NEW HORIZONS IN SOIL SCIENCE

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Using Flue Gas Desulfurization (FGD) Gypsum in Wisconsin

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Greater than 50% of the electricity produced in the USA is generated from burning coal. As a consequence of the 1990 Clean Air Act Amendment many coal-burning power plants burn low S coal and some have installed flue gas scrubbers to reduce sulfur emissions. Use of a wet scrubber results in the byproduct flue gas desulfurization (FGD) gypsum. FGD gypsum is created from a process where a stream of finely-divided calcitic lime is sprayed through the flue gasses resulting in the precipitation of calcium sulfate (gypsum). The USEPA estimated that 12 million tons were produced in 2006, with about 9 million tons beneficially reused. Approximately 80% of the material was reused for the production of wallboard. Industry experts suggest the production of FGD gypsum will double over the next 10 years with a minimal increase in demand for current uses. This gypsum source is more reasonably priced and more readily available than mined gypsum in Wisconsin. Currently, Wisconsin has two power plants in the southeastern part of the state producing FGD gypsum, with a third to come on-line in 2012. Over 500,000 tons of FGD gypsum will be produced at that time. The EPA and USDA are encouraging farmers to consider land applying this material in lieu of landfilling at great expense to society and environment. However, not all soil and agronomic benefits are fully understood or quantified.

There has been limited research on the agronomic benefit of gypsum use on Wisconsin soils resulting in modest utilization of the material by producers. Land application of gypsum has potential to be beneficial to Wisconsin crop producers through S fertilization, which ironically has become more important as S emissions decrease. Gypsum use has other claims that have yet to be documented in the state including improved soil aggregation and physical properties, enhanced N use efficiency, and reduction of dissolved P losses in runoff. Gypsum also contains calcium. Calcium fertilization is unnecessary for most field crops on Wisconsin soils, however research has shown yield and quality benefits for potato. Because gypsum contains Ca some

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believe that it can be used as lime to increase soil pH. This belief is erroneous since it is the carbonate anion (CO_3^{2-}) in lime that actually neutralizes the H^+ in the soil.

As gypsum improves the chemical and physical properties of a soil, agronomic productivity would also be expected to increase. A recent Ohio study showed a tendency for increased corn grain yield at low nitrogen (N) fertilizer rates when the N was applied in combination with gypsum suggesting that gypsum can decrease the amount of N required for corn production. This would reduce production costs and improve N use efficiency reducing the risk of N loss to the environment.

Wisconsin FGD research

Several small plot research studies are being conducted with FGD material by the authors. FGD gypsum was obtained for all studies from a power plant near Kenosha operated by We Energies. This material has the consistence of damp flour and is relatively easy to handle with little dust. However, if allowed to air dry the finely-divided nature of the product would make it difficult to spread in the presence of even a light breeze. FGD gypsum is typically purer than mined deposits. A comparative analysis for two materials from an Ohio State University publication is shown in Table 1.

Table 1. Elemental analysis of a FGD gypsum and commercially available mined gypsum fertilizer (Source: OSU Extension Factsheet ANR-20-05).

Material	Ca	S	Mg	As	Cd	Cr	Co	Cu	Pb	Hg	Mo	Ni	Se	Zn
	------- % --------			---------------- ppm ----------------										
FGD	23.0	18.6	0.03	0.56	<0.48	1.30	<0.48	1.16	0.80	<0.26	0.51	0.73	5.51	3.88
Mined	19.1	15.2	1.35	<0.52	<0.48	1.38	0.53	1.33	2.92	<0.26	1.28	1.42	<1.45	0.91

Alfalfa Studies

Research studies were established as a portion of a national project examining the land application of FGD gypsum that is being coordinated by Dr. Warren Dick of The Ohio State University. Dr. Darrell Norton of the USDA National Soil Erosion Laboratory located at Purdue University is cooperating on the project. It is anticipated that data collected through the project will be presented to the EPA to encourage land application programs for FGD gypsum.

Small plot studies were established on a Plano silt loam soil in separate locations at the Arlington Agricultural Research Station in 2009 and 2010. Each plot received applications of either FGD gypsum or a commercially available pelletized mined gypsum at rates of 1, 2, and 4 tons/acre. Materials applied in 2009 were incorporated by tillage and then seeded to alfalfa, whereas materials applied in 2010 were broadcast to the surface over a recently seeded field prior to emergence. Two cuttings were collected from each site in their respective seeding year and three cuttings were collected in the first hay year for the site seeded in 2009. Other measurements collected include plant elemental composition, aggregate stability, bulk density, and penetrometer resistance. A stated concern associated with the use of FGD gypsum is the release of Hg that exists in trace amounts in the coal and is volatilized when burned and becomes trapped in the FGD gypsum. Shallow porous cup samplers were installed in the control, and the 4 ton/acre treatments of both gypsum materials to determine if Hg is migrating through the soil. Results for these samples have not been made available, but related projects in other states have not shown that Hg levels were increased in the soil water where FGD gypsum was applied.

The first hay-year yield response for alfalfa seeded in 2009 and the seeding year yield response for 2010 are shown in Table 2. There was no residual effect of the 2009 application as measured in 2010. The 4 t/acre treatments would have applied over 1400 lb S/acre, and it should be safe to assume that the site was not responsive to S. The alfalfa seeded in 2010 did respond to FGD gypsum compared to the commercial material in the first cutting. This response did not continue in the second cutting, nor was total yield affected. This analysis did not statistically compare the untreated control, but visually it would appear there was some response to gypsum. Elemental analysis of the samples, when completed, may indicate whether the response was to S or was due to an improvement in the soil condition.

Gypsum is claimed to improve soil aggregation, which would be expected to reduce bulk density, thereby increasing porosity. Fall measurement of bulk density core samples and in situ data collected for hydraulic conductivity for the 2010 seeded alfalfa study are shown in Table 3. Neither parameter was affected by treatment; however there was an apparent trend for an increase in hydraulic conductivity where gypsum was applied. Figure 1 shows the penetration resistance measured at approximately the same time from the plots. An increase in hydraulic conductivity may have lead to the significant reduction in penetration resistance at a depth of about one foot in these plots. Higher moisture content would be expected to reduce penetration resistance. Unfortunately moisture measurements at depth were not collected to confirm the response.

Corn Tillage x N x FGD Gypsum Study

A study was initiated in 2010 to examine the response of corn to N in the presence of gypsum. As previously mentioned researchers in Ohio found that less N was needed in no-till corn where gypsum was applied. Their study suggested the gypsum helped the crop overcome S deficiency, and improved N use efficiency.

A plot area that had been in no-till corn for the past two seasons was selected at the Arlington Agricultural Research Station in a field that had received sub-optimal N in the previous season. A split-split plot treatment arrangement with three replications was established where the main plot was tillage (spring chisel/field cultivator or no-till w/residue managers), the subplot was N rate (0 to 150 lb N/acre in 30 lb N/acre increments), and gypsum (with or without 1 ton/acre FGD gypsum) that was surface applied shortly after planting. The N was applied as urea on 21 April 2010 and the appropriate plots were immediately chisel plowed. Corn (DeKalb DKC52-59) was planted on 28 April 2010 with 150 lb 9-23-30/acre applied to all plots. The FGD gypsum was applied 29 April 2010. Measurements taken in 2010 include earleaf mineral nutrient content and grain yield.

Table 2. Yield of alfalfa for plots treated with FGD gypsum and commercially available pelletized mined gypsum, Arlington, Wis., 2010.

Treatment	Alfalfa yield				Stand
	Cut 1	Cut 2	Cut 3	Total	
	---------------------------- ton DM/acre			--------------------------	Plants/sq ft
Seeded 2009					
Control	1.8	1.2	1.1	4.2	6.4
FGD 1 t/acre	1.8	1.2	1.2	4.2	5.8
FGD 2 t/acre	1.8	1.4	1.2	4.3	5.6
FGD 4 t/acre	1.7	1.2	1.1	4.0	5.5
Fert. Gyp. 1 t/acre	1.8	1.3	1.2	4.3	5.8
Fert. Gyp. 2 t/acre	1.8	1.2	1.2	4.2	6.5
Fert. Gyp. 4 t/acre	1.8	1.5	1.0	4.2	5.8
Pr > F					
Source	0.88	0.24	0.49	0.69	0.20
Rate	0.10	0.61	0.05	0.26	0.44
S * R	0.55	0.08	0.29	0.59	0.44
Seeded 2010					
Control	1.2	1.0	--	2.2	--
FGD 1 t/acre	1.3	1.2	--	2.5	--
FGD 2 t/acre	1.3	1.3	--	2.6	--
FGD 4 t/acre	1.3	1.2	--	2.5	--
Fert. Gyp. 1 t/acre	1.1	1.2	--	2.4	--
Fert. Gyp. 2 t/acre	1.1	1.3	--	2.4	--
Fert. Gyp. 4 t/acre	1.2	1.3	--	2.6	--
Pr > F †					
Source	0.04	0.86	--	0.28	--
Rate	0.60	0.58	--	0.76	--
S * R	0.44	0.77	--	0.43	--

†Analyzed as a 2 source x 3 rate factorial. The control was not included in the AOV.

Table 3. Measurement of selected soil physical properties as affected by gypsum application to alfalfa, Arlington, Wis., 2010.

Treatment	Bulk density	Saturated hydraulic conductivity
	g/cc	cc/hr
Control	1.36	3.08
FGD 4 t/acre	1.33	4.74
Fert. Gyp. 4 t/acre	1.34	3.72
Pr > F	0.85	0.42
LSD	NS †	NS

† NS = not significant.

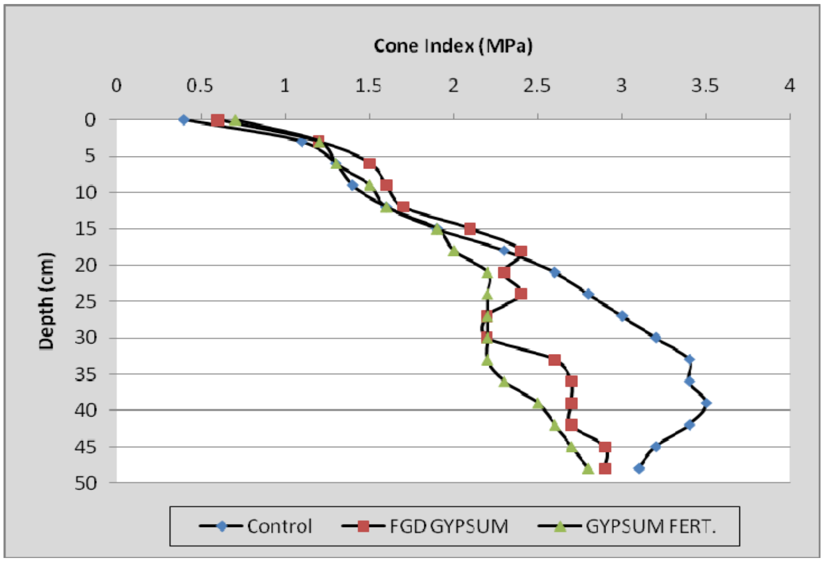

Figure 1. Penetration resistance measured in the 2010 seed FGD gypsum study, Arlington, Wis., 2010

Table 4 shows the corn grain yield response to tillage, N fertilization, and FGD gypsum application at Arlington in 2010. The response to tillage was significant at the p=0.10 level in favor of chisel compared to no-till. Most of this response was found at the sub-optimal rates of N, but where recommended rates of N were applied yields were nearly equivalent. The site was very responsive to N and the interaction between N rate and FGD gypsum was significant at the p=0.10 level. The interactive trend showed depressed yield where FGD gypsum was applied at the lower N rates, but equivalent or increased yield where at the higher N rates. This data set represents one year of study and the value of FGD gypsum as a tool to increase N use efficiency is not yet confirmed by the research. The study will be repeated in 2010.

Table 4. Grain yield response of corn to tillage, N fertilization, and FGD gypsum application, Arlington, Wis., 2010.

		N rate (lb N/acre)					
Tillage	FGD	0	30	60	90	120	150
		bu/acre					
Chisel	-	131	147	196	215	225	229
	+	115	139	174	213	227	238
No-till	-	123	143	179	188	210	229
	+	99	144	171	208	208	228
Pr > F							
Tillage	0.09	N rate	<0.01				
FGD	0.20	T * N	0.62				
T * F	0.57	N * F	0.10				
		T * N * F	0.64				

Evaluation of FGD Gypsum as a Soil Amendment

In addition to the obvious benefit of FGD gypsum as a S source, there have been claims that gypsum can improve the soil physical condition, thereby increasing yield. There has also been the suggestion that gypsum could reduce P in runoff. The reduction in P loss has both been attributed to improved infiltration from better aggregation and a reduction in soluble P in the surface soil. The red soils of eastern and northern Wisconsin may be the most responsive to such a treatment. Eleven on-farm sites were selected (eight in Brown Co. and three on the Lake Superior Clay Plain in Douglas/Bayfield Co.) where replicated small plot studies were established in the spring of 2010. Preference was given to high soil test P sites when possible. All but one site in Douglas Co. were planted to corn and that site was planted to soybean. Shortly after planting by the cooperator treatments of none, 0.5, 1, and 2 tons/a FGD gypsum were surface broadcast (not incorporated) to the fields. A separate treatment consisted of 30 lb S/acre applied as pelletized commercial gypsum fertilizer.

Data collected in 2010 will include corn earleaf or soybean trifoliate nutrient content, routine soil test, 0 to 2 inches dissolved reactive soil P (DRP) at 30 and 90 days after application, soil penetrometer resistance, and grain yield. Selected sites will also be evaluated for infiltration, bulk density, and water retention. Dr. Meghan Buckley of the UW-Stevens Point is conducting the latter tests. Site characteristics are shown in Table 5. Note the relatively light texture of the soils in the Brown Co. and the heavy texture in Bayfield Co. The producer on the clay soil (PTG site) rotates small grains and soybean in a completely no-till operation.

Data from all experiments were statistically analyzed using the appropriate method for an analysis of variance. Where statistical difference is observed at the p=0.05 level means will be separated by a Fisher's LSD.

Table 5. Site characteristics of the on-farm FGD studies, 2010.

Site ID	Web soil survey name	Physical analysis			Texture	Soil test P
		Sand	Silt	Clay		
E. Wis.		-----------	%	-----------		ppm
COG	Manawa silty clay loam	47	37	16	Loam	59
JUG	Kewaunee silt loam	31	51	18	Silt loam	23
STG	Kewaunee silt loam	53	33	14	Sandy loam	36
SVG	Namur silt loam	61	29	10	Sandy loam	35
SZG	Sisson fine sandy loam	53	26	14	Sandy loam	49
VHG	Kewaunee silt loam	41	40	19	Loam	63
VWG	Oshkosh silt loam	35	42	23	Loam	62
WEG	Oshkosh silt loam	43	35	22	Loam	83
N. Wis.						
JOG	Amnicon-Cuttre complex	27	34	39	Clay loam	24
PTG	Amnicon-Cuttre complex	19	34	47	Clay	45
SYG	Amnicon-Cuttre complex	34	26	40	Clay loam	7

The grain yield for several of the sites is shown in Table 6. Unfortunately some of the sites were harvested by the farmer as silage. Crop growth was extremely variable in 2010 at several of the sites because of heavy rains and the inconsistent surface drainage that is common to these soils. Therefore, while some trends were apparent significant differences were observed only at the PTG site (soybean). The response at the SVG site was significant at the p=0.10 level. It is anticipated that this study will be repeated in 2011 at a similar number of sites.

Table 6. Grain yield from the on-farm FGD gypsum studies, 2010.

	Site						
Treatment	COG	STG	SVG	SZG	SYG	JOG	PTG†
	---------- bu/acre ----------						
Control	157	210	195	178	148	179	47
30 lb S/acre	166	226	208	169	159	164	49
FGD 0.5 t/acre	138	213	212	177	170	158	56
FGD 1 t/acre	144	213	220	176	181	170	44
FGD 2 t/acre	135	217	217	191	194	164	48
Pr > F	0.76	0.79	0.10	0.33	0.49	0.44	<0.01
LSD	NS ‡	NS	NS	NS	NS	NS	4

† Soybean yield.
‡ NS = not significant.

The effect of treatment on selected soil physical properties was measured at several of the sites. Most of this data has not been fully analyzed at this writing; however, a summary of the bulk density for five sites is shown in Table 7. These data did not show large differences in soil bulk density.

Table 7. Soil bulk density measured at selected on-farm FGD gypsum studies, 2010.

	Site				
Treatment	JOG	SYG	WEG	VHG	COG
	---------- g/cc ----------				
Control	1.11	1.10	1.43	1.27	1.32
FGD 0.5 t/acre	1.21	0.99	1.44	1.25	1.35
FGD 1 t/acre	1.19	1.02	1.44	1.27	1.35
FGD 2 t/acre	1.19	1.09	1.50	1.26	1.35

The most interesting claim associated with the application of FGD gypsum is its potential effect on reducing dissolved reactive phosphorus (DRP), which is the soluble P that could be carried off fields in runoff. It has been suggested that gypsum would reduce DRP loss through a combination of precipitation with Ca and improved internal drainage. DRP is simply calculated by measuring the filtrate after extracting a soil sample with distilled water. Soil samples were collected in 2010 from the 0- to 2-inch depth at 30 and 90 days after application from all sites. Results for the VHG and SVG sites are shown in Table 8. These soils had an average soil test P of 63 and 35 ppm in the plowlayer, respectively.

These preliminary data show that the addition of FGD gypsum significantly decreased the DRP at the VWG site and showed a trend at the SVG site as measured on these samples collected 30 days after application. The 1 and 2 t/acre rates appeared to have the best effect. Note also that the relative concentration of DRP was consistent with the soil test levels for the sites, where higher DRP was found on the higher testing site. More confirmation on the efficacy of this practice will be gained once all samples from both times of sampling are analyzed. The significance of this response does suggest that the FGD gypsum may be a tool for reducing DRP in runoff, but more importantly the overall management of soil test P must be considered first to avoid the unnecessary P buildup in the soil.

Table 8. Dissolved reactive P measured 30 days after application from two sites treated with FGD gypsum, 2010.

	Site	
Treatment	SVG	VWG
	----------- ppm -----------	
Control	1.97	5.93
FGD 0.5 t/acre	1.33	4.74
FGD 1 t/acre	0.92	2.33
FGD 2 t/acre	0.78	1.83
Pr > F	0.15	<0.01
LSD	NS	2.27

Summary

Several studies were conducted in Wisconsin in 2010 to evaluate the efficacy of relatively high rates of gypsum, specifically FGD gypsum collected from coal burning power plants. None of the studies demonstrated substantial yield effects, and those that showed response may be due to S addition. Soil physical properties were not affected, in general, by FGD application, but there was evidence at one site that penetration resistance was reduced at depth where either FGD or commercial gypsum was applied at a high rate. This may be due to changes in soil water properties that would affect the resistance measured by the probe. The most interesting response measured in 2010 was that for dissolved reactive P from the surface of soils treated with high rates of gypsum. Preliminary data show that the DRP was reduced where 1 to 2 ton/acre of FGD gypsum was applied to the surface post-planting. While these data are promising no recommendation for FGD gypsum can be made beyond its proven benefit as a calcium and sulfur source for plants.

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