Increased Crop Yield and Economic Return and Improved Soil Quality Due to Land Application of FGD-Gypsum

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ABSTRACT

Combustion of coal for production of electricity in the United States often requires the removal of SO_2 produced in the flue gas in order to meet clean air regulations. Some scrubbing technologies lead to the production of large amounts of flue gas desulfurization (FGD)-gypsum. Gypsum is a soluble source of the plant nutrients Ca and S and can also improve the physical and chemical properties of soils. However, there are few reports on the use of FGD-gypsum for enhancement of crop growth or soil quality in agriculture. FGD products, used as S fertilizers, were applied at a rate of 30 lbs S/acre to an agricultural soil (Wooster silt loam, Typic Fragiudalf). Corn (*Zea mays*) grain yield was statistically ($P \leq 0.05$) increased by 18.3% in 2002 and 6.6% in 2003 as compared to a no-treatment control. Based upon measurements of soil chemical properties, the quality of a Blount soil (Aeric Epiaqualf) in Ohio was improved by application of 1,500 to 3,000 lbs of FGD-gypsum/acre. Water-soluble Ca and S were increased to a depth of 80 cm and exchangeable Al was decreased between 10 and 40 cm depth. Preliminary results of an economic analysis suggested that a gypsum/no-tillage crop production system had economic advantages compared to a no gypsum/conventional tillage system for soybean production.

INTRODUCTION

In the United States, use of high S coal for energy often requires the SO_2 produced during burning be removed to meet the clean air regulations. The materials produced during scrubbing are given the generic name of flue gas desulfurization (FGD) products. FGD products are typically composed of $CaSO_4$, $CaSO_3$, unreacted sorbent and coal combustion ash (Chen et al., 2001; Laperche and Bigham, 2002). Forced air oxidation procedures bring about the production of high quality gypsum from some FGD waste streams. This FGD-gypsum is suitable for industrial (e.g. wallboard) applications and has the potential to be used in major new FGD-gypsum markets for the agricultural sector.

Sulfur and Ca are essential macroelements for plant growth. Gypsum is a quality source of both Ca and S for plant nutrition (Shainberg, 1989; Chen et al., 2005). It is one of the earliest forms of fertilizer in the U.S., having been applied to agricultural soils for over 250 years (Tisdale et al., 1985). Gypsum amendments can also improve the physical properties of soils (especially heavy clay soils) by promoting soil aggregation and by increasing water surface infiltration rates and movement into and through the soil profile (Miller, 1987; Norton and Dontsova, 1998). Chemical properties improved by application of gypsum include the mitigation of subsoil acidity and Al toxicity (Farina and Channon, 1988; Sumner, 1970; Reeve and Sumner, 1972; Pavan et al., 1984). This enhances deep rooting and the ability of plants to access adequate supplies of water and nutrients during drought periods (Ritchey et al., 1995).

The objectives of this research were (1) to determine the suitability of FGD-gypsum as a S fertilizer source and soil amendment for agricultural use during production of corn; (2) to evaluate the effects of FGD-gypsum on the chemical properties of soils; and (3) to evaluate economic benefits of land application of FGD-gypsum to no-tillage agricultural fields in Ohio.

MATERIALS AND METHODS

Two sources of FGD product were used in these studies. One was a material from Sorbent Technologies Corporation (Twinsburg, OH) produced when a perlite based sorbent removed S from the flue gases. The other was an FGD-gypsum wet scrubber material obtained from Cinergy Corporation (Cincinnati, OH). Some selected properties of these materials are reported in Table 1.

For three consecutive years (i.e. from 2002 to 2004), a S by N interaction for corn production was determined on a Wooster silt loam (Table 2) at The Ohio Agricultural Research and Development Center (OARDC), Wooster, Ohio. Nitrogen fertilizer (NH_4NO_3) was applied at rates equivalent to 0, 60, 90, 120, 150, 180 and 210 lbs N/acre. Sulfur fertilizer was applied as FGD product at rates of 0 and 30 lbs S/acre. In 2002, the S material used was from Sorbent Technologies Corporation and in 2003-2004 the S material used was FGD-gypsum from Cinergy Corporation. These treatments were surface applied by broadcast and immediately incorporated 8 inches into the soil. Corn was planted at a population of 34,000 plants/acre at a row width of 2.5 feet, and corn was harvested from the middle two rows.

Table 1. Concentrations of major and trace elements in the flue gas desulfurization (FGD) product or FGD-gypsum.

Element	FGD product[a]	FGD-gypsum[a]
Major element	------------------------------g kg^{-1}	---------------------------------
Al	19.6	0.292
Ca	260	230
Mg	27.1	0.3
S	67.1	187
Fe	16.5	0.045
Trace element	-----------------------------mg kg^{-1}	--------------------------------
As	118	0.56
B	194	55.1
Ba	122	
Cd	<0.12	<39
Cr	123	<37
Cu	1.57	<42
Mn	302	<2.6
Mo	13.2	<65
Ni	72.4	<44
Pb	139	<26
Se	<6.0	0.87
Zn	33.2	<21

[a]FGD product was from Sorbent Technologies Corporatation and FGD-Gypsum was from Cinergy Corporation.

Table 2. Selected characteristics of the Wooster silt loam soil (0-20 cm depth) before application of fertilizers.

pH	Available P	Exchangeable Cations			CEC[a]	Total N	Total C
		K	Ca	Mg			
	-------------------	mg kg^{-1}	---------------		$cmol_c kg^{-1}$	------- %	-------
6.75	27	125	1047	208	7.4	0.114	1.04

[a] Cation exchange capacity

In 2004, a new experiment site was established at the OARDC Northwest Station, Wood County, Ohio. FGD-gypsum application rates were 0, 1500, and 3000 lbs/acre under a no-tillage system. Corn was planted at a population of 34,000 plants/acre at a row width of 2.5 feet on April 29 as the test crop and corn grain yield was measured.

A study of soil chemical properties was carried out in the soil from the plots on a Blount silty clay loam in Crawford County, Ohio under a no-tillage management system. The treatments were a control compared to areas treated with surface-applied FGD-gypsum at rates of 1500 and 3000 lbs/acre in April, 2003 and April 2004. The experiment was arranged in a randomized block design with four replications. Soil samples were collected in October, 2004 to a depth of 110 cm using a hydraulic coring device. The samples were air-dried, crushed, and sieved through a 2-mm sieve. The water-soluble Ca and Mg were analyzed by atomic absorption spectroscopy and water-soluble S was obtained by using ion chromatography. Exchangeable Al was extracted with 1 M KCl and determined by a titration method.

Economic benefits of land application of FGD-gypsum to no-tillage agricultural fields in Ohio were evaluated by surveying farmers from seven counties in north and northwest Ohio. The farmers were selected as pairs with one farmer of each pair using a gypsum/no-tillage crop production system and the other nearby farmer using a no-gypsum/conventional tillage system. The return on investment of a gypsum/no-tillage system was compared with a no-gypsum/conventional tillage system. The paired analysis was performed for corn production on five farmer pairs and for soybean production on four farmer pairs.

RESULTS AND DISCUSSION

Fertilizer S by N interaction for corn. In 2002, corn grain yield was increased when applied in combination with S in the FGD product (Table 3). Because of drought at Wooster in 2002, the corn yield for this year was significantly decreased compared with normal years.

In 2003, corn grain yields increased more at low N fertilizer rates, when applied with S, than at high N fertilizer rates (Table 3). The optimum N rate treatment was at 180 lbs N/acre and 30 lbs/acre of S. Sulfur treatment significantly ($P \leq 0.05$) increased the overall average yield of corn from 150 bu/acre for the no S control to 159 bu/acre for the 30 lbs/acre S treatment---a 6.6% increase).

In 2004, corn grain yields again were impacted by S fertilizer additions in a way that was similar to results observed in 2003, i.e. the relative yield of corn when S was applied at low N fertilizer rates was greater than at high N rates (Table 3). Sulfur treatment increased corn yield when N was applied at rates of 0 to 120 lbs/acre. However, S treatment decreased corn yield when N was applied at the rates from 150 to 210 lbs/acre.

The above results clearly indicate the site where the experiment was conducted was deficient in S. When S fertilizer was applied, it increased corn grain yield, especially when applied in combination with low N fertilizer rates. This suggests that one way to improve the efficiency of fertilizer N use is to add S with N fertilizer when growing corn. This will not only improve the profit of farmers since less fertilizer N is needed to achieve good yields, but also will prevent nitrate contamination due to excess fertilizer N use during years when yields do not reach expected levels.

Table 3. Effects of N and S on corn yield on Wooster silt loam soil from 2002 to 2004.

N Rate	Corn Yield (bu/acre)		Increase by S
	No S	30 lbs S/acre	%
		2002	
0	37.2	38.1	2.5
60	35.1	38.4	9.3
90	33.4	40.8	22.0
120	36.7	37.1	1.0
150	33.8	45.5	34.5
180	40.2	44.2	10.1
210	36.4	39.1	7.4
		2003	
0	110	121	10.0
60	151	156	3.3
90	140	156	11.4
120	159	166	4.4
150	158	166	5.1
180	164	178	8.5
210	167	171	2.4
		2004	
0	117	122	3.8
60	128	149	16.0
90	148	158	6.9
120	160	189	18.2
150	170	167	-1.9
180	171	161	-5.7
210	186	167	-10.2
Overall Means	113	120	6.2

FGD-gypsum as a no-tillage soil amendment. The FGD-gypsum treatment had a positive effect on corn grain yield when applied to no-tillage plots (Figure 1). When gypsum application rate was 1500 lbs/acre, corn grain yield was increased by 3 bu/acre (1.9%). When gypsum application rate was 3000 lbs/acre, corn grain yield was increased 14 bu/acre (8.8%).

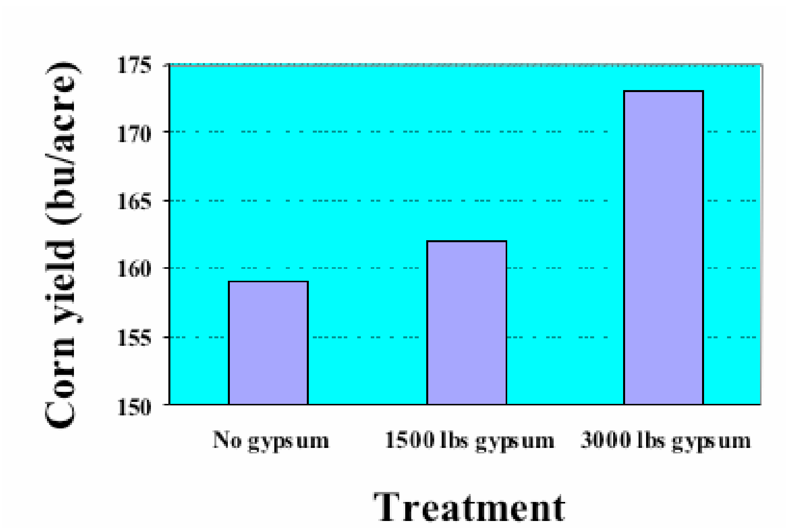

Figure 1. Corn grain yield at OARDC Northwest Station in 2004 as affected by application of FGD-gypsum.

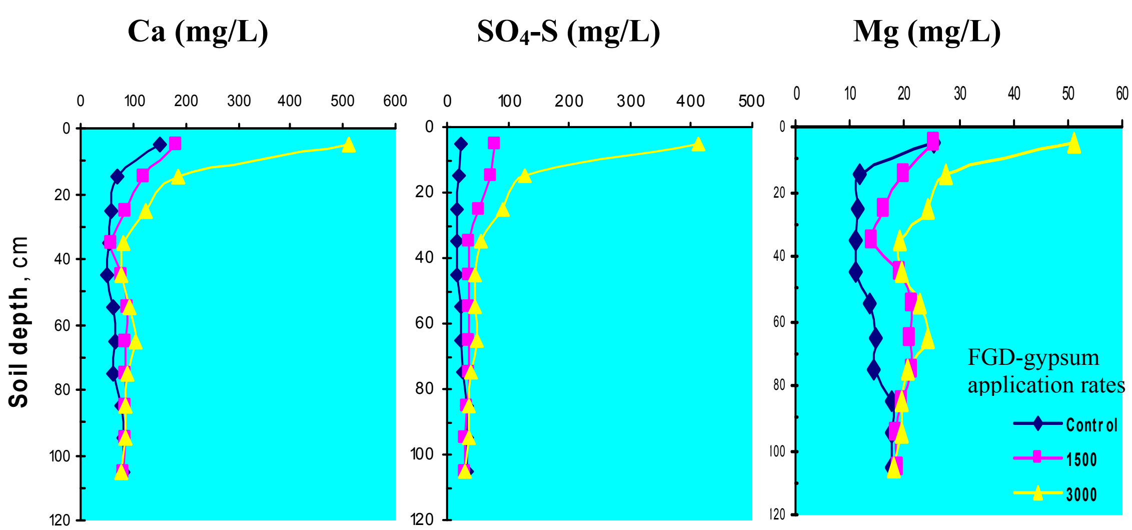

Figure 2. Effects of surface-applied FGD-gypsum on water soluble Ca, SO_4-S and Mg at different soil depths.

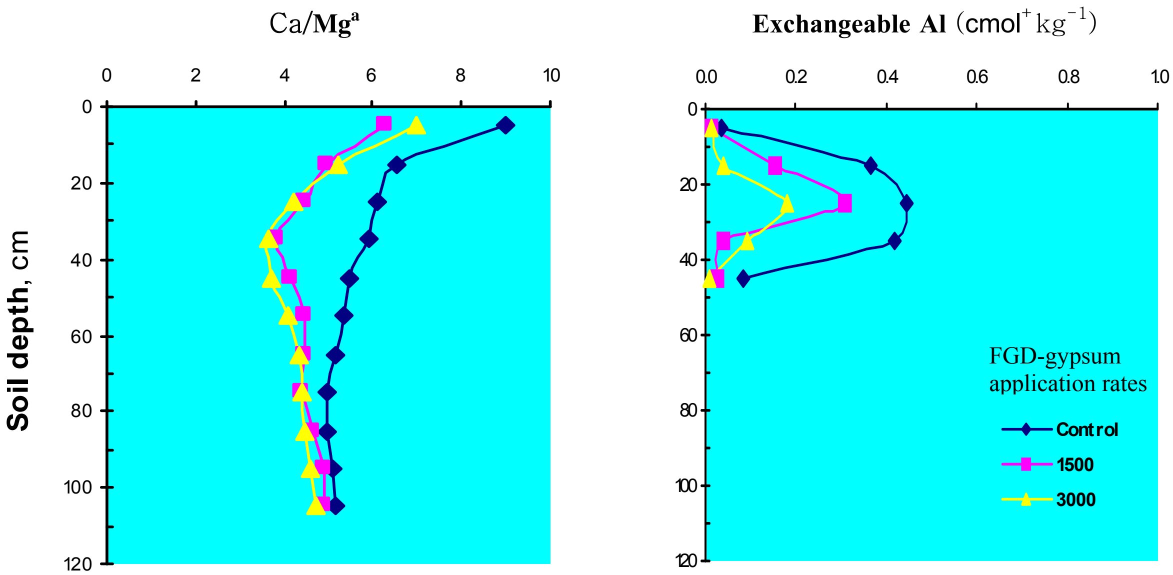

Figure 3. Effects of surface-applied FGD-gypsum on water-soluble Ca/Mg (meq/meq) and exchangeable Al at different soil depths.Ca/Mg = water soluble Ca (meq L^{-1})/water soluble Mg (meq L^{-1})

FGD-gypsum effects on soil chemical properties. FGD-gypsum treatments increased water-soluble Ca and S to a depth of 80 cm (Figure 2). Water-soluble Mg also increased even though the FGD-gypsum contained very low concentrations of total Mg. This result, together with a decrease in the soluble Ca/Mg ratios (Figure 3), indicated that Mg on the soil exchange complex was displaced by soluble Ca from applied gypsum. There was also a measurable decrease in exchangeable Al between 10 and 40 cm depth following gypsum application (Figure 3).

Economic benefits of FGD-gypsum application for no-tillage crop production. Total cost per acre for production of using the gypsum/no-tillage system was $321.41/acre while for the no-gypsum/conventional tillage system it was $374.64/acre. However, the economic return (i.e. profit) difference between the two systems was not significantly different because slightly lower yields associated with the gypsum/no-tillage system. It is well known that there is a transition period associated with converting from conventional tillage to no-tillage and so the profit returns associated with each system are likely to change. Total cost per acre for soybean production using the gypsum/no-tillage system was $228.50/acre while for the no-gypsum/conventional tillage it was $272.25/acre. The average return per acre (i.e. profit) for the gypsum/no-tillage soybean was $78.90/acre while that for no-gypsum/conventional tillage was only $18.07/acre. The results indicated that the gypsum/no-tillage system had economic advantages compared to the no-gypsum/conventional tillage system. However, because of the limited sample size, conclusions are considered preliminary in nature.

CONCLUSIONS

FGD-gypsum is a soluble source of Ca and S, thus improving plant nutrition. FGD products, applied at rates sufficient to supply 30 lbs/acre of S, increased corn grain yields over a three year period from 113 bu/acre to 120 bu/acre. The relative yields of corn grain were greater at low N than at high N fertilizer rates suggesting improved N use efficiency. This will provide more profit to farmers and help reduce N pollution of the environment. In addition to improving nutrient levels in soil, FGD-gypsum applied at much higher rates (1,500-3,000 lbs/acre) also improves soil physical properties. This resulted in increased yield of corn grain under a no-tillage system, presumably by promoting soil aggregation and by increasing water surface infiltration rates and water movement into and through the soil profile. Chemical properties improved by application of FGD-gypsum include the mitigation of subsoil acidity and Al toxicity. Preliminary results suggest that the gypsum/no-tillage system had economic advantages compared to the no-gypsum/conventional tillage system for soybean production.

REFERENCES

Chen, L. W.A. Dick, and S. Nelson. 2001. Flue gas desulfurization by-products additions to acid soil: alfalfa productivity and environmental quality. Environmental Pollution 114, 161-168.

Chen, L. W.A. Dick, and S. Nelson. 2005. Flue gas desulfurization by-products as sulfur sources for alfalfa and soybean. Agronomy Journal 97:265-271.

Farina, M.P.W., and P. Channon. 1988. Acid-subsoil amelioration: II. Gypsum effects on growth and subsoil chemical properties. Soil Sci. Soc. Am. J. 52:175-180.

Laperche, V., and J.M. Bigham. 2002. Quantitative chemical and mineralogical characterization of flue gas desulfurization by-products. J. Environ. Qual. 31:979-988.

Miller, W.P. 1987. Infiltration and soil loss of three gypsum amended Ultisols under simulated rainfall. Soil Sci. Soc. Am. J. 51:1314-1320.

Norton, L.D., and K. Dontsova. 1998. Use of soil amendments to prevent soil surface sealing and control erosion. Adv. Geoecology 31:581-587.

Pavan, M.A., F.T. Bingham, and P.F. Pratt. 1984. Redistribution of exchangeable calcium, magnesium, aluminum following lime or gypsum applications to a Brazilian Oxisol. Soil Sci. Soc. Am. J. 48:993-997.

Reeve, N.G., and M.E. Sumner. 1972. Amelioration of subsoil acidity in Natal Oxisol. Soil Sci. Soc. Am. J. 48:993-997.

Ritchey, K.D., C.M. Feldhake, R.B. Clark, and D.M.G. de Sousa. 1995. Improved water and nutrient uptake from subsurface layers of gypsum-amended soils. p. 157-181. In: D.L. Karlen, R.J. Wright, and W.O. Kemper (eds). Agricultural Utilization of Urban and Industrial By-Products. ASA Special Publication No. 58, American Society of Agronomy, Madison, WI, USA.

Shainberg, I., M.E. Sumner, W.P. Miller, M.P.W. Farina, M.A. Pavan, and M.V. Fey. 1989. Use of gypsum on soils: A review. Adv. Soil Sci. 9:1-11.

Sumner, M.E. 1970. Aluminum toxicity--- a growth limiting factor in some Natal sands. Proceedings of the Annual Congress of South African Sugar Technology Association 44:1-6.

Tisdale, S.L., W.L. Nelson, and J.D. Beaton. 1985. Soil fertility and fertilizers, 4th ed. Macmillan Publishing Company, New York, NY, USA.