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Interaction of Nitrogen and Flue Gas Desulfurization Sulfur for Production of Corn

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ABSTRACT

Nitrogen deficiency in soil often limits corn (*Zea mays* L.) growth, thus requiring fertilizer N inputs to achieve optimum yields. Nitrogen fertilizer is becoming more expensive and methods are needed to improve N use efficiency. Sulfur deficiency in several crops, including corn, has recently been observed in Ohio. However, little information is available related to the interaction of N and S fertilizers to affect the production of corn. Field experiments were conducted on a silt loam soil at Wooster, Ohio from 2002 to 2005 to test corn responses to the addition of N (seven rates from 0 to 233 kg ha^{-1}) as NH_4NO_3 and S (two rates of 0 and 33 kg ha^{-1}) from flue gas desulfurization (FGD) products. Corn grain yields, averaged over 4 years, were increased 7.0% when S was applied. This increase was statistically significant ($P \leq 0.05$). A statistically significant interaction effect of N by S was observed in 2004 and 2005 with the low N rates from 0 to 133 kg ha^{-1} responding better to S than the high N rates. The highest grain yields were reached at the 133 kg N ha^{-1} application rate with S addition. This suggests that S application can improve N use efficiency and decrease the amount of N required for optimum corn production. Reduced N fertilizer application rates reduce input costs and can also help maintain good water quality. Nitrogen, P, K, Mg and S in corn grain were slightly increased by application of 33 kg ha^{-1} of S when N was applied at rates of 100 and 200 kg ha^{-1}. These results indicate application of N fertilizer with S promoted uptake, by corn plants, of N and other major plant nutrients.

INTRODUCTION

Nitrogen is a key nutrient limiting yields of corn. Economically optimal N fertilizer rate varies among fields and is influenced by a number of factors including soil conditions. Sulfur is also an essential element for higher plants. In recent years, deficiencies of S in crops have increased worldwide. Plant requirement for S is closely related to N nutrition. Flue gas desulfurization (FGD) products are created when coal is burned and SO_2 is removed from the flue gas. The FGD products contain sulfates, especially gypsum ($CaSO_4.2H_2O$), which is an excellent source of S for corn. The objectives of this study were to evaluate FGD products as S fertilizers and to assess the interaction of N and S fertilizer addition on the yield and element composition of corn grain and plant available nutrients in soil.

MATERIALS AND METHODS

For four consecutive years (from 2002 to 2005), field experiments for corn production were conducted on an agricultural soil (Wooster silt loam, Oxyaquic Fragiudalf) near Wooster, Ohio. Before treatments were applied, soil samples (0-20 cm) were collected and analyzed as described in Sparks et al. (1996) to determine fertility status (Table 1). Two sources of S fertilizer (FGD- product and FGD-gypsum) were used in this study. Some selected properties of these materials are reported in Table 2.

Table 1. Selected characteristics of the Wooster silt loam soil (0-20 cm depth) from 2002-2005 corn fields before application of N and S fertilizers.

Year	pH	Available P	Exchangeable Cations K	Exchangeable Cations Ca	Exchangeable Cations Mg	CEC†	Available SO_4-S	Organic Matter
		mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	cmol$_c$kg^{-1}	mg kg^{-1}	g kg^{-1}
2002-2003	6.8	27.0	125	1050	208	7.4	33.9	25.2
2004-2005	6.9	29.0	102	1170	245	8.1	46.7	30.1

†Cation exchange capacity

Nitrogen fertilizer (NH_4NO_3) was applied at rates of 0, 67, 100, 133, 167, 200 and 233 kg N ha^{-1} and S fertilizer (FGD-product in 2002 or FGD-gypsum in 2003, 2004 and 2005) was applied at rates of 0 and 33 kg S ha^{-1}. The experimental design was a split-plot in a randomized complete block with four replicates.

Table 2. Concentrations of major and trace elements in the flue gas desulfurization (FGD) product and FGD-gypsum.

Element	FGD product†	FGD-gypsum
Major element	g kg^{-1}	
Al	19.6	0.228
Ca	260	213
Mg	27.1	0.112
S	67.1	164
Fe	16.5	0.222
Trace element	mg kg^{-1}	
As	118	<11
B	194	5.8
Ba	122	5.5
Cd	<0.12	<1.0
Cr	123	<1.0
Cu	1.57	<3.0
Mn	302	1.3
Mo	13.2	<3.0
Ni	72.4	<3.0
Pb	139	<5.0
Se	<6.0	<25.0
Zn	33.2	4.8

†FGD product was from Sorbent Technologies Corporatation (Chen et al., 2005) and FGD-gypsum was from Cinergy Corporation.

In 2002, the annual total precipitation and the total rainfall from May to September of corn growing season were 901 and 346 mm, which were below normal and below the typical water requirement of 510 to 560 mm during the corn growing season. As a result, 2002 was very dry during the growing season. From 2003 to 2005, the annual total precipitation was1275, 1255, and 965 mm, and the total rainfall from May to September of corn growing season was 830, 731, and 490 mm. It provided enough water for corn growth. In 2002 and 2003, the grain was analyzed for N and other elements. In 2003 and 2005, soil samples were collected from the plots treated with 0 and 200 kg N ha^{-1} from depth of 0 to 30 cm. Soil samples were extracted with Mehlich-III extractant (Mehlich, 1984) and extracted elements were determined by inductively coupled plasma (ICP) emission spectrometry. Data were subjected to analysis of variance (ANOVA) using the PROC GLM statement of the SAS statistics program. When ANOVA generated a significant F value for treatment ($P \leq 0.05$), means were compared by the LSD test.

RESULTS

Grain Yield

Nitrogen and S effects on the yields of corn at Wooster, Ohio for individual years from 2002 to 2005 are presented in Fig. 1 and Table 3. Four year corn yield averages from 2002 to 2005 are presented in Fig. 2 and show that the maximum yield was reached at the rate of 167 kg N ha^{-1} when 33 kg S ha^{-1} was applied and at the rate of 233 kg N ha^{-1} when no S was applied. There was an interaction of N x S on corn yield in 2004 and 2005 with the low N rates (0 to 167 kg N ha^{-1}) responding better to the S additions than the higher N rates

Fig. 1. Nitrogen and S effects on the yields of corn at Wooster, Ohio from 2002 to 2005.

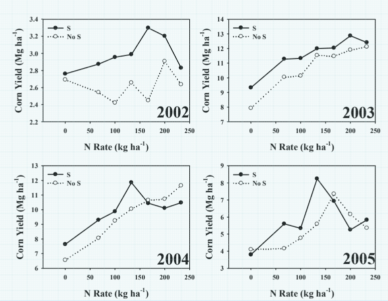

Fig. 2. Average corn yields from 2002 to 2005 as affected by application of N and S fertilizers.

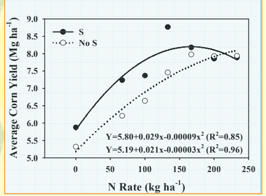

Table 3. Effects of N and S fertilizers on corn yields on Wooster silt loam from 2002 to 2005.

Treatment	*P*-value 2002	2003	2004	2005	Average
N	0.97	<0.0001	<0.0001	0.0014	<0.0001
S	0.04	0.0009	0.16	0.06	0.0002
N x S	0.90	0.78	0.07	0.02	0.02

Table 4. Mean concentrations in 2002 and 2003 of major elements in corn grain harvested from plots treated with N fertilizer and flue gas desulfurization (FGD) product or FGD- gypsum.

N-S Rate	N	P	K	Ca	Mg	S
kg ha^{-1}	g kg^{-1}					
2002						
N Rate						
0	16.1	2.39	2.82 a†	0.051	1.09	1.04
100	16.8	2.41	2.83 a	0.040	1.10	1.05
200	16.5	2.28	2.69 b	0.048	1.07	1.07
$LSD_{0.05}$	0.9	0.16	0.12	0.016	0.08	0.08
S Rate						
0	16.6	2.37	2.78	0.045	1.10	1.05
33	16.3	2.34	2.79	0.048	1.07	1.05
$LSD_{0.05}$	0.6	0.12	0.09	0.016	0.05	0.03
P-value						
N	0.18	0.18	0.045	0.33	0.43	0.69
S	0.34	0.56	0.87	0.63	0.29	0.90
N x S	0.45	0.88	0.74	0.59	0.66	0.68
2003						
N Rate						
0	12.3	2.56	3.24 a	0.050 b	1.02	0.90
100	12.7	2.44	2.98 b	0.051 b	0.96	0.92
200	13.3	2.45	3.00 b	0.076 a	0.97	0.96
$LSD_{0.05}$	1.7	0.22	0.21	0.022	0.10	0.07
S Rate						
0	13.1 a	2.39 b	2.99 b	0.058	0.95 b	0.92
33	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
P-value						
N	0.40	0.38	0.03	0.05	0.38	0.17
S	0.01	0.007	0.04	0.71	0.01	0.35
N x S	0.06	0.36	0.23	0.03	0.41	0.19

†Different letters in the same column within an area represent a significant difference at $P \leq 0.05$.

Table 5. Mean concentrations of essential elements in Mehlich-III extracts obtained from 0-30 cm soil layer of corn field in 2003 and 2005 six months after treating the soil with FGD-gypsum and N fertilizer.

N-S Rate	B	Cu	K	S	Zn
kg ha^{-1}	mg kg^{-1}				
2003					
N Rate					
0	3.00	4.30	228	61.0 b†	2.49 b
200	2.99	4.45	235	88.1 a	4.21 a
$LSD_{0.05}$	0.21	0.22	16	8.1	1.55
S Rate					
0	2.95	4.20 b	237	73.9	3.16
33	3.04	4.55 a	227	75.2	3.54
$LSD_{0.05}$	0.10	0.20	20	14.0	1.95
P-value					
N	0.86	0.11	0.30	0.0018	0.04
S	0.07	0.0052	0.28	0.84	0.66
N x S	0.39	0.12	0.79	0.57	0.34
2005					
N Rate					
0	1.26 b	1.13	94.3	51.9	2.70
200	1.30 a	1.44	159	56.3	3.09
$LSD_{0.05}$	0.03	0.73	110	17.4	1.04
S Rate					
0	1.27	1.26	113 b	50.4 b	2.70
33	1.29	1.31	141 a	57.8 a	3.10
$LSD_{0.05}$	0.06	0.08	28	3.2	0.55
P-value					
N	0.03	0.27	0.16	0.47	0.31
S	0.59	0.16	0.05	0.001	0.13
N x S	0.59	0.05	0.67	0.88	0.17

†Different letters in the same column within an area represent a significant difference at $P \leq 0.05$.

Grain Elements and Selected Available Nutrients in Soil

Concentrations of N, S, and other major plant essential elements in the corn grain in 2002 and 2003 are presented in Table 4. In 2002, application of N fertilizer slightly increased Ca, N and S concentrations a decreased K concentration in corn grain, In 2003, concentrations of P, K, and Mg were also increased a concentrations of N decreased by application of S fertilizer. The concentrations of all the other element including S, were not affected by the application of N and S fertilizers.

Mean concentrations of selected plant essential elements in Mehlich-III extracts obtained from the 0-30 soil layer in 2003 and 2005 are presented in Table 5. In 2003, application of N fertilizer increased solub from 61 to 88 mg kg^{-1} and Zn from 2.5 to 4.2 mg kg^{-1} in the soil. Application of S fertilizer increased soluble Cu from 4.2 to 4.6 mg kg^{-1}. In 2005, application of N fertilizer increased available B from 1.26 1.30 mg kg^{-1}. Application of S fertilizer increased available S from 50 to 58 mg kg^{-1} and K from 113 to mg kg^{-1}. All the other element were not changed by N or S fertilizer application, and data were not sho

CONCLUSIONS

The experimental sites were clearly deficient in S for corn. During the four-year experiment, corn yield averages were significantly ($P \leq 0.05$) increased 7.0% from 7.1 to 7.6 Mg ha^{-1} by application 33 kg S ha^{-1}. When S was applied, the highest yields were reached with a lower N application rate interaction of N x S was observed with the low N rates (0 to 167 kg N ha^{-1}) responding better to t additions than the higher N rates. This suggests that the efficiency of fertilizer N use can be impro by adding S with N fertilizer when growing corn.

REFERENCES

1. Chen, L., W.A. Dick, and S. Nelson Jr. 2005. Flue gas desulfurization products as sulfur sources for alfalfa and soybean. Agron. J. 97:265-271.
2. Mehlich, A. 1984. Mehlich III soil test extract: A modification of Mehlich II extractant. Commun. Soil Sci. Plant Anal. 15: 1409-1419.
3. Sparks, D.L., A.L. Page, P.A. Helmke, R.H. Loeppert, P.N. Soltanpour, M.A. Tabatabai, C.T. Johnston, and M.E. Sumner. (ed). 1996. Method of soil analysis. Part 3. Chemical methods. SSSA Book Ser. and ASA, Madison, WI.