Environmental and Production Management Guides for Land Application Uses of FGD Gypsum

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Gypsum as an Agricultural Amendment

Management Guide

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Chapter 1
Background

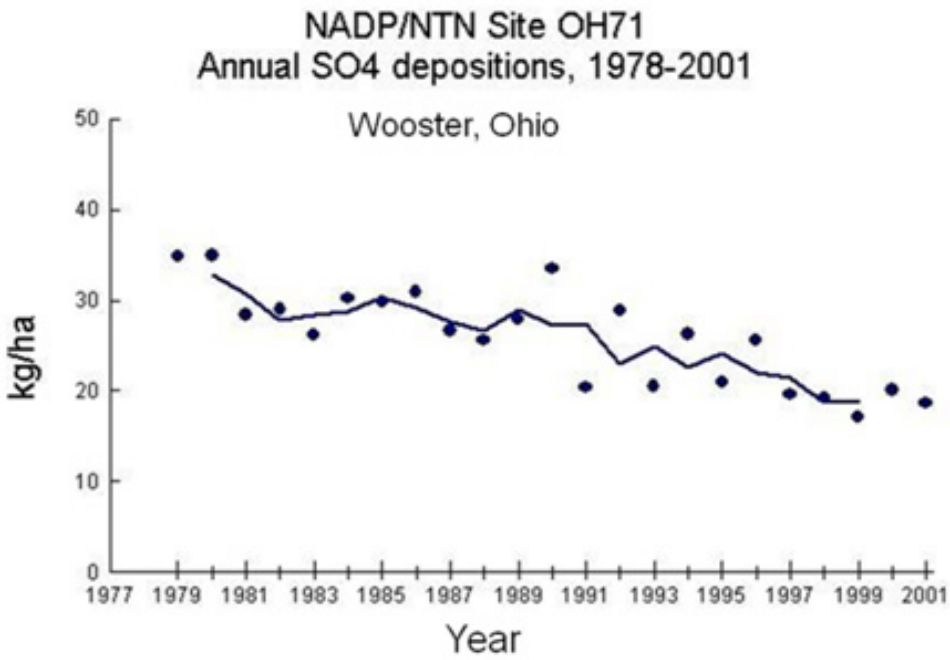


Table 1-3. Chemical properties of FGD gypsum from the W.H. Zimmer Station of Duke Energy (Moscow, OH) and mined gypsum from the Kwest Group (Port Clinton, OH) (Dontsova et al. 2005)

Composition	FGD gypsum	Mined gypsum
Elements – Plant Macronutrients (ppm)		
Nitrogen (ppm)	970	
Phosphorus (ppm)	<1.0	30
Potasssium(ppm)	<74.0	3,600
Calcium (%)	**24.3**	**24.5**
Magnesium (ppm)	200	26,900
Sulfur (%)	18.5	16.1
Elements – Plant Micronutrients (ppm)		
Boron	12.7	98.9
Copper	<0.38	<0.60
Iron	150	3800
Manganese	0.623	225
Molybdenum	3.20	<0.60
Nickel	<3.0	<0.6
Zinc	1.20	8.70

Close the Ecological Loop

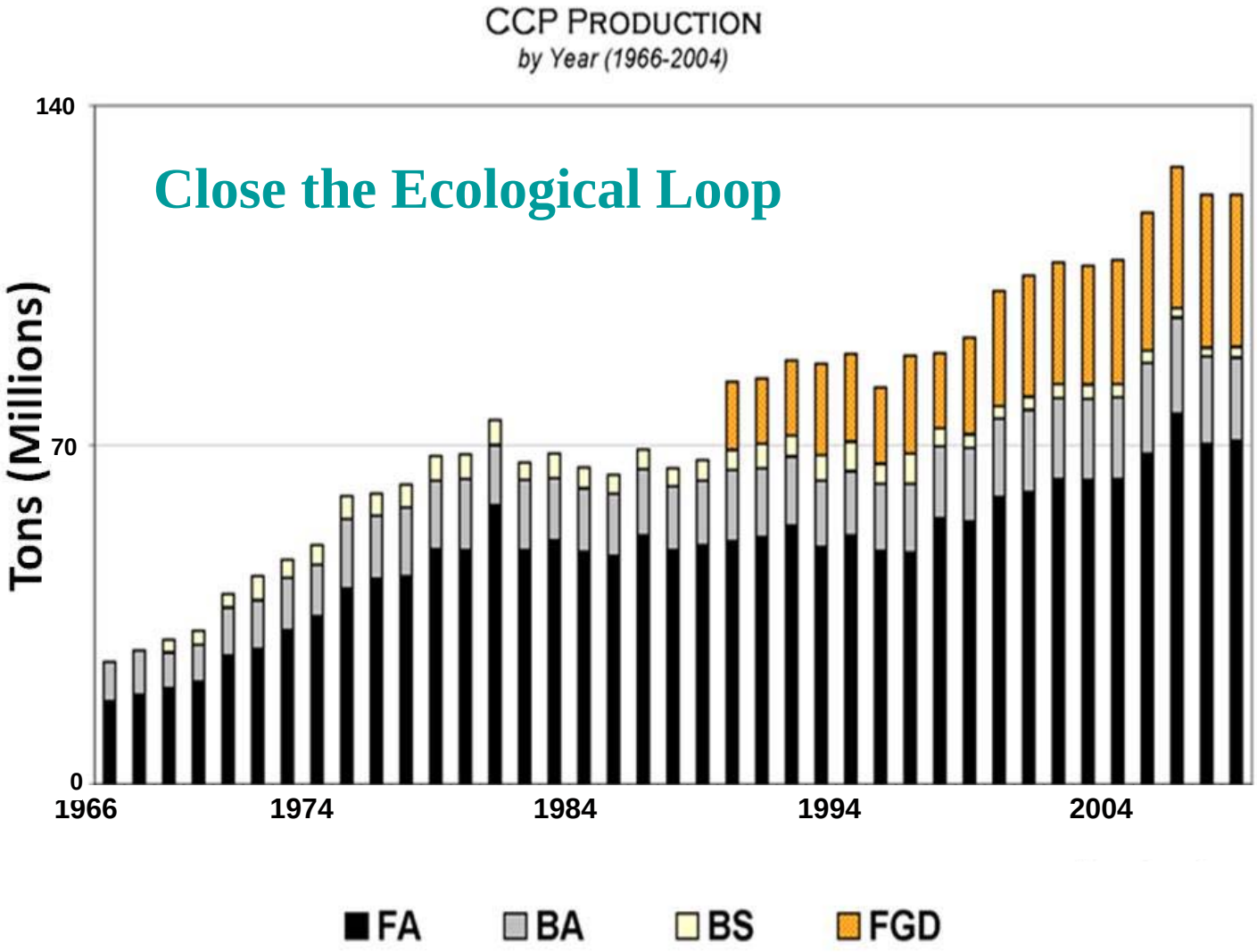
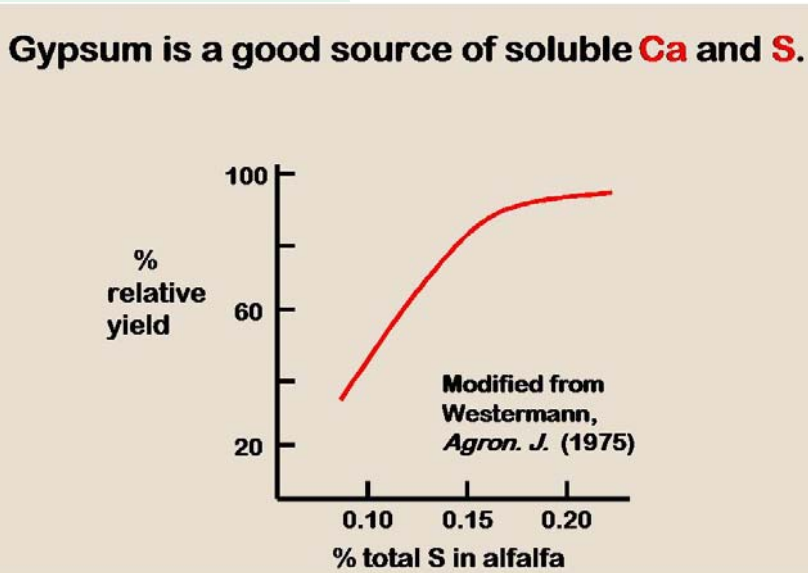


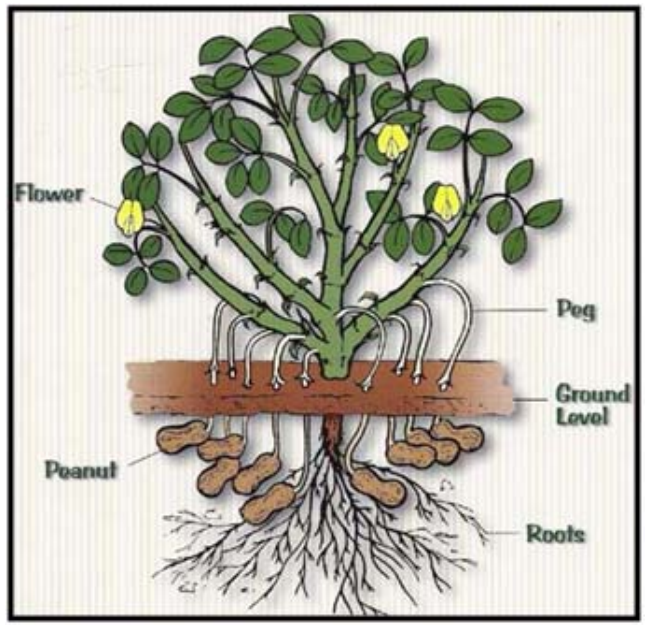
Table 1-1. FGD gypsum production, total use, and agriculture use from 2002 to 2007 in the USA (American Coal Ash Association, 2008).

Year	FGD production	Total use	Agricultural use
	Short tons	Short tons	Short tons
2007	12,300,000	9,228,000	115,000
2006	12,100,000	9,561,000	168,000
2005	11,975,000	9,268,000	362,000
2004	11,950,000	9,045,000	131,000
2003	11,900,000	8,299,000	33,000
2002	11,400,000	7,770,000	78,000

Chapter 2
Properties of FGD That Provide Agricultural Benefits

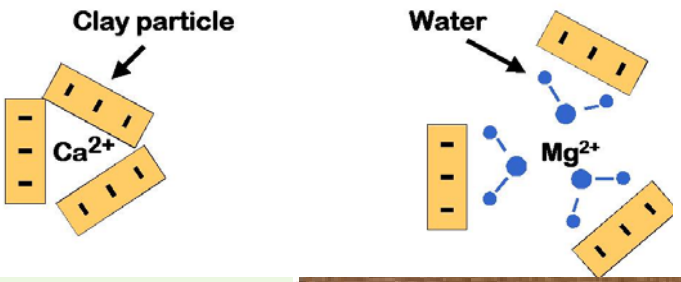
I. FGD Gypsum as a Source of Plant Nutrients

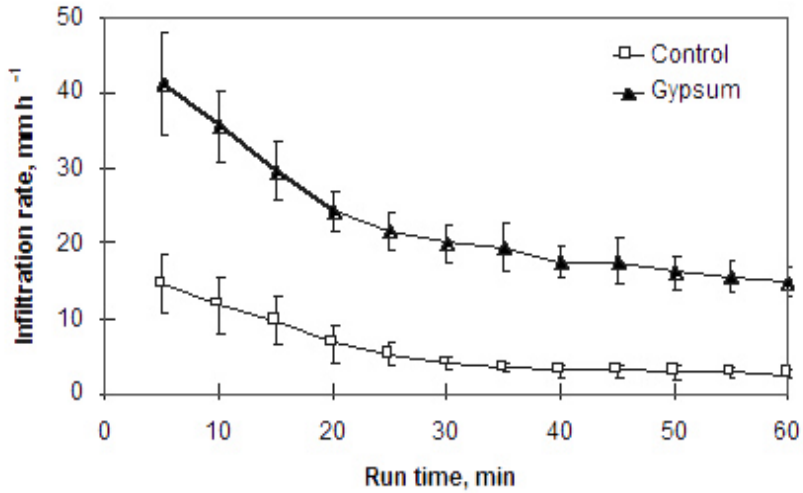




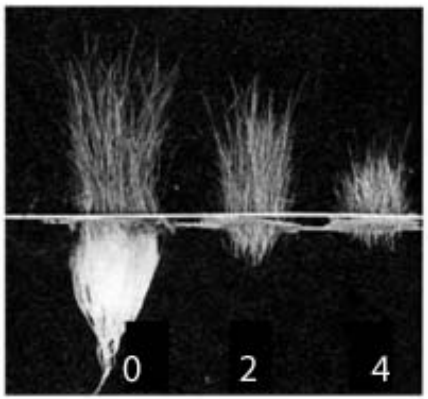
II. FGD Gypsum to Improve Soil Physical Properties

Soil dispersion is mainly caused by highly hydrated Na^+ and Mg^{2+} attracted to the surfaces of clay particles.





III. FGD Gypsum to Improve Soil Chemical Properties



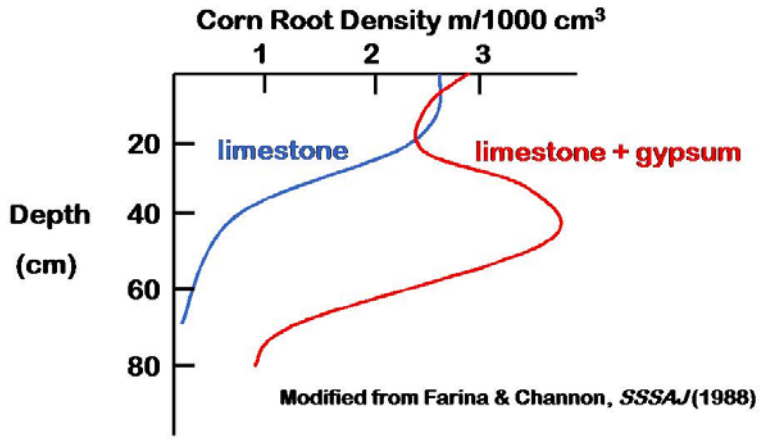
Al^{3+} Concentration (ppm)

Al^{3+} is highly toxic to most plant roots.

← Fescue grown in nutrient solution containing soluble Al^{3+}

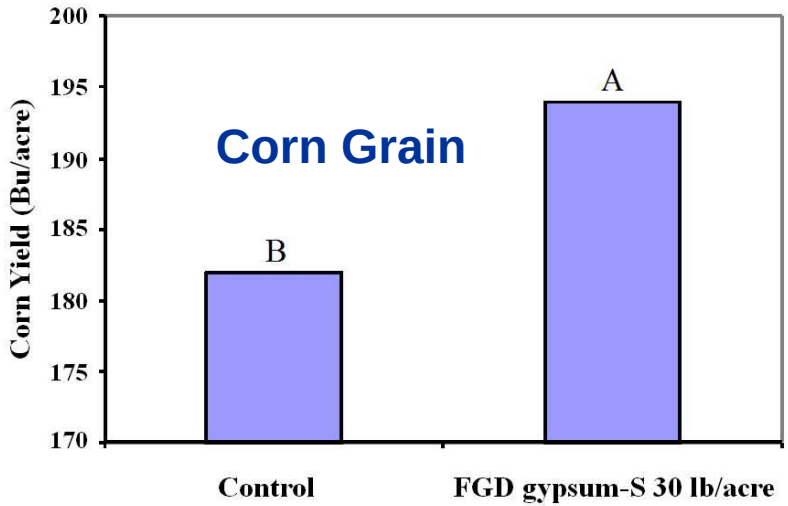
Gypsum forms soluble complexes with Al^{3+}

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



Chapter 3
Agricultural Uses

I. FGD Gypsum as a Source of Plant Nutrients for Crops



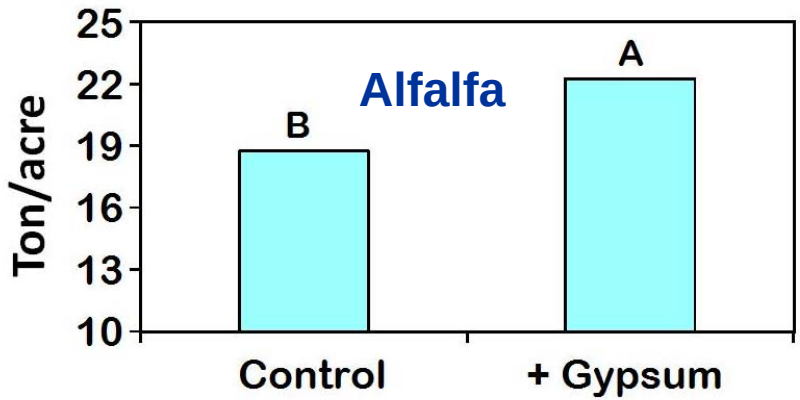
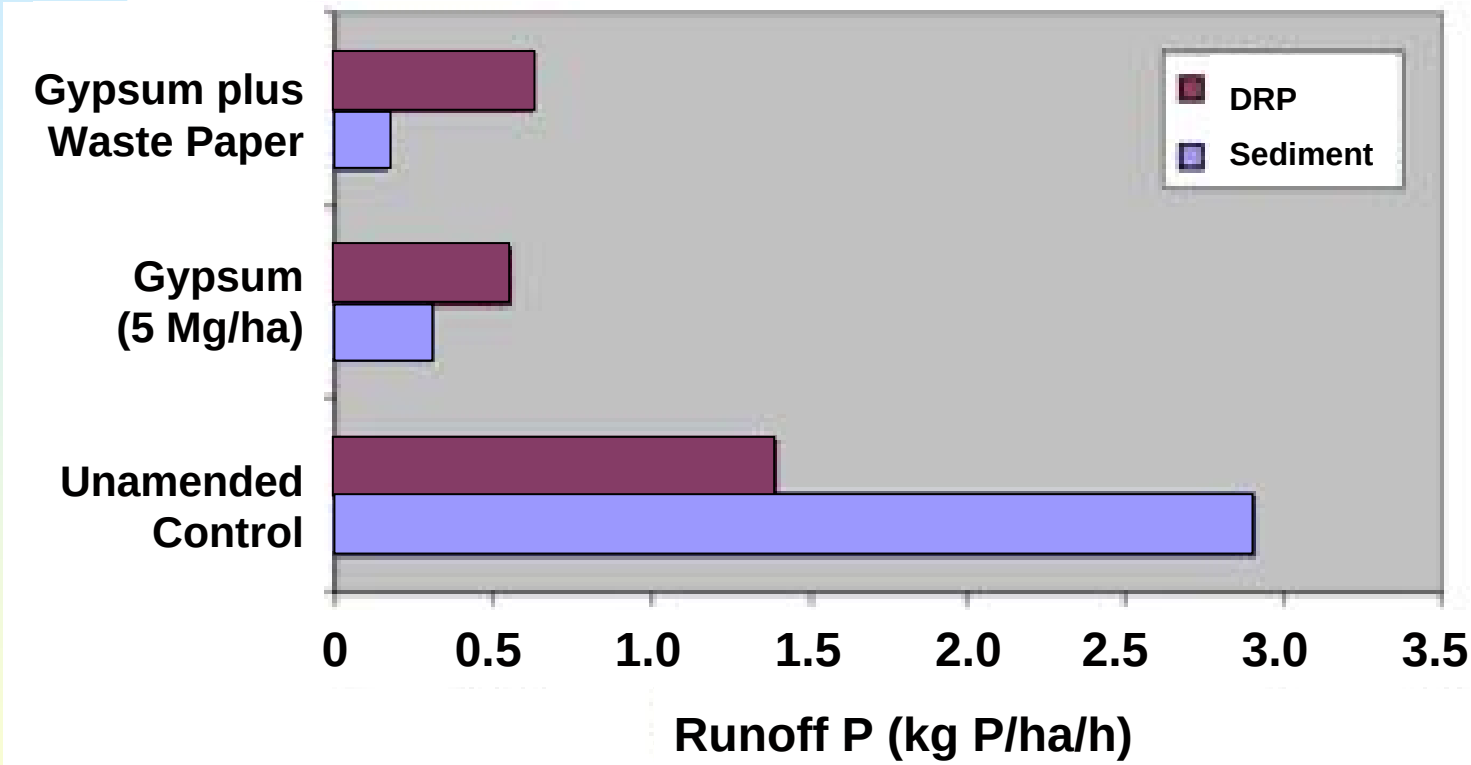


Table 3-1. Effect of gypsum on the yield, quality and value of peanut grown in Florida (Sumner and Larrimore, 2006).

Gypsum	Yield	Value	Seed Ca
Ton/acre	Lb/acre	$/acre	%
0	3,280	540	0.021
0.5	3,940	649	0.034

II. FGD Gypsum to Improve Soil Physical Properties



III. FGD Gypsum to Improve Soil Chemical Properties

Table 3-2. Effect of gypsum on the yield and quality of cotton in a acid subsoil in Mississippi (Sumner and Larrimore, 2006).

Gypsum treatment	Seed cotton	Lint	Quality
Ton/acre	Lb/acre		
0	1,661	612	303
4.4	1,993	729	336

IV. Other Uses in Agriculture

Turf

Composting

Chapter 4
Application Rates

Table 4-1. Sulfur removed by various crops at specific yields and the amount of gypsum should be applied for making up (Dick et al., 2008).

Crop	Yield	S removed	Gypsum Application for S removed
	Ton/acre	Lb/acre	Lb/acre
Corn	5.8	15	81
Sorghum	4.2	22	120
Wheat	2.4	7	38
Canola	1.0	12	63
Soybean	1.8	12	63
Sunflower	1.7	6	34
Alfalfa	5.8	30	163
Cool-season grass	4.0	16	87
Cotton	0.8	40	216
Peanut	2.0	21	115
Rice	3.5	12	63
Sugar beet	30	45	240
Orange	27	28	149
Tomato	30	41	221
Potato	25	22	120

Table 4-2. Critical sulfur concentrations in crop plants (Dick et al., 2008).

Crop	Part sampled	Time of sampling	Concentration			
			Deficient	Low	Sufficient	High
			%	%	%	%
Alfalfa	Top 15 cm	Early bud	<0.20	0.20-0.25	0.26-0.50	>0.50
Corn	Ear leaf	Silking	<0.10	0.10-0.20	0.21-0.50	>0.50
Oats	Top Leaves	Boost stage	<0.15	0.15-0.20	0.21-0.40	>0.40
Soybean	First trifoliate	Early flower	<0.15	0.15-0.20	0.21-0.40	>0.40
Barley	YEB	Mid-late tillering			0.15-0.40	
Canola	YMB	Prior to flowering			0.35-0.47	
Cotton	YMB	Early flowering			0.20-0.25	
Ryegrass	Young herbage	Active growth			0.10-0.25	
Peanut	YML	Pre-flowering			0.20-0.35	
Sugar cane	Top visible dewlap	Active growth			0.12-0.13	
White clove	Young herbage	Active growth			0.18-0.30	
Wheat	YEB/YMB	Mid-late tillering			0.15-0.40	
Rice	Whole top	Maximum tillering			0.14	
Rice	Whole top	Active tillering			0.23	

Table 3-2. Application rates of sulfur and calcium calculated based on the amount of FGD gypsum application.

FGD gypsum	**Sulfur**	**Calcium**
Lb/acre	Lb/acre	Lb/acre
50	9.3	11
100	19	23
300	56	68
1000 (0.5 ton)	186	226
5000 (2.5 ton)	930	1130
20000 (10 ton)	3720	4520

Table 4-5. The most satisfactory predictions for the gypsum requirement (GR) for remediating subsoil acidity, magnesium soils, and sodic soils.

Amendment	Equation*	Source
Subsoil Acidity Amendment	GR (kg S ha^{-1}) = -114 + 82.773A_s – 2.739A_s^2	Ritchey et al., 1995
Magnesium Amendment	GR (lb/acre) = [((% Mg-22)/100 x CEC)) X 2000] + (pH-7.2) X 2000 or GR (lb/acre) = [(((PPM Mg/120) - (0.22 X CEC)) X 2000) + ((pH -7.2) X 2000)	Hecht, 2006
Sodium Amendment	GR (lb/acre) = [(((PPM Na/230) - (0.02 X CEC)) X 2000)) + (((PPM Mg/120) - (0.22 X CEC)) X 2000)))]	Hecht, 2006

*A_s = (S sorbed)/(S in solution) after 2 gram of soil is shaken for 18 h with 20 mL of 0.75 mM $CaSO_4 \cdot 2H_2O$ solution.
CEC is cation exchange capacity (meq/100g).

Chapter 5
Economic Considerations

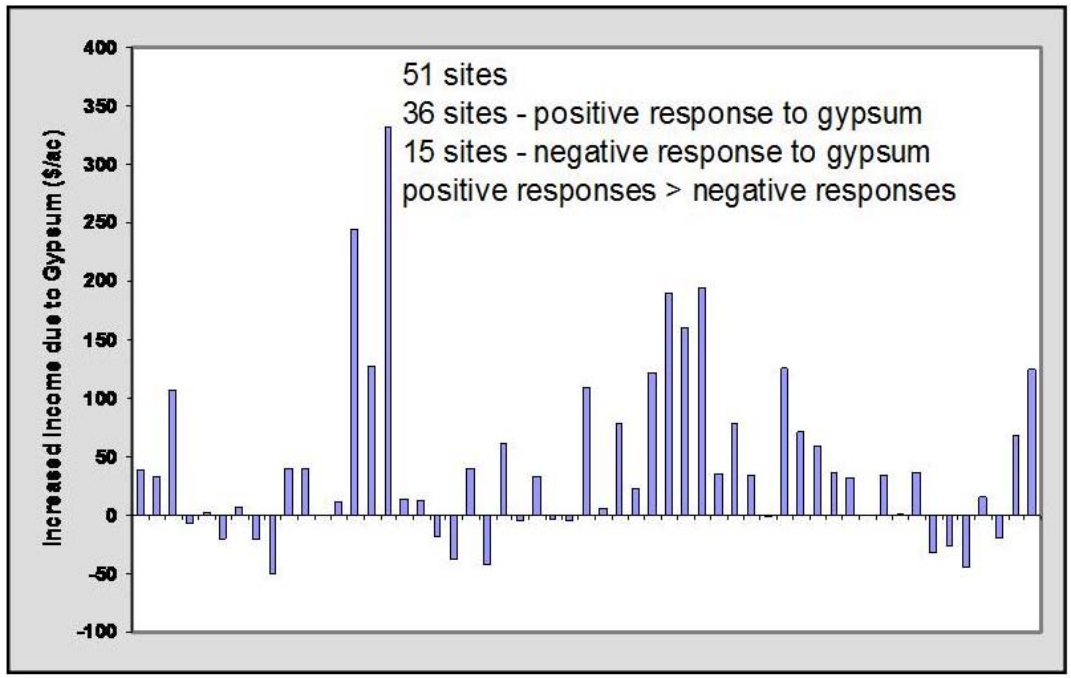
Table 5-1. Total costs and return above total costs for two different management systems (NT--- no tillage and CT--- conventional tillage) for corn and soybean production (Chen et al., 2005).

Crop	Management System[a]	Total Cost ($/acre)[b]	Return Above Total Cost ($/acre)[c]
Corn	NT + gypsum	321	17
	CT – gypsum	374	-28
Soybean	NT + gypsum	228	79
	CT – gypsum	272	18

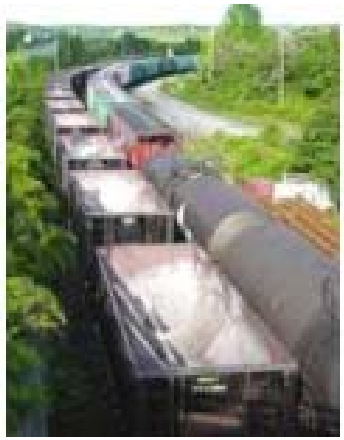
[a] NT+gypsum is a no-tillage crop production system that includes gypsum applications. CT-gypsum is a conventional tillage crop production system that does not include gypsum.
[b] Includes fuel, machinery and equipment, land costs, management costs and labor.
[c] The differences for soybean, but not corn, between the two management systems were significantly different at the 5% level of significance.

Table 5-3. Effect of gypsum on tomato yield and value in Mississippi (Sumner and Larrimore, 2006).

Gypsum	Yield	Value
Ton/acre	Lb/acre	$/acre
0	14,782	5,896
2	17,695	7,072



Chapter 7
FGD Gypsum Handling and Storage



Gypsum Storage and Loading (Wholesale and Retail)

Gypsum Storage and Loading (Farm Site)

Table 7-1. Comparison of FGD gypsum storage alternatives.

FGD Storage Type	Advantages	Disadvantages
Open (not covered)	Inexpensive.	Rainfall adds extra water; Rainfall/runoff contamination potential; Runoff controls may be required.
Open (covered with plastics)	Less expensive ; No rainfall effects; Maintains FGD gypsum moisture	No feasible for long-term storage
Open sided (roof cover only)	No rainfall effects; Maintains FGD gypsum moisture	Expensive
In facility	No rainfall effects; Feasible for long-term storage; Maintains FGD gypsum moisture	Most expensive

Equipment and Other Land Application Considerations for FGD Gypsum

Figure 4-1. FGD gypsum can be applied directly to the soil surface using conventional dry material spreaders (Source: National Research and Demonstration Network of FGD products in Agriculture).

Chapter 6
Analtyical and Technical Support

- **Sampling Soil and FGD Gypsum for Analysis**
- **Recording FGD Gypsum Use and Analysis Results**
- **Institutional Support (*Ohio State University Extension)***
- **National Research and Demonstration Network of FGD Products in Agriculture**
- **American Coal Ash Association (ACAA)**
- **Soil and Crop Consultants**
- **Rules and Regulations**

Gypsum Application to Agriculture

Environmental and Ecological Guidelines

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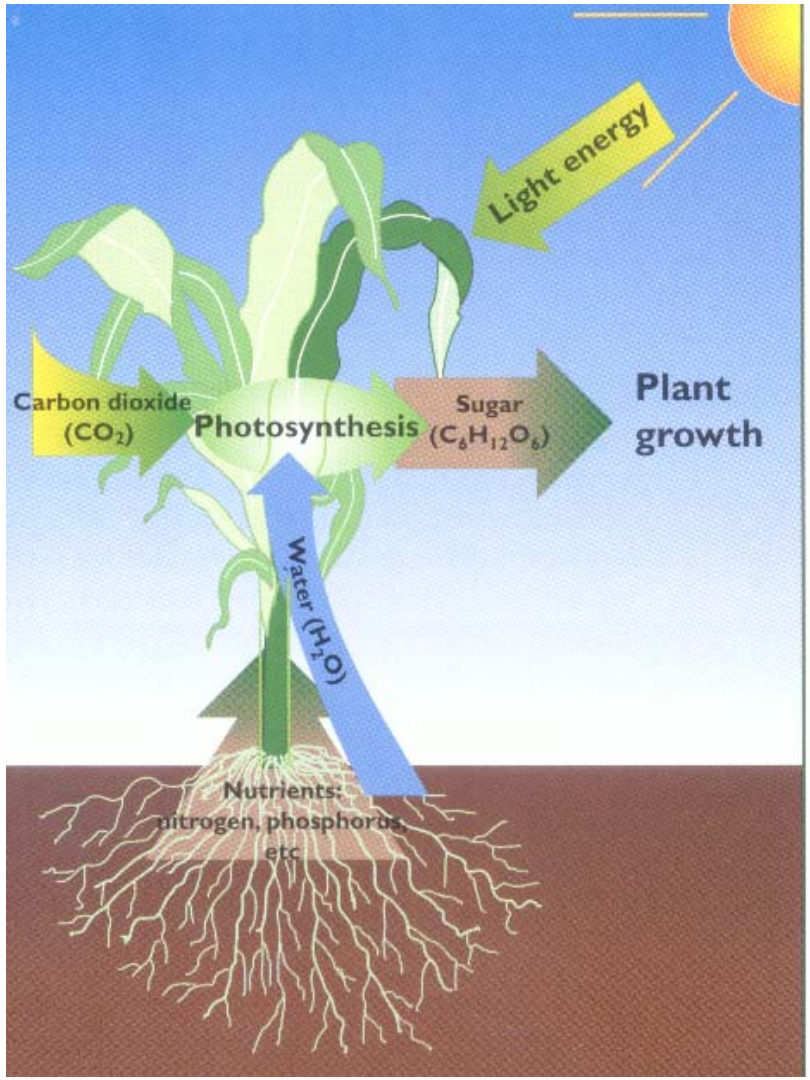
Defining Agriculture



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Reduction of P and N Concentrations in Surface Water Runoff
Amelioration of Problem Associated with Subsoil Acidity
Remediation of Sodic Soils
No-tillage Crop Production on Clay Soils
Synthetic Soils and Mixes
Landscape and Sport Field Uses

Chapter 2
Composition of FGD Gypsum

Table 2-1. Mineralogical composition of gypsum samples (Dontsova et al., 2005).

Source	Mineral
FGD gypsum	Gypsum, quartz
Mined gypsum	Gypsum, quartz, dolomite
Cast gypsum	Gypsum, quartz, anhydrite
Wallboard gypsum	Gypsum, quartz, portlandite, calcite

Table 2-2. Purity and selected physical properties of gypsum (Dontsova et al., 2005).

Material	Purity of gypsum	Water content	Particle size	Insoluble residue
	%	%		%
FGD gypsum	99.6	5.55	120 µm	0.4
Mined gypsum	87.1	0.38	NA	12.9
Cast gypsum	99.8	0.15	NA	0.2
Wallboard gypsum	97.8	10.1	<0.5 inch	2.2

NA--- not available

Table 2-3. Selected macro- and micronutrient[1] concentrations in gypsums (Dontsova et al., 2005).

Element	Units	Museum specimen[2]	FGD gypsum	Mined gypsum	Cast gypsum	Drywall gypsum	Ideal analysis
Ca	%	22.6	23.0	19.1	22.4	21.9	23.3
Mg	%	0.01	0.03	1.35	0.05	0.22	
S	%	18.6	18.7	15.1	19.3	18.1	18.6
B	ppm	<13.1	26.7	9.4	0.4	7.3	
Fe	ppm	<1.0	264	1045	44	547	
Mn	ppm	0.1	5.5	14.6	9.1	9.4	
P	ppm	3.8	16.7	30.6	7.5	51.6	

[1]Micronutrient data obtained by EPA method 3050 (USEPA, 1996).
[2]The museum specimen is included as a pure sample of gypsum.

Table 2-4. Trace metal concentrations[1] of gypsum from different sources compared with U.S. EPA Part 503 pollutant concentration limits for excellent quality biosolids (Dontsova et al., 2005).

Element	Museum specimen	FGD gypsum	Mined gypsum	Cast gypsum	Drywall gypsum	Part 503[2]
	----------mg/kg----------					
As	<0.52	0.56	<0.52	<0.52	0.98	41
Cd	<0.48	<0.48	<0.48	<0.48	<0.48	39
Cr	0.01	1.30	1.38	0.07	1.09	1200
Cu	<0.48	1.16	1.33	1.40	0.95	1500
Pb	<0.48	0.80	2.92	0.57	0.70	300
Hg	<0.26	<0.26	<0.26	<0.26	<0.26	17
Mo	<0.24	0.51	1.28	<0.24	<0.24	75
Ni	<0.24	0.73	1.42	<0.24	0.83	420
Se	<1.45	5.51	<1.45	<1.45	1.85	36
Zn	<0.24	3.88	0.91	<0.24	3.08	2800

[1]Trace metal data obtained by EPA method 3050 (USEPA, 1996).

[2]Part 503---Standards for the Use or Disposal of Sewage Sludge; 503.13, Table 1 and Table 3.

Table 2-9. Concentrations of trace elements in FGD gypsum samples from four power plants (Thorneloe et al., 2007).

Element	Total	Leach	MCL	TC
	Mg/kg	µg/L	µg/L	µg/L
Hg	0.01-0.5	<0.01-0.6	2	200
Sb	2-6	<0.3-10	6	-
As	2-4	0.5-10	10	5000
Ba	3-60	40-400	2000	10^5
B	NA	40-70000	7000 DWEL	6500
Cd	0.3-0.5	<0.2-50	5	1000
Cr	6-20	<0.3-50	100	5000
Co	1-4	<0.2-10	15	5000
Pb	1-12	<0.2-10	15	5000
Mo	2-12	1-600	200 DWEL	-
Se	2-30	4-3000	50	1000
Tl	0.6-2	<0.3-20	2	-

MCL-Maximum concentration limit for drinking water.
DWEL-Drinking water equivalent level.
TC- Toxicity characteristic Š Threshold for hazardous waste determinations.

Chapter 3
Loading Rates of Nutrients and Metals

Table 3-1. Rates of application of FGD gypsum for various functions.

Function	Suggested rates of application
Sulfur fertilizer to enhance crop production	100-500 lb/acre
Calcium fertilizer to enhance crop production (especially root crops, e.g. peanuts)	1000-4000 lb/acre
Soil amendment to remediate subsoil acidity	3000-10000 lb/acre
Soil amendment to remediate sodic or sodium affected soils	1-25 ton/acre (once a year)
Soil amendment to improve water quality (e.g. by reducing phosphorus concentrations in surface water runoff)	1000-9000 lb/acre
Soil amendment to improve soil physical properties and water infiltration and percolation	1000-9000 lb/acre
As a component of synthetic soils for nursery, greenhouse, and landscape use	5-20% of the medium
As a lawn care product	2-7 ton/acre
Golf and sport field application	2-7 ton/acre

Table 3-2. Application rates of sulfur and calcium calculated based on the amount of FGD gypsum application.

FGD gypsum	**Sulfur**	**Calcium**
Lb/acre	Lb/acre	Lb/acre
50	9.3	11
100	19	23
300	56	68
1000 (0.5 ton)	186	226
5000 (2.5 ton)	930	1130
20000 (10 ton)	3720	4520

Table 4-5. Effects of gypsum application at 20 Mg/ha on concentrations of elements in soil in 2008 (Chen et al., 2009).

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

Chapter 4
FGD Gypsum Effects on Soil Properties

Table 4-1. Effect of gypsum application on soil erosion (Gypsum workshop, 2007).

Gypsum added	Infiltration	Runoff	Soil Loss
Mg/ha	mm	mm	Mg/ha
0	7	50	20.9
3.36	13	44	12
6.72	21	36	8.2
13.44	24	32	5.4

Table 4-6. Effect of gypsum on the chemical properties of alkali soil one year after application (Hecht, 2006).

	pH	P1	P2	K	Na	Na	Mg	Ca	Zn
						%	%	%	
Before application	8.0	7.0	52	265	337	6.6	44.7	45.7	1.4
After application	6.4	19	55	379	68	1.0	34.2	52.5	2.2

Effect of gypsum on dissolved reactive phosphorus in soil (Brauer, 2006).

Table 4-6. Rate, time, and method of application of FGD gypsum for various functions.

Function	Suggested rates of application	Suggested time of application	Suggested application method
Sulfur fertilizer to enhance crop production	100-500 lb/acre	Before planting	Soil surface or incorporated
Calcium fertilizer to enhance crop production (especially root crops, e.g. peanuts)	1000-4000 lb/acre	Before peanut pegg	Soil surface
Soil amendment to remediate subsoil acidity	3000-10000 lb/acre	1-180 days before planting	Soil surface
Soil amendment to remediate sodic or sodium affected soils	1-25 ton/acre (once a year)	90-180 days before planting, before rainy season	Soil surface or incorporated
Soil amendment to improve water quality (e.g. by reducing phosphorus concentrations in surface water runoff)	1000-9000 lb/acre	1-180 days before planting	Soil surface
Soil amendment to improve soil physical properties and water infiltration and percolation	1000-9000 lb/acre	1-180 days before planting	Soil surface
As a component of synthetic soils for nursery, greenhouse, and landscape use	5-20% of the medium	During preparation of synthetic soils	Mixing with other components
As a lawn care product	2-7 ton/acre	Spring, Summer, Autumn	Soil surface
Golf and sport field application	2-7 ton/acre	Spring, Summer, Autumn	Soil surface

Chapter 5
FGD Gypsum Effects on Water Quality

Table 5-1. Effects of FGD gypsum application at 2000 lb/acre on concentrations of elements in soil water in Indianan in 2008.

Element	Treatment		
	Control	FGD gypsum	Mined gypsum
	---------- mg/L ----------		
P	0.05	0.83	1.4
K	3.3	4.2	4.9
Ca	43	83	65
Mg	16	32	25
S	23	74	53
Al	<0.034	<0.034	<0.034
B	0.09	0.12	0.05
Cu	<0.001	<0.001	<0.001
Fe	<0.001	<0.001	<0.001
Mn	0.006	0.036	0.101
Mo	0.05	0.03	0.02
Na	37	53	42
Zn	<0.002	0.005	0.003
As	<0.006	<0.006	<0.006
Ba	0.12	0.24	0.18
Be	<0.001	<0.001	<0.001
Cd	<0.001	<0.001	<0.001
Co	<0.001	<0.001	<0.001
Cr	<0.001	<0.001	<0.001
Hg	28	17	65
Li	0.05	0.11	0.07
Ni	0.004	0.006	0.004
Pb	<0.003	<0.003	<0.003
Sb	0.02	0.02	0.02

Chapter 6
FGD Gypsum Effects on Plants

Table 6-1. Effect of FGD gypsum on yields of crops.

Crop	FGD gypsum rate	Beneficial properties	Yield increase %	Reference
Corn	160 lb/acre	Sulfur nutrient	6.6	Chen et al., 2008
Canola	120 lb/acre	Sulfur nutrient	20-300	DeSutter et al. 2009
Corn		Sodic immediate	600-800	Xu, 2006
Bermudagrass		Soil physical	9.0%	Schlossberg, 2006

Table 6-2. Concentrations of major plant essential elements in corn grain harvested from plots treated with FGD gypsum in 2003 and 2005 (Chen et al., 2008).

FGD gypsum treatment	N	P	K	Ca	Mg	S
Lb/acre	---------- g/kg ----------					
2003						
0	13.1 a	2.39 b	2.99 b	0.058	0.95 b	0.92
183	12.4 b	2.58 a	3.16 a	0.060	1.02 a	0.93
$LSD_{0.05}$	0.5	0.13	0.16	0.015	0.05	0.03
2005						
0	13.9	3.20	2.31	0.038	0.89	1.03 b
183	13.8	3.29	2.15	0.035	0.87	1.06 a
$LSD_{0.05}$	0.7	0.14	0.19	0.015	0.07	0.03

Means in a column for each year followed by different letters are significantly different at P ² 0.05.

Table 6-5. Concentrations of major plant essential elements in broccoli harvested from plots treated with FGD gypsum in 2007.

Element	Treatment	
	Control	FGD Gypsum (1.0 Mg/ha)
Macronutrient (k/kg)		
N	64	62
P	7.1 a	6.8b
K	26	26
Ca	5.7	6.4
Mg	2.5	2.5
S	5.9 b	7.5 a
Micronutrient (mg/kg)		
B	25 a	18 b
Cu	<0.38	<0.38
Fe	96	86
Mn	43	40
Mo	2.4 a	1.1b
Ni	9.1 a	3.7 b
Zn	52	49
Nonessential elements (mg/kg)		
Al		
Na		
As	<1.3	<1.3
Ba	5.1 a	3.3 b
Cd	0.11	0.13
Co	0.43	0.38
Cr	0.92	0.92
Pb	4.7	6.1
Se	<2.3	<2.3

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

Table 6-7. 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	2640	2830	2780
K	19700	20600	18500
Ca	4550 b	6710 a	6610 a
Mg	2390 a	1960 b	2420 a
S	3160 b	5580 a	5050 a
Al	688	90	493
B	4.0	3.6	4.0
Cu	4.2	4.1	3.7
Fe	802	209	582
Mn	246	239	276
Mo	0.51	0.57	0.66
Na	16	21	49
Zn	31	25	29
As	<1.3	<1.3	<1.3
Ba	29 a	11 b	15 b
Be	<0.09	<0.09	<0.09
Cd	0.16	0.18	0.16
Co	<0.15	<0.15	<0.15
Cr	1.8	1.1	1.6
Hg	0.013 b	0.021 a	0.015 b
Li	26 a	9.2 b	13 b
Ni	2.0	1.3	1.8
Pb	<0.77	<0.77	<0.77
Sb	1.5 b	2.5 a	2.4 ab

Chapter 7
FGD Gypsum Effects on Soil Animals

Table 7-1. 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

Means in a column for each state followed by different letters are significantly different at $P \leq 0.05$.

Table 7-2. Effects of gypsum on concentrations of elements in earthworm tissue in 2008 (Chen et al., 2009).

Element	Treatment		
	Control	FGD gypsum	Mined gypsum
	----------mg/kg ----------		
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 $P \leq 0.05$.

Chapter 8
FGD Gypsum Handling and Storage


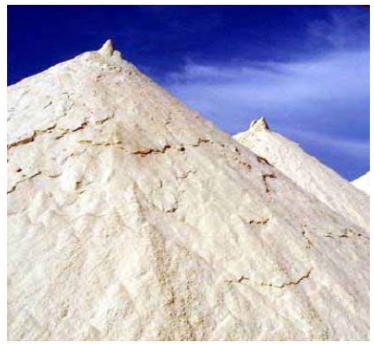


Table 7-1. Comparison of FGD gypsum storage alternatives.

FGD Storage Type	Advantages	Disadvantages
Open (not covered)	Inexpensive.	Rainfall adds extra water; Rainfall/runoff contamination potential; Runoff controls may be required.
Open (covered with plastics)	Less expensive ; No rainfall effects; Maintains FGD gypsum moisture	No feasible for long-term storage
Open sided (roof cover only)	No rainfall effects; Maintains FGD gypsum moisture	Expensive
In facility	No rainfall effects; Feasible for long-term storage; Maintains FGD gypsum moisture	Most expensive

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