGyp10	3880.0	3904.2	396.4	1707.2	1823.6
4	FGD 65	CommGyp10	3926.6	4132.6	443.2	1775.1	1970.3

Rep	Sample ID	Treatment tons/A	As µg/g	Ba µg/g	Be µg/g	Cd µg/g	Co µg/g
1	FGD 55	Check0	<1.284	10.040	<0.091	<0.048	<0.146
2	FGD 57	Check0	<1.284	9.608	<0.091	<0.048	<0.146
3	FGD 62	Check0	<1.284	7.315	<0.091	<0.048	<0.146
4	FGD 63	Check0	<1.284	9.307	<0.091	<0.048	<0.146
1	FGD 54	FGDGyp10	<1.284	5.624	<0.091	0.051	<0.146
2	FGD 59	FGDGyp10	<1.284	4.702	<0.091	0.082	<0.146
3	FGD 61	FGDGyp10	<1.284	4.462	<0.091	0.138	<0.146
4	FGD 64	FGDGyp10	<1.284	6.135	<0.091	0.131	<0.146
1	FGD 56	CommGyp10	<1.284	5.279	<0.091	0.050	<0.146
2	FGD 58	CommGyp10	<1.284	5.816	<0.091	0.061	<0.146
3	FGD 60	CommGyp10	<1.284	3.340	<0.091	0.151	<0.146
4	FGD 65	CommGyp10	<1.284	4.380	<0.091	0.101	<0.146

Development of Network for FGD Gypsum Use in Agriculture

Al µg/g	B µg/g	Cu µg/g	Fe µg/g	Fe µg/g	Mn µg/g	Mo µg/g	Na µg/g	Zn µg/g
<6.985	<1.523	2.71	59.44	54.15	62.46	<0.225	<13.04	37.9
<6.985	<1.523	2.85	57.93	55.20	64.32	<0.225	<13.04	44.2
<6.985	1.61	3.35	61.16	58.85	63.90	<0.225	<13.04	50.9
<6.985	1.63	3.75	59.95	56.66	70.35	<0.225	<13.04	42.5
<6.985	<1.523	2.37	55.31	50.29	60.31	<0.225	<13.04	40.3
<6.985	<1.523	3.36	61.24	57.38	65.60	<0.225	<13.04	56.1
<6.985	1.68	3.09	55.81	51.56	70.12	<0.225	<13.04	49.6
7.83	<1.523	2.73	50.58	48.15	62.35	<0.225	<13.04	38.9
<6.985	<1.523	3.34	55.24	50.92	64.90	<0.225	<13.04	43.4
<6.985	<1.523	3.11	59.71	55.62	67.70	<0.225	<13.04	48.1
<6.985	2.23	2.91	55.58	53.27	70.52	0.69	<13.04	55.0
<6.985	<1.523	3.70	61.14	58.05	68.90	<0.225	<13.04	54.8

Cr µg/g	Li µg/g	Ni µg/g	Pb µg/g	Sb µg/g	Se µg/g	Si µg/g	Sr µg/g	V µg/g
<0.194	9.143	1.295	<0.774	<1.047	<2.321	71.329	2.153	<0.29
<0.194	9.796	1.222	<0.774	<1.047	<2.321	38.809	2.461	<0.29
<0.194	7.020	0.958	<0.774	<1.047	<2.321	50.585	2.419	0.37
<0.194	8.693	1.612	<0.774	<1.047	<2.321	54.973	2.370	<0.29
<0.194	4.823	1.443	<0.774	<1.047	<2.321	27.190	2.172	<0.29
<0.194	4.711	1.351	<0.774	<1.047	<2.321	45.508	2.619	<0.29
<0.194	4.143	1.215	<0.774	<1.047	<2.321	46.716	2.589	<0.29
<0.194	5.777	1.456	<0.774	<1.047	<2.321	38.387	2.233	<0.29
<0.194	4.963	1.204	<0.774	<1.047	<2.321	33.032	2.543	<0.29
<0.194	5.557	1.617	<0.774	<1.047	<2.321	35.137	2.273	<0.29
<0.194	<3.403	1.186	<0.774	<1.047	<2.321	32.761	2.263	<0.29
<0.194	4.570	1.474	<0.774	<1.047	<2.321	41.681	2.414	<0.29

Development of Network for FGD Gypsum Use in Agriculture

Rep	Treatment tons/A	%Nitrogen	%Carbon	%Sulfur	Hg ppb or ng/g
1	Check0	2.65	43.70	0.237	2.161
2	Check0	2.83	43.46	0.284	3.655
3	Check0	2.86	43.36	0.268	1.096
4	Check0	2.77	44.06	0.242	1.276
1	FGDGyp10	2.69	43.52	0.315	1.415
2	FGDGyp10	2.86	43.42	0.300	1.297
3	FGDGyp10	2.84	43.69	0.308	1.086
4	FGDGyp10	2.66	43.54	0.265	2.169
1	CommGyp10	2.85	43.61	0.299	1.719
2	CommGyp10	2.88	43.54	0.295	1.420
3	CommGyp10	3.09	43.81	0.383	2.123
4	CommGyp10	2.91	43.37	0.309	0.905

Treatment Descriptions
Check0 = No gypsum applied
FGDGyp10 = FGD gypsum at 10 tons/A
CommGyp10 = Commercial gypsum at 10 tons/A

Earthworm Study

Earthworm Study

Concentrations of elements in the FGD gypsum and mined gypsum used

Element	FGD gypsum	Mined gypsum
	------------------ mg kg^{-1} ------------------	
P	<0.98	19
K	<75	560
Ca	87900	104400
Mg	600	15100
S	184000	110000
Al	140	1390
B	2.2	7.0
Cu	3.3	<0.38
Fe	334	1850
Mn	3.9	95
Mo	0.70	0.70
Na	<13	1280
Zn	4.7	12
As	<1.3	<1.3
Ba	31	60
Be	<0.09	<0.09
Cd	0.16	0.16
Co	<0.15	<0.15
Cr	1.8	3.4
Hg	0.3761	0.0027
Li	11	35
Ni	0.88	2.3
Pb	<0.77	<0.77
Sb	4.6	3.5
Se	<2.3	<2.3
Si	176	857
Sr	67	557
Ti	<1.4	<1.4
V	2.4	5.7

Earthworm Study

Effects of gypsum on concentrations of elements in soil in 2008

Element	Treatment		
	Control	FGD gypsum	Mined gypsum
	mg kg^{-1}		
P	605	588	591
K	5560	5330	5540
Ca	1690 c	6490 b	13200 a
Mg	3040 b	2920 b	4720 a
S	484 b	4260 a	5620 a
Al	26500	25900	26000
B	15	15	15
Cu	9.3	9.4	8.3
Fe	20300	19900	19500
Mn	922	879	857
Mo	1.3	1.2	1.1
Na	223	214	241
Zn	99	96	95
As	11	9.0	9.8
Ba	186	180	188
Be	<0.05	<0.05	<0.05
Cd	1.02	1.01	0.97
Co	11.3 a	10.7 b	10.4 b
Cr	31	30	30
Hg	0.057	0.066	0.061
Li	172	165	172
Ni	19 a	19 a	18 b
Pb	19	18	18
Sb	<0.52	<0.52	<0.52
Se	4.2	3.0	4.3
Si	355	417	373
Sr	29 b	28 b	86 a
Ti	<0.72	<0.72	<0.72
V	53	51	51

Means in a row followed by different letters are significantly different at $P \leq 0.05$.

Earthworm Study

Effects of gypsum on concentrations of elements in plant tissue from the second harvest in 2008.

Element	Treatment		
	Control	FGD gypsum	Mined gypsum
	mg kg^{-1}		
P	605	588	591
K	5560	5330	5540
Ca	1690 c	6490 b	13200 a
Mg	3040 b	2920 b	4720 a
S	484 b	4260 a	5620 a
Al	26500	25900	26000
B	15	15	15
Cu	9.3	9.4	8.3
Fe	20300	19900	19500
Mn	922	879	857
Mo	1.3	1.2	1.1
Na	223	214	241
Zn	99	96	95
As	11	9.0	9.8
Ba	186	180	188
Be	<0.05	<0.05	<0.05
Cd	1.02	1.01	0.97
Co	11.3 a	10.7 b	10.4 b
Cr	31	30	30
Hg	0.057	0.066	0.061
Li	172	165	172
Ni	19 a	19 a	18 b
Pb	19	18	18
Sb	<0.52	<0.52	<0.52
Se	4.2	3.0	4.3
Si	355	417	373
Sr	29 b	28 b	86 a
Ti	<0.72	<0.72	<0.72
V	53	51	51

Means in a row followed by different letters are significantly different at $P \leq 0.05$.

Earthworm Study

Effects of FGD gypsum on the number and biomass of earthworms

Site	Treatment	Earthworm number	Biomass
		m^2	g/m^2
Ohio	Control	233 a	14.9 a
	FGD gypsum	115 b	5.0 b
	Mined gypsum	144 b	5.3 b
Alabama	Control	46	6.4
	FGD gypsum	13	1.4
	Mined gypsum	36	6.2
Wisconsin	Control	125	17.2
	FGD gypsum	121	12.7
	Mined gypsum	117	12.5

Earthworm Study

Effects of gypsum on concentrations of elements in earthworm tissue in 2008

Element	Treatment		
	Control	FGD gypsum	Mined gypsum
	------------------------------mg kg^{-1} ------------------------------		
P	7380	10900	8510
K	6780	9380	6990
Ca	3650	6310	13700
Mg	1460	1350	3380
S	6190	10500	11000
Al	5190 a	3160 b	6270 a
B	3.1 ab	2.5 b	4.4 a
Cu	9.5	12	11
Fe	5460 ab	3770 b	6200 a
Mn	279 a	174 b	347 a
Mo	0.55	0.94	0.79
Na	2750	3960	2820
Zn	433	732	589
As	5.6	6.7	8.0
Ba	38 ab	33 b	53 a
Be	<0.09	<0.09	<0.09
Cd	11	17	19
Co	6.0	5.8	7.2
Cr	6.9 ab	5.0 b	8.4 a
Hg	0.79	1.11	0.94
Li	36 ab	31 b	48 a
Ni	5.8 ab	4.7 b	6.8 a
Pb	7.4 ab	6.6 b	10 a
Sb	<1.1	<1.1	<1.1
Se	10	31	28
Si	160	262	192
Sr	12	9.7	62
Ti	<1.4	<1.4	<1.4
V	12 a	9.2 b	14 a

Means in a row followed by different letters are significantly different at $P \leq 0.05$.

THANK YOU!

RISK ASSESSMENT FOR USE OF FGD GYPSUM IN AGRICULTURE

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Old vs. New FGD-Gypsum

- Old FGD-Byproduct contained much of the elements in fly ash, such that B, As, Se, etc. were a source of concern depending on the coal source used.
  - Used at limestone rate for alfalfa, FGDB supplied B, Ca, alkalinity and Se that served as fertilizers without causing excessive transfer of toxics to crops.
- New FGD-Gypsum produced post fly ash removal contains very low levels of all trace elements.
  - Difficult to find potential adverse effects of constituents of present high quality FGD-Gypsum.

Alternative Beneficial Uses: FGD-Gypsum

- Calcium fertilizer for peanuts, etc.
- Sulfate fertilizer for many crops.
- Improve water infiltration.
  - Reduce soil erosion/crusting.
- Reduce P runoff by Ca precipitation.

Pathways for Risk Assessment of Elements in Soils, and Highly Exposed Individuals-1.

Pathway	Highly Exposed Individual
• 1. Soil➔Plant➔Human	Farm markets; 2.5% of food
• 2. Soil➔Plant➔Human	Home gardens; 60% of garden foods for lifetime; 1000 t/ha
• 3. Soil➔Human	200 mg/day soil/dust ingestion; 1000 t/ha
• 4. Sol ➔Plant➔Animal➔Human	Farms; 45% home-grown meat; 1000 t/ha
• 5. Soil➔Animal➔Human	Grazing ruminants; soil is 2.5% of annual diet; 45% home-grown meat.
• 6. Soil➔Plant➔Animal	100% of livestock feeds grown on soils;
•	1000 t/ha
• 7. Soil➔Animal	Grazing ruminants; 2.5% soil in diet.

Pathways for Risk Assessment of Elements in Soils, and Highly Exposed Individuals-2.

Pathway	Highly Exposed Individual
8. Soil→Plant	Sensitive crops; strongly acidic; 1000 t/ha.
9. Soil→Soil Biota	Earthworms; microbes; metabolic function of soil; 1000 t/ha.
10. Soil Biota→Soil Biota Predator	Shrews; 1/3 of diet presumed to be earthworms full of Soil; 1000 t/ha
11. Soil→Airborne Dust→Human	Tractor operator; 1000 t/ha.
12. Soil→Surface water→Human	Subsistence fishers.
13. Soil→Air→Human	Farm households
14. Soil→groundwater→Human	Well water on farms.

Complex Equilibria of Metal Ions with Components of Soil Environments

Chelated to Organic Matter
Humics; fulvics

Plant Shoots

Plant Roots

Adsorbed on Fe/Mn

Soil Solution

$Ni^{2+} + L \leftrightarrow NiL$

Soil Microbes

Occluded in Fe/Mn oxides

Inorganic Solids

$Ni(OH)_2$ Ni-Silicate
NiO Ni-Al-hydroxide

L = Ligands
Organic
Inorganic

Soil-Plant Barrier

PROCESSES IN SOILS OR PLANTS THAT PREVENT EXCESSIVE FOOD-CHAIN TRANSFER OF ELEMENTS

- Insolubility or adsorption in soil or plants roots:
  - Cr, Pb, Fe, Hg, Sn, Au, Ag, Zr, Al, F, Ti, etc.
- Phytotoxicity limits plant yield at levels which are not toxic for lifetime consumption by livestock:
  - Zn, Cu, Ni, As, Mn, B, etc.
- Exceptions to Soil-Plant Barrier:
  - Cd, Se possible risk to humans
  - Mo, Se, (Co) possible risk to livestock
- Barrier can be circumvented by direct ingestion of biosolids; **Volatilization of Hg is separate risk.**
  - Fe, F, Pb, As, Hg may comprise risk in high on surface.

Use of 503 Limits for Materials Other Than Biosolids

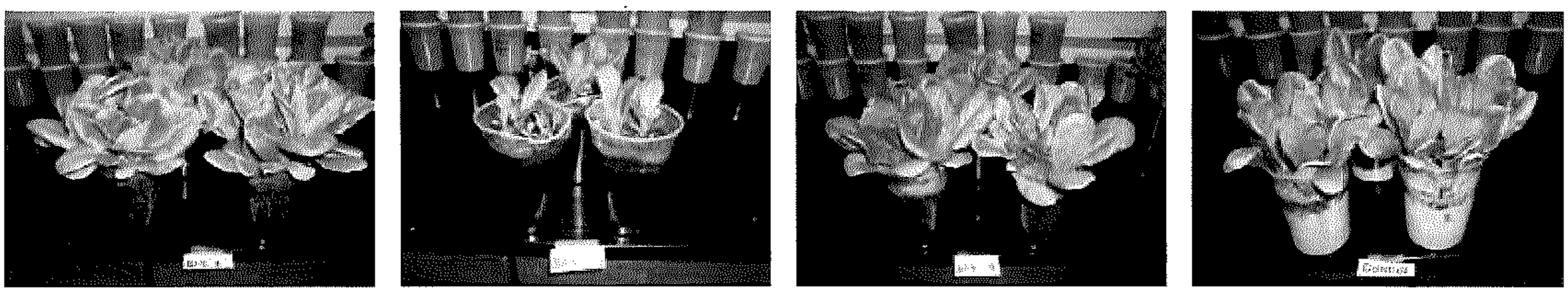
- In the absence of regulations for other materials, some have used the 503 limits.
- Should never consider use of Ceiling Limit.
- APL limit might be acceptable if other elements are not source of risk and material is applied at low fertilizer rates.
- Biosolids contain adsorptive materials (Fe oxides) which lower risk of applied metals; field derived plant uptake factors needed for other materials.
- Other elements may be more important than for biosolids, e.g., Boron
- High pH due to source may affect risk (Se, Mo).

Risk Assessment for Beneficial Use of Spent Foundry Sand

- USDA-ARS and Ohio State worked with US-EPA to conduct a risk assessment for beneficial use of spent foundry sand in agricultural applications.
  - Manufactured soil assumed to contain 50% by weight Spent Foundry Sand (SFS) as lifetime home garden for soil and garden crop exposure.
  - The Risk Assessment was completed in 2009, and is now undergoing external EPA Peer Review.
  - Errors in use of the EPA Exposure Factors Handbook for risk assessment would have limited soil As, but correction of garden foods intake database use gave unlimited beneficial use of SFS with 12 ppm As.
  - 95^{th} %ile of background soil as practical element limit; SFS contained lower levels of elements than US soils.

USDA/OSU SFS Characterization

- **Spent foundry sand characterization**
  - 43 Samples from 37 foundries in 13 states
  - 31 iron, 6 steel, 4 aluminum and 2 non-leaded brass
  - Total metals, leachable metals, phenolics, PAHs (includes dioxins, furans, dioxin-like PCBs)
- **Effects on plants/soil biota**
  - Importance of good agronomic practices (e.g. soil pH appropriate for plants)



Scope of Risk Evaluation

Evaluated Non-olivine molding sands from iron, steel, and aluminum foundries.

- Not Evaluating Olivine Sands
  - Insufficient data
  - Olivine contains about 2000 ppm Ni which can dissolve is soils become strongly acidic.
- Excluded SFS from foundries that cast alloys that are high in Co, Cr, Cu, Ni, Pb, and Zn (e.g. stainless steel, brass, bronze, pewter)

Evaluation Steps

- Obtain SFS-specific data
  - Trace elements at low detection limits.
  - Xenobiotics likely to be present.
  - Nutrients.
- Review SFS-specific data
  - Constituents, properties
  - Environmental behavior (e.g. plant survival/uptake)
- Develop/Choose Conceptual Model
- Screen out exposure pathways, constituents
- Model remaining pathways, constituents
- Characterize risk w/in context of soil science
- Conclusions

Screening / Modeling

Inhalation of Fugitive Dust

- Resident Downwind of Soil Blending Facility
- Conservative estimate of particulate concentrations
- Calculated screening values

Results: All SFS concentrations at least order of magnitude below screening values

Screening / Modeling (cont.)

Leaching to Groundwater: Screening constituents

—Compared SFS leachate to MCLs, NSDWSs

—Presumed soil contained 50% SFS by dry weight and comprised large soil area.

Results: Screened out phenolics, PAHs, dioxins/furans/dioxin-like PCBs, most metals.

- As, (*Be, Cd, Sb*) remained for further study

Screening / Modeling (cont.)

- **Leaching to Groundwater: Modeling**
  - **10,000 runs of probabilistic model (IWEM)**
  - **High-end exposures compared to MCLs**
  - **Results: all exposure** conc. estimates below benchmarks.

Screening / Modeling (cont.)

Home gardener - ingestion of produce, soil: screening constituents

- Soil assumed to be 50% SFS and large enough to provide garden foods to high end hime gardener.
- Compared soil conc. to human and ecological Soil Screening Levels.
- Results: phenolics, PAHs, dioxin/furan/dioxin-like PCBs, most metals screened out.
  - As, Mn, Ni, Pb remained for further study

Screening / Modeling (cont.)

Ingestion of Produce & Soils: Modeling Home Gardener

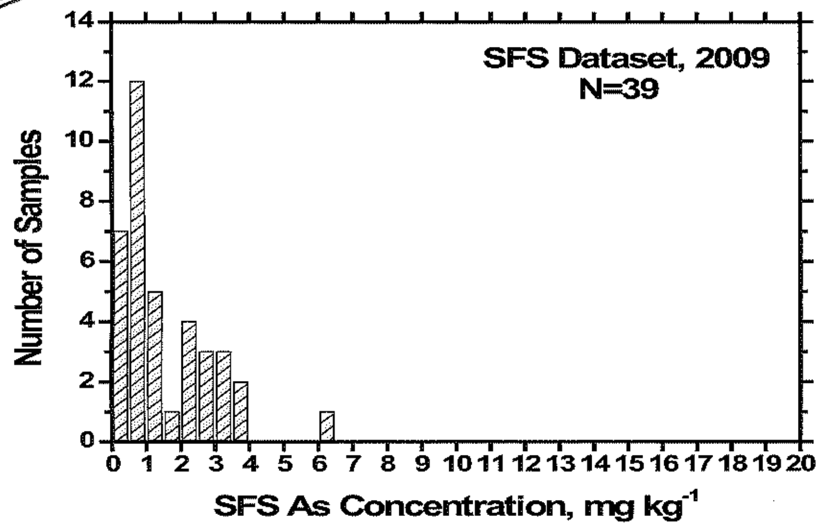
- EPA's Biosolids Methodology.
- Probabilistic Model Runs for 1 mg/kg.
- Used high-end hazard estimates to calculate <u>conservative</u> screening values
- Compared high-end SFS concentrations to screening values

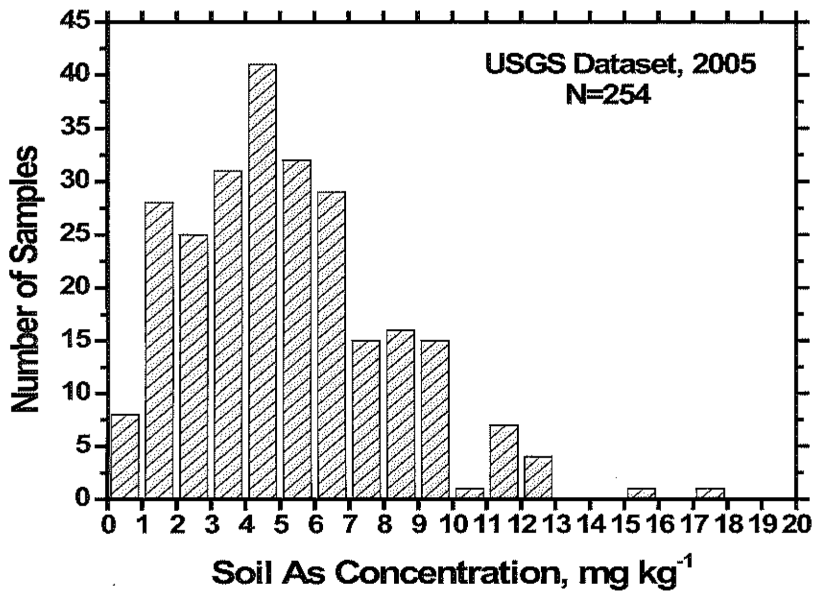
Results: SFS concentrations below screening values

Soil Background

- SFS media similar to natural soils.
- As, Co, Fe, Mn, and Ni all have similar distributions to national soils, usually lower.
- Example: As 95^{th} percentile in SFS is lower than median of national background.

Comparing As in Spent Foundry Sand and US Soils





SFS:

95th %ile : 4.1

50th %ile: 1.1

US Background Soils:

95th %ile: 12

50th %ile: 5

Conclusions for SFS

- **Non-Olivine Iron, Steel, and Aluminum Spent Foundry Sands:**
  - Have constituent concentrations similar to that of native soils
  - Do not pose a threat to human health or the environment when used:
    - As an ingredient in manufactured soils used at 50% of dry weight of home garden soil.
    - As an ingredient in soil-less media
    - In roadway sub-base

Table 7-1: Comparing SFS Concentrations to Various Screening Values (mg kg^{-1}, unless otherwise noted)

Element †	Max	95%tile	Median	Human Screening Values[a]				Eco Screening Values			U.S. and Canadian surface soils ‡		
				SSL[b]	Modeled[c] HG	Modeled[c] GP50	Modeled[c] GP90	Eco-SSLs[b]	Modeled	USDA[d]	Max	95%tile	Median
Al (g/kg)	11.7	10.6	5.56	78	-	-	-	-	-	-	87.3	74.6	47.4
As[e]	7.79	4.11	1.05	4.3	8	20	11	18	37	-	18	12	5
B	59.4	11.0	10.0	16,000	-	-	-	-	-	-	N/A	N/A	N/A
Ba	141	6.27	5.00	16,000	-	-	-	330	-	-	1800	840	526
Be	0.60	0.37	0.15	160	-	-	-	40	-	-	4.0	2.3	1.3
Cd	0.36	0.19	0.05	78	-	-	-	32	-	-	5.2	0.6	0.2
Co	6.62	5.89	0.88	23	-	-	-	13	-	-	143.4	17.6	7.1
Cr (III)	115	96.5	4.93	120,000	-	-	-	-	-	-	5320	70	27
Cu	137	90.1	6.22	3,100	-	-	-	70	-	200	81.9	30.1	12.7
Fe (g/kg)	64.4	55.8	4.26	55	-	-	-	-	-	-	87.7	42.6	19.2
Mn	707	501	54.5	3,900	1,034	4,158	1,334	220	440	-	3,120	1,630	490
Mo	22.9	19.9	0.50	390	-	-	-	-	-	-	21	2.16	0.82
Ni	117	83.5	3.46	1,600	259	1,308	361	38	77	100	2,314	37.5	13.8
Pb	22.9	9.29	3.74	400	-	-	-	120	240	-	244.6	38.0	19.2
Sb	1.71	1.06	0.17	31	-	-	-	78	-	-	2.3	1.39	0.60
Se	0.44	0.20	0.20	390	-	-	-	0.52	-	-	2.3	1.0	0.3
Tl	0.10	0.09	0.04	5.1	-	-	-	-	-	-	1.8	0.7	0.5
V	11.3	9.12	2.88	550	-	-	-	-	-	-	380	119	55
Zn	245	64.5	5.00	23,000	-	-	-	120	-	300	377	103	56

† Dayton et al (in review)

‡ Smith et al 2005, A Horizon

[a] For some constituents, no health benchmark was available upon which to base screening value.

[b] Recall that concentrations in the blended soils, and not concentrations in SFS, were examined with relation to the SSLs listed here. Human ingestion SSLs are from the EPA Regional Screening Tables http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm and soild concentrations were compared to an order of magnitude below. (Unless otherwise noted, all human values are based on non-carcinogenic impacts.) Eco-SSLs are either for plants or soil invertibrates (whichever is lower) as taken from http://www.epa.gov/ecotox/ecossl/

[c] HG = Home Gardener Scenario, GP50/GP90 = General Population with the 50^{th} and 90^{th} percentile consumption rates, respectively

[d] See Appendix C. Explanation of USDA Eco Screening Values for Cu, Ni, and Zn.

[e] Arsenic human screening values based on carcinogenic risk, set at the OSWER-standard 1×10^{-5} risk target level.

Composition of Old CCPs (mg/kg)

	MN	23 Fly Ash			59 FGDs		
	Dowdy	Furr et al., 1977			Kost et al., 2005		
		Mean	Min	Max	Mean	Min	Max
B	824.	255.	10.	600.	145.	68.	948.
Mo	7.4				8.6	<0.02	63.7
Se		8.4	1.2	17.	3.6	2.7	23.0
As		85.6	2.3	312	75.	5.2	386.
Cd	<0.5				2.3	<0.5	40.7
Zn	33.9				119.	5.0	469.
Cu	52.4				177.	13.3	1490.
Ni	16.9				33.0	12.4	156.
Pb	22.7				11.3	5.0	139.
Cr	32.7				16.9	11.4	89.3

Trace Elements in Gypsum and Soils

Element	FGD-Gypsum	Mined-Gypsum	95%ile Soil
• As	3.4	<2.6	12.
• B	42.4	<3.0	.
• Cd	1.2	0.2	0.6
• Co	1.0	0.3	17.6
• Cr	13.2	5.1	70.
• Cu	<0.8	<0.8	30.1
• Mo	1.8	0.6	2.16
• Ni	5.0	2.3	37.5
• Pb	2.1	<1.5	38.0
• Se	18.8	<4.6	1.0
• Zn	16.5	4.3	103.

OSU preliminary dataset from EPRI.

Present Considerations of As Limit at US-EPA

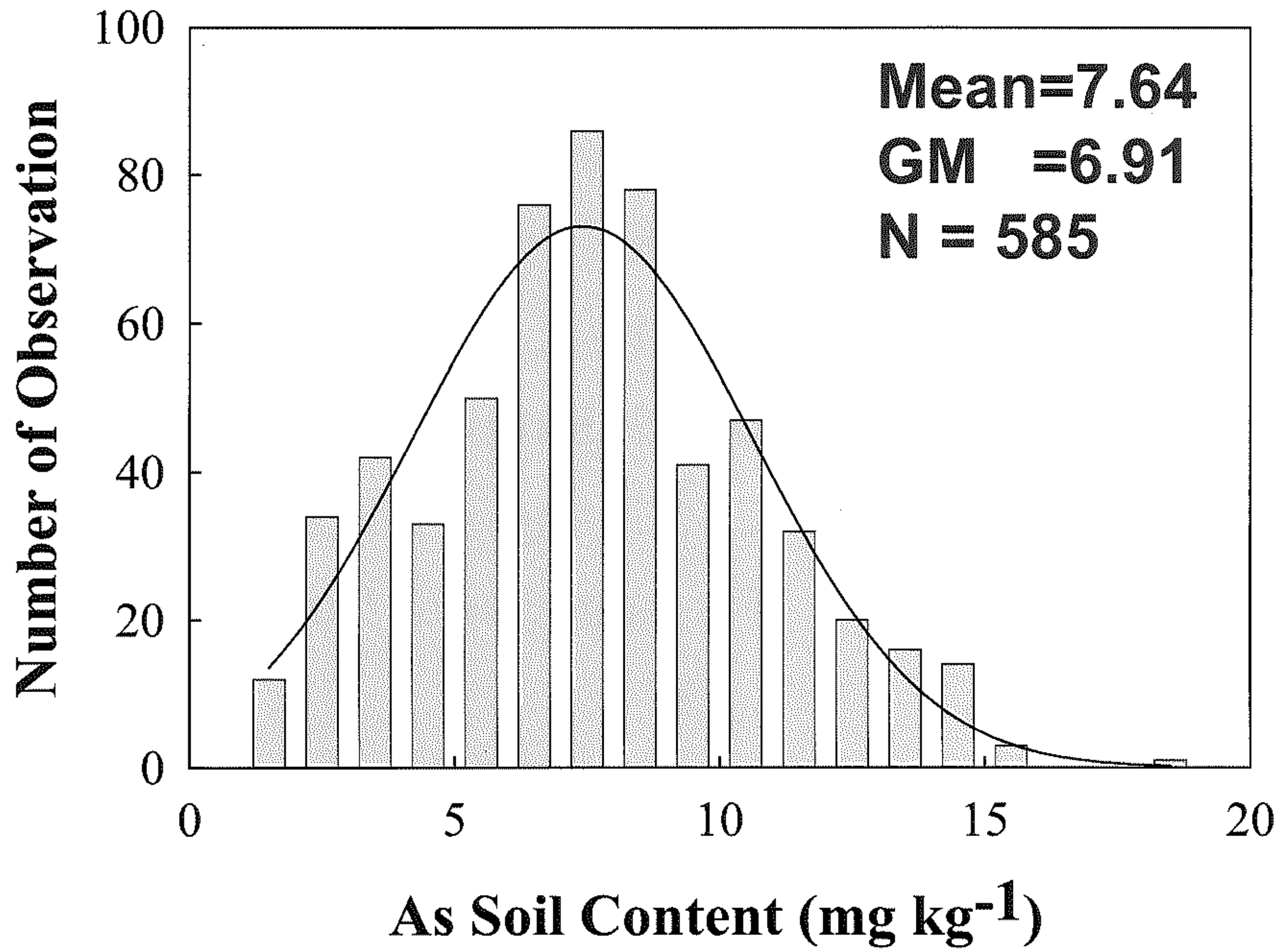
- EPA concludes that soil may not exceed 0.4 mg As/kg without risk thru soil ingestion by children.
- This concentration is below As in normal US soils.
- Many question the validity of the 0.4 mg/kg limit for soil As (10^{-5} lifetime cancer risk).
- EPA considering 20-fold increase in As cancer slope.
- For iron foundry sands, some sands are above the 0.4 mg/kg level, but lower than normal soils such that application of spent foundry sand would reduce "risk" from ingestion of background soils.
- Foundry sand risk assessment accepts use on land.
- EPA previously attempted to make fly ash hazardous due to As level but were caught with bad calculations.

Concentrations of As in US Soils

Mean	Range	N	Reference
• 7.2	<0.1-97	1318	**US**: Shacklette & Boerngen, 1984
• 11.3	0.1-194	>3000	**World**: Ure and Berrow, 1982
• 0.42	0.1-50.6	441	**FL**: Chen, Ma & Harris, 2002
• 5.8	1.0-18.0	254	**USGS**: Smith et al., 2005
• 7.6	1.2-18.4	585	**CA**: Chang et al. (2006)
• 0.69	0.04-4.8	43	**Foundry Sand**: Dungan (2007)

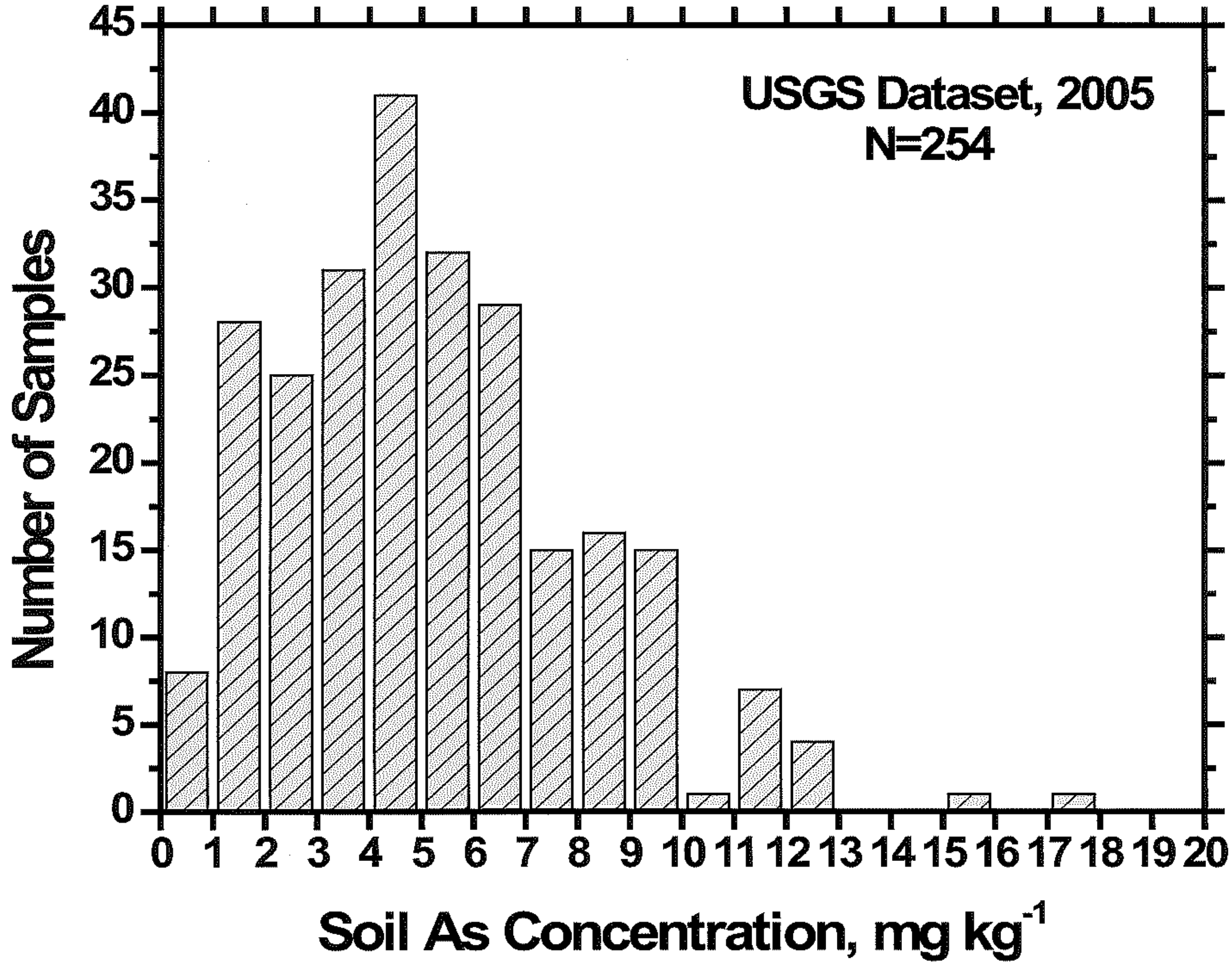
How should the US deal with background soil As which varies with parent rock As levels and soil formation processes, as well as historic agricultural and industrial practices?

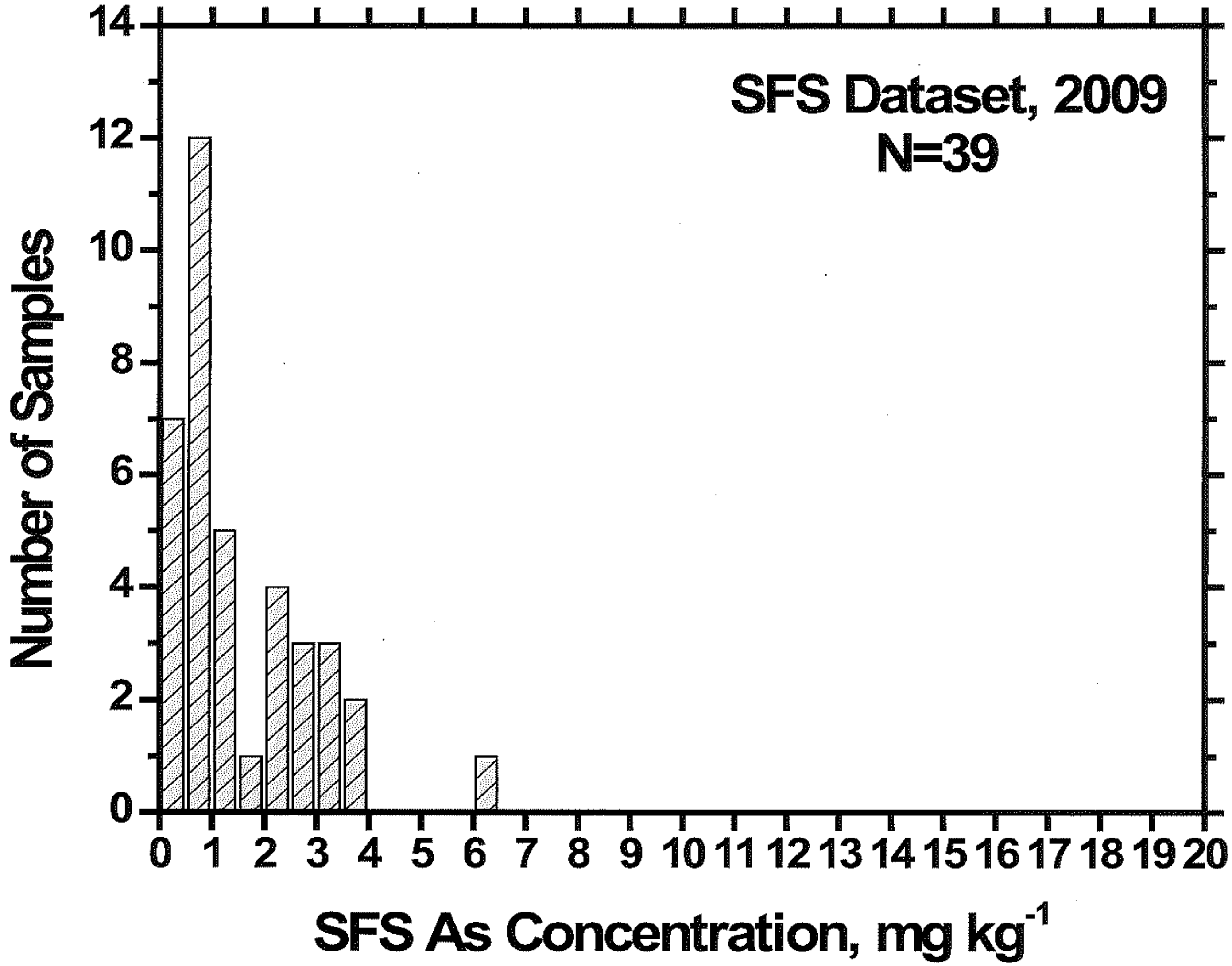
Distribution of Soil As Concentration in California Soils
(Chang et al, 2007)

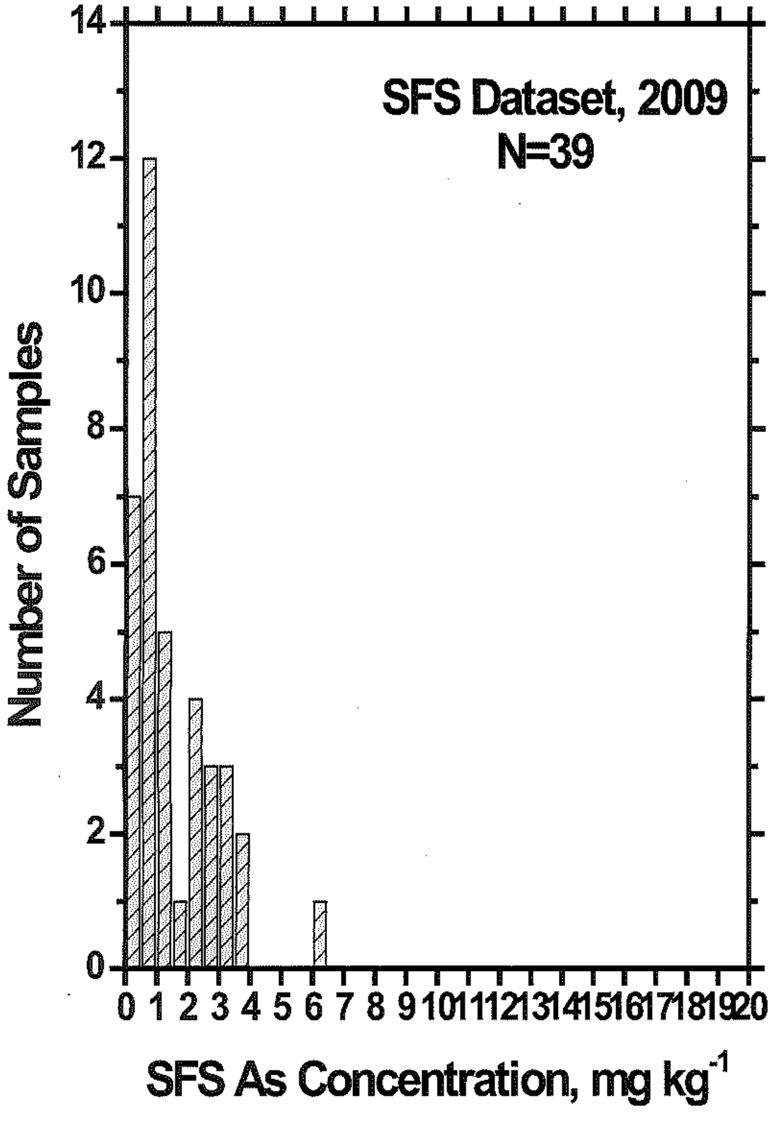


Distribution of Soil As Concentrations in Recent USGS Transects of USA (Smith et al., 2005) [N=256]

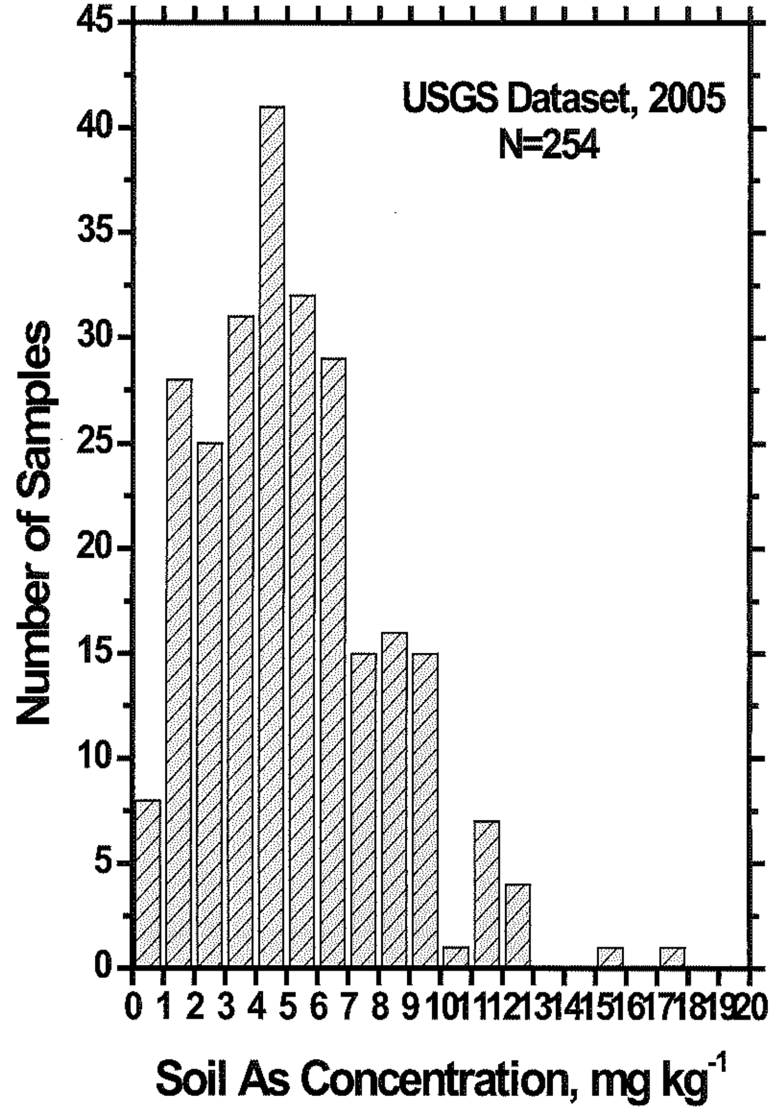
Statistic	$mg\ kg^{-1}$ DW
Mean	5.8
Minimum	1.0
Maximum	18.0
Median	5.0
90^{th}	10.0
95^{th}	11.4
99^{th}	13.0
EPA-SSL	0.426


USGS Dataset, 2005
N=254
Number of Samples
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Soil As Concentration, mg kg-1


SFS Dataset, 2009
N=39
Number of Samples
0
2
4
6
8
10
12
14
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
SFS As Concentration, mg kg-1



SFS Dataset, 2009
N=39
Number of Samples
SFS As Concentration, mg kg-1



USGS Dataset, 2005
N=254
Number of Samples
Soil As Concentration, mg kg-1

Summary/Conclusions

- New FGD-Gypsum is low in trace elements and other problem contaminants compared to background soils.
- Presuming low trace element levels, FGD-Gypsum will be below the 95^{th} %-ile of background US soils.
- The Spent Foundry Sand Risk Assessment found no risk to humans or the environment when elements were below the 95^{th} %-ile of US soils.
- Dioxins, PAHs, and other xenobiotics were also subjected to risk assessment.
- Questions about Hg emissions remain, but it seems difficult to conclude it would be a new and significant hazard to prohibit use of FGD-Gypsum

BREAK

FGD PRODUCTION AND MARKET TRENDS

Looking Back and Looking Ahead

Dave Goss
for ACAA

Production Trends

Year	Tons Produced	Tons Used	Wallboard	Disposal
2008	17,754,939	10,853,344	8,533,732	6,901,595
2007	12,300,000	9,228,271	8,254,849	3,071,729
2006	12,100,000	9,561,489	7,579,187	2,538,511
2005	11,975,000	9,268,365	8,178,079	2,706,635

Future Production

- As more power plants add air emission scrubbers, more FGD gypsum will be produced
- Anticipate volumes in excess of 25 million tons annually
- Not all will be used in wallboard or cement production
- Some will go into agriculture where market conditions permit

Marketing Considerations

- Does the gypsum meet quality needed for crop use?
- Not all crops can use FGD gypsum effectively
- Is the delivery distance economically achievable?
- Market saturation may limit expansion in some regions
- Regulatory acceptance is important
- Negative perception or stigma could cause market loss

Conclusions

- Agricultural use of FGD gypsum is likely to increase significantly
- Shifting from wet impoundments to mechanically dewatered systems will allow more FGD gypsum to be stored for future use
- However, larger amounts of FGD gypsum will be disposed of in the future requiring new landfill facilities
- Increased agricultural use could reduce landfills needed

IMPLEMENTATION

Ron Chamberlain &

Bob Spoerri

Regulation of FGD Gypsum in Agriculture

- Permitting for agricultural use by States- requirements vary
- BRM holds permits in 2 States, applications in process in 5 other States
- Typically considered under State Environmental Departments Water regulations
- State Agricultural Departments typically issue licenses and collect taxes

Common State Permitting Procedures

- Materials Testing against Clean Water Act Part 503 Standards for land application of “Exceptional Quality” Bio-solids

- Management Plan Required
  - Appropriate utilization
  - Materials Handling
  - Application Rates
  - User Information Sheets
  - Storage requirements

- Record Keeping and Reporting
  - Individual application site
  - Statewide volumes

FGD Composition Breakdown

(mg/kg)	Part 503 Exceptional Quality BioSolid	FGD Gypsum Typical Range per USEPA	BRM Customer Plant A	BRM Customer Plant B
<u>Metal</u>				
Arsenic	41	.6-4.0	<.43	2.4
Cadmium	39	.2-1.2	0.042	n.d.
Copper	1500	1.1-4.7	no data	4.6
Lead	300	.8-12.0	1.5	n.d.
Mercury	17	.01-1.4	0.97	0.08
Molybdenum	75	.5-12.0	0.31	2.89
Nickel	420	.73-20.1	2.6	2.6
Selenium	100	2.0-30.0	12	4.12
Zinc	2800	3.4-47.5	5.5	10

n.d. = Not Detectable

Management Plan

- Appropriate Utilization
  - Soil Properties
  - Soil Test Values
  - Field Observations
    - Water
    - Soil Structure
    - Crop development
    - Biological systems

- Materials Handling
  - Transport
  - Land Application

- Application Rates
- User Information Sheets
- Storage requirements

DISCUSSION:

Q & A

THANK YOU