SULFUR APPLICATION TO CORN AND SOYBEAN CROPS IN IOWA[1]

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Introduction and Background

Historically sulfur (S) application has not been recommended on Iowa soils for corn and soybean production. Prior research in Iowa has not determined a consistent need for S fertilization, with field research predominantly indicating no corn or soybean yield response to applied S (Thorup and Leitch, 1975; Webb, 1978; Alesii, 1982; Pierce et al., 1997; Sexton et al., 1998; Mallarino et al., 2000). In research conducted from the 1960's through the 1990's only three instances out of many comparisons resulted in statistically significant yield response to applied S. Two of the three were single-year corn yield increases at individual sites (Tables 1 and 2), and one was a small but statistically significant corn yield decrease as an average over many years and sites – 146 bu/acre with S applied vs. 148 bu/acre without S (Pierce et al., 1997). Other trials have shown no yield response to applied S. An example is shown in Table 3 for research conducted by J. Webb (summarized by Pierce et al., 1997) with S fertilization of corn and soybean at five sites in Iowa over a 14-year period.

The soil supply, in combination with sources such as atmospheric deposition, has apparently met corn and soybean S needs. Iowa surface soils contain approximately 95-98% of total S in the organic form (Tabatabai and Bremner, 1972). Mineralization of organic-S is therefore an important contributor of plant-available sulfate. Tabatabai and Bremner (1972) measured an average 1.3% mineralization of total soil S to sulfate-S in a ten-week aerobic incubation at 86°F. Cold soils can result in reduced sulfate formation and a low plant-available sulfate level. This is sometimes observed in early-season corn growth and coloration response under those conditions. This mineralization from organic matter, in conjunction with other factors that easily affect sulfate levels in surface soils (such as leaching and deposition), makes soil testing and interpretation based solely on sulfate difficult. Most Iowa soils also contain large amounts of profile sulfate. Work by Alesii (1982) found available S in the top 5-ft of soils ranged from 56 to 317 lb S/acre (Table 4). Sulfate accumulation through the soil profile tended to occur with higher clay - lower pH horizons.

The ability of the top six- to seven-inches of soil to solely supply adequate S has been shown to be low in greenhouse studies where greater plant response to S application occurs than observed in the field (Dunphy and Hanway, 1972; Widdowson and Hanway, 1974; Hoeft et al., 1985; Sexton et al., 1998). Soil S levels or S supply may become depleted with prolonged crop removal, sulfate leaching, low atmospheric deposition, low or no fertilizer or manure input, and declining soil organic matter. Sulfate-S in precipitation, for instance, is considerably lower in Iowa now than thirty years ago. In a set of six sampling sites located along a transect from

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northeast to southwest Iowa, Tabatabai and Laflen (1976) measured a range of 11.8 to 15.4 lb sulfate-S/acre annually in precipitation from 1971 to 1973. This amount of sulfate is similar to the S removal in corn and soybean grain (5 to 15 lb S/acre). The range of wet deposition measured across Iowa in the National Atmospheric Deposition Program (NADP, 2002) from 1998 to 2001 was 2.4 to 4.2 lb sulfate-S/acre (lowest in western Iowa to greatest in eastern Iowa). This is an approximate 3.5 to 5.0 times lower amount of sulfate-S being deposited in precipitation today than 30 years ago. This low sulfate deposition makes reliance on organic matter mineralization, profile sulfate, or other S inputs more important.

Sulfur deficiencies have been reported over the years in various areas of the Midwestern USA, examples including Alway (1940), Hoeft and Walsh (1970), Thorup and Leitch (1975), Rehm (1976), Hoeft (1980), Hoeft et al. (1985), Stecker et al. (1995), Lamond et al. (1997), Bly et al. (2000), Woodard and Bly (2000), and Mallarino et al. (2000). However, positive yield responses are not consistent and often infrequent – for example Hoeft et al. (1985) and Stecker et al. (1995). Responsive sites are most often noted as eroded or low organic matter-coarse textured soils. The most recent work in Iowa (Mallarino et al., 2000) did measure corn yield increase to applied S. However, that study was conducted at only one site (northwest Iowa) and response was not consistent across years.

The objective of the study was to determine if corn and soybean would respond to S fertilizer rate and material source at multiple sites across Iowa soils and climatic conditions.

Materials and Methods

This study was conducted in 2000 and 2001 at six Iowa State University Research and Demonstration farms representing major soil areas of Iowa. Site characteristics are listed in Table 5. Corn and soybean crops were grown each year, except at Castana where there was only one crop. The sites had no record of recent manure application. Calcium sulfate and elemental S fertilizers were broadcast applied to corn and soybean at rates of 0, 10, 20, and 40 lb S/acre in the spring of 2000. The sulfur fertilizers were either incorporated with spring tillage or left on the soil surface if the site used no-till. Corn and soybean crops were rotated at each site and the residual response to S fertilizers applied in 2000 was measured in 2001. A complete factorial arrangement of S rate and source was replicated four times in a randomized complete block design. Plot size was 15 or 20 feet wide by 50 feet long. Cultural practices common to the area were used for each crop. Nitrogen application for corn was a product and rate common for the area, tillage system, and rotation. Phosphorus and potassium was applied if directed by soil test. All locations were in a corn-soybean rotation.

Soil samples were collected in the spring of 2000 prior to S application at 0-6, 6-12, 12-24, and 24-36 inch depths and analyzed for sulfate-S by the monocalcium phosphate sulfate-S soil test method (Combs et al., 1998). Soil samples were collected at 0-6 and 6-12 inch depths in 2001 prior to planting from the zero S rate plots and from a composite of both S sources at the 40 lb S/acre rate and analyzed for sulfate-S. Corn ear leaf greenness, leaf opposite and below primary ear, was measured with a Minolta® SPAD 502 chlorophyll meter (Peterson et al., 1993) at the VT growth stage (Ritchie et al., 1986) at all sites except Castana. Corn ear leaves, leaf opposite and below the primary ear (VT growth stage), and soybean leaves, uppermost fully developed trifoliate leaves with petioles removed at onset of the R3 growth stage (Ritchie et al., 1988), were collected for S analysis at all sites except Castana.

Grain was harvested from the middle three to six rows the length of the plots. Reported grain yields were corrected to standard moisture – 15.5% for corn and 13% for soybean. Grain samples (all sites but Castana) were analyzed by near infrared spectroscopy (NIR) for protein concentration (corrected to standard moisture) by the Iowa State University Grain Quality Lab using the procedure of Rippke et al. (1995).

Results and Discussion

Sulfur application in 2000 had no statistically significant effect on corn or soybean grain yield at any site in 2000 (Table 6). Residual-year S (from the S fertilizers applied in 2000) had no statistically significant effect on corn or soybean grain yield at any site in 2001 (Table 7). High winds and plant lodging may have contributed to corn yield variability measured in 2001 at Kanawha. This study was not a statewide survey of potential yield response across Iowa, so it is possible that specific soils or soil situations may respond positively to S application. However, these results are consistent with those of recent research conducted in Southwestern, Western and Northwestern Iowa at Iowa State University Research and Demonstration Farms and in producers fields with field-length comparison strips (Sexton et al., 1998; DeJong, 1998; Mallarino et al., 2000; C.R. Olsen and C. McGrath personal communication, 2000); and with the results of statewide studies conducted previously in Iowa (Webb, 1978; Pierce et al., 1997).

Chlorophyll meter readings of the corn ear leaf did not change with S rate at any site in either year (individual site data not shown). Mean chlorophyll meter readings of the corn ear leaf (mean across all sites) did not change with S rate or source in either year (Table 8). At Ames in 2001, corn plants showed early-season yellowing and leaf striping on the zero S rate plots. However, visual symptoms disappeared as the season progressed and no chlorophyll meter reading or yield difference was measured.

Averaged across all sites, corn and soybean leaf S concentrations were significantly increased by addition of S in 2000, but only for corn in 2001 (Table 8). The increase in S concentration was not large, approximately 0.02% increase for corn and soybean. For corn, the mean leaf S concentrations across all sites were lower than the 0.21% level considered sufficient by Neubert et al. (1969), and at individual sites were above this level only at Ames in 2000 (Tables 9 and 10). Leaf S concentrations below 0.21%, however, have not always been indicative of S response, for example Reneau and Hawkins (1980) and Stecker et al. (1995). Corn leaf S concentrations were lower in 2001 than 2000 (Tables 8, 9, and 10). A significant S rate effect on corn leaf S concentration was measured at all sites but Ames and Doon in 2000, and at all sites but Crawfordsville in 2001 (Tables 9 and 10). The lowest S concentration without applied S was measured at Ames in 2001 (0.14%). The increases in corn leaf S concentration did not translate to an increase in leaf chlorophyll meter readings (leaf greenness) or grain yields.

For soybean, the mean leaf S concentrations across all sites were within the sufficiency range of 0.20 - 0.40% reported by Mills and Jones (1996), and were not below this range at any site in either year. Soybean leaf S concentrations were lower in 2001 than 2000 (Tables 8, 9, and 10).

At individual sites, a significant effect due to S rate was only measured at Ames in 2000 (Tables 9 and 10), with the soybean leaf S concentration at that site increasing from 0.23 to 0.28% (control and 40 lb S/acre rate). The increases in soybean leaf S concentration did not translate to an increase in grain yields.

Corn and soybean grain protein was not increased by application of S, at individual sites (Tables 11 and 12) or across sites (Table 8). Protein levels were similar both years.

Soil sulfur concentrations (extractable sulfate-S by the monocalcium phosphate method) in the spring of 2000 were variable between sites and soil depths (Table 13). Sulfate-S concentration increased slightly with depth, although there were differences in this trend between sites. In 2001, similar sulfate-S concentrations were measured (control plots) in the 0-6 inch depth sample as in 2000. Sulfur applied at 40 lb S/acre in 2000 increased sulfate-S concentrations in the spring of 2001 (mean 2.5 ppm increase with 40 lb S/acre in the 0-6 and 6-12 inch soil depths). An extensive analysis of profile sulfate-S (5-foot depth) in Iowa soils by Alesii (1982) indicated a wide range in amount of sulfate-S, with most soils containing large amounts. The samples collected to three feet in this study also indicate a range in sulfate-S, with a trend in amount similar in the same soils as measured by Alesii (1982). There was no relationship between the three-foot profile sulfate-S and leaf S concentration or yield response.

Although extractable levels in the 0-6 inch depth at several sites were lower than the reported 10 ppm critical level (Hoeft et al., 1973) each year, there was no response in crop yield. Since no site had a significant yield increase to applied S, neither sites with high nor low sulfate-S concentrations in the top six inches of soil responded to applied S. This illustrates a common occurrence found in S research trials; soils with high sulfate-S concentrations in the top six- to seven-inches of soil indicate no response to applied S, but at the same time soils with low sulfate-S concentrations do not reliably predict a response.

Conclusion

The lack of corn and soybean grain yield increase to S application was consistent across fertilizer materials, rates, and sites in both years of this study. These results are consistent with multi-year and multi-site field research conducted for 30+ years in Iowa. It appears that combined S supply from soil profile sulfate, atmospheric deposition, crop residue and organic matter mineralization continues to meet crop requirements and will do so in the foreseeable future. Sulfur fertilization is not expected to improve corn and soybean yield across the preponderance of Iowa soils. Although not a component of this study, manure currently being applied to large crop acreage in Iowa is an important S input and should further lessen the need for S fertilization.

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References

Alesii, B.A. 1982. How much sulfur is in Iowa soils? Proc. 34th Annu. Fert. and Ag Chem. Dealers Conf. Jan. 12-13, Des Moines, IA. Coop. Ext. Pub. CE-1720a. Iowa State Univ., Ames, IA.

Alway, F.J. 1940. A nutrient element slighted in agricultural research. J. Am. Soc. Agron. 32:913-921.

Bly, A., J. Gerwing, R. Gelderman, G. Erickson, R. Bade, J. Schumacher, and D. Winther. 2000. Corn response to sulfur and zinc across soil landscapes in northeast South Dakota. Soil/water research, South Dakota State Univ. 2000 progress report, soil pr 00-30. Agric. Exp. Sta., Plant Sci. Dept., South Dakota State Univ., Brookings, SD.

Combs, S.M, J.L. Denning, and K.D. Frank. 1998. Sulfate-sulfur. p. 35-40. *In* J.R. Brown (ed.) Recommended Chemical Soil Test Procedures for the North Central Region. N. C. Reg. Res. Pub. No. 221 (Rev.). Missouri Ag. Exp. Sta. SB 1001, Columbia, MO.

DeJong, J. 1998. Sulfur application to corn trial. p. 3. Western Res. Farm Annu. Prog. Rep. - 1998, ISRF98-10. Iowa State Univ., Ames, IA.

Dunphy, E.J., and J.J. Hanway. 1972. Sulfur supplying power of Iowa soils. Proc. 24th Annu. Fert. and Ag Chem. Dealers Conf. Jan 11-12, Des Moines, IA. Coop. Ext. Pub. EC-713s. Iowa State Univ., Ames, IA.

Hoeft, R.G. 1980. Crop response to sulphur in the midwest and northeastern U.S. Sulphur Agri. 4:12-15.

Hoeft, R.G., and L.M. Walsh. 1970. Alfalfa and corn respond to sulfur. Better Crops with Plant Food 2:28-31.

Hoeft, R.G., L.M. Walsh, and D.R. Keeney. 1973. Evaluation of various extractants for available soil sulfur. Soil Sci. Soc. Am. Proc. 37:401-404.

Hoeft, R.G., J.E. Sawyer, R.M. Vanden Heuvel, M.A. Schmitt, and G.S. Brinkman. 1985. Corn response to sulfur on Illinois soils. J. Fert. Issues 2:95-104.

Lamond, R.E., M.A. Davied, W.B. Gordon. 1997. Sulphur research in Kansas, U.S.A. Sulphur in Agric. 20:10-14.

Mallarino, A.P., D. Haden, and A. Christensen. 2000. Sulfur fertilization for corn. p. 19-21. Northwest Res. Farm Annu. Prog. Rep. - 1999, ISRF99-29, 31. Iowa State Univ., Ames, IA.

Mills, H.A., and J. B. Jones, Jr. 1996. Plant analysis handbook II. MicroMacro Publishing, Inc., Atlanta, GA.

National Atmospheric Deposition Program. 2002. National atmospheric deposition program 2001 annual summary. NADP data report 2002-01. Illinois State Water Survey, Champaign, IL.

Neubert, P., W. Wrazidlo, N.P. Vielemeyer, I. Hundt, F. Gullmick, W. Bergmann. 1969. Tabellen zur Pflanzenanalyze-Erste Orientierende Ubersicht. Institutfur Planzenernahrung Jena, Berlin.

Peterson, T.A., T.M. Blackmer, D.D. Francis, and J.S. Schepers. 1993. Using a chlorophyll meter to improve N management. NebGuide G93-1171-A. Coop. Ext., Inst. Ag. Nat. Res., Univ. Nebraska, Lincoln, NE.

Pierce, E.G., A.P. Mallarino, and P.N. Hinz. 1997. Analysis of sulfur applications to corn and soybean crops across time and locations. Creative Component, Master of Science in Statistics, Iowa State Univ., Ames, IA.

Rehm, G.W. 1976. Sulphur response on irrigated corn in Nebraska. Sulphur Inst. J. Fall-Winter, pp. 13-14.

Reneau, R.B. Jr., and G.W. Hawkins. 1980. Corn and soybeans respond to sulphur in Virginia. Sulphur Agric. 4:7-11.

Rippke, G.R., C.L. Hardy, C.R. Hurburgh, Jr., and T.J. Brumm. 1995. Calibration and field standardization of Tecator Infratec analyzers for corn and soybeans. p. 122-131. In Proc. 7th International Conf. on Near Infrared Spectroscopy, Montreal, Canada, 6-11 Aug. 1995.

Ritchie, S.W., J.J. Hanway, and G.O. Benson. 1986. How a corn plant develops. Spec. Rep. 48. Rev. ed. Iowa State Coop. Ext. Serv., Ames, IA.

Ritchie, S.W., J.J. Hanway, H.E. Thompson, and G.O. Benson. 1988. How a soybean plant develops. Rev. ed. Iowa State Coop. Ext. Serv., Ames, IA.

Sexton, P.J., N.C. Paek, and R. Shibles. 1998. Soybean sulfur and nitrogen balance under varying levels of available sulfur. Crop Sci. 38:975-982.

Stecker, J.A., D.D. Buchholz, and P.W. Tracy. 1995. Fertilizer sulfur effects on corn yield and plant sulfur concentration. J. Prod. Agric. 8:61-65.

Tabatabai, M.A., and J.M. Bremner. 1972. Distribution of total and available sulfur in selected soils and soil profiles. Agron. J. 64:40-45.

Tabatabai, M.A., and J.M. Laflen. 1976. Nitrogen and sulfur content and pH of precipitation in Iowa. J. Environ. Qual. 5:108-112.

Thorup, R.M., and D.G. Leitch. 1975. Corn response to S in Iowa. Sulphur Inst. J. Spring, p. 5.

Webb, J. 1978. The sulfur situation in Iowa. Proc. 30th Ann. Fert. and Ag Chem. Dealers Conf. Jan 10-11, Des Moines, IA. Coop. Ext. Pub. EC-1270q. Iowa State Univ., Ames, IA.

Widdowson, J.P., and J.J. Hanway. 1974. Available-sulfur status of some representative Iowa soils. Agric. Home Econ. Exp. Sta. Bull., Iowa State Univ. 579:713-736.

Woodard, H.J., and A. Bly. 2000. Crop responses to sulfur fertilization and management. Soil/water research, South Dakota State Univ. 2000 progress report, soil pr 00-31. Agric. Exp. Sta., Plant Sci. Dept., South Dakota State Univ., Brookings, SD.

Table 1. Corn grain yield response to sulfur and lime application, 1974.

Treatments		Corn Grain Yield
lb S/acre	Ton lime/acre	bu/acre
0	0	62.8
0	2	62.5
24	0	68.4
24	2	71.6
	LSD (0.05)	4.6

From Thorup and Leitch, 1975. Site near Fort Madison, IA. Sulfur fertilizer source was ammonium sulfate.

Table 2. Corn yield response to S fertilization on a Moody soil from 1995-1999 at the Northwest Research Farm, Sutherland, IA.

Treatment†							5-year
Material	S Rate	1995	1996	1997	1998	1999	mean
	lb S/acre	- - - - - - - - - -	- - - - - - - - - -	- - - - bu/acre - - - -	- - - - - - - - - -	- - - - - - - - - -	- - - - - - - - - -
Sulpomag	60	140	153	133	144	122	138
KCl + S	60	140	159	130	135	127	138
Elemental S	60	137	158	129	140	125	138
KCl	0	133	154	125	133	132	135
Statistics		*	NS	NS	NS	NS	NS

From Mallarino et al. (2000).

† Potassium was applied at an equal rate of 60 lb K_2O per acre to all treatments. The treatmetns were applied each year before corn, and the study area was alternated back-and-forth each year with soybean. Soil test S (surface 6-inch layer) was 5 to 8 pm in the non-S treated plots and 30 to 46 ppm in the S treated plots after the 1999 season.

* Significant response to S (P = 0.05) and NS = no significant difference.

Table 3. Corn and soybean grain yield response to S rate and source at five sites in Iowa from 1977 to 1990.

		S Treatment†			
		30 lb S/acre		60 lb S/acre	
Location	Control	ES	ATS	ES	ATS
	- - - - - - - - - - - - - - - - - bu/acre	- - - - -	- - - - -	- - - - -	- - - - -
Corn					
Castana	113	110	113	112	112
Kanawha	168	164	166	163	163
Doon	126	126	125	126	125
Nashua	177	175	175	175	174
Sutherland	145	143	145	143	142
Mean	148	146	147	146	143
Soybean					
Castana	26.5	26.7	27.1	26.1	26.1
Kanawha	40.9	38.9	40.8	40.0	39.8
Doon	44.5	43.7	43.7	42.9	43.9
Nashua	45.1	44.1	45.2	44.9	45.5
Sutherland	40.7	41.9	41.1	40.4	40.4
Mean	40.0	39.4	39.9	39.2	39.4

From Pierce et al., 1997.

† Elemental S (ES) and ammonium thiosulfate (ATS) surface broadcast applied to the same plot each year. Corn and soybean crops were rotated. No statistically significant (P = 0.05) effect of S source or rate for either crop. The average control vs S contrast was significant for corn yield (control at 148 bu/acre vs. S at 146 bu/acre).

Table 4. Amount of available S in the top 5-ft of selected Iowa soil profiles, Alesii, 1982.

Soil Series	Available S in 5-ft profile	Soil Series	Available S in 5-ft profile	Soil Series	Available S in 5-ft profile
	lb/acre		lb/acre		lb/acre
Edina	262	Ida	56	Clarion	174
Clarinda	317	Monona	135	Primghar	249
Haig	247	Tama	196	Galva	151
Pershing	258	Muscatine	279	Weller	158
Marshall	117	Readlym	269	Taintor	124
Sharpsburg	125	Cresco	251	Otley	195
Chelsea	119	Webster	148	Clinton	169
Fayette	188	Nicollet	161		

Table 5. Site characteristics, 2000 and 2001.

Site	General Location	Soil Name	Soil Organic Matter	Tillage System
			%	
Ames	Central	Clarion l; Nicollet l	4.0	Chisel/Disk/Field Cultivate
Atlantic	Southwest	Marshall sicl	3.7	No-Till
Crawfordsville	Southeast	Taintor sicl; Mahaska sicl	5.0	Chisel/Disk/Field Cultivate
Doon	Northwest	Moody sicl	4.1	Chisel/Disk/Field Cultivate
Kanawha	North Central	Canisteo cl; Nicollet l	6.7	Chisel/Disk/Field Cultivate
Castana	Western	Monona sil	3.3	No-Till

Table 6. Effect of sulfur source and rate on corn and soybean grain yield, 2000.

	Ames		Atlantic		Crawfordsville		Doon		Kanawha		Castana	
S Rate	CaS†	S†	CaS	S	CaS	S	CaS	S	CaS	S	CaS	S
lb S/acre	bu/acre											
Corn												
0	175	179	150	150	172	158	154	144	159	159	159	163
10	180	174	146	150	157	167	143	148	161	156	160	161
20	174	176	152	152	170	164	142	143	156	160	155	156
40	177	175	147	149	151	161	144	147	163	162	163	163
	NS‡		NS		NS		NS		NS		NS	
Soybean												
0	53.8	54.2	47.5	46.6	51.4	52.3	43.5	43.1	52.5	52.7	---	---
10	53.9	53.4	46.3	48.5	51.2	49.7	42.4	42.6	51.7	52.6	---	---
20	52.8	55.0	46.3	45.5	50.0	50.2	39.9	44.3	53.1	53.1	---	---
40	50.4	54.5	46.4	47.4	51.0	49.5	42.3	43.8	53.1	51.7	---	---
	NS		NS		NS		NS		NS		---	

† CaS = calcium sulfate; S = elemental sulfur. Sulfur fertilizers applied spring 2000.

‡ No significant effect due to S rate, source, or interaction (P = 0.05).

Table 7. Effect of sulfur source and rate on corn and soybean grain yield, 2001.

	Ames		Atlantic		Crawfordsville		Doon		Kanawha		Castana	
S Rate	CaS†	S†	CaS	S	CaS	S	CaS	S	CaS	S	CaS	S
lb S/acre	bu/acre											
Corn												
0	159	159	147	147	118	111	145	142	164	173	--	--
10	154	156	145	152	110	109	138	141	169	177	--	--
20	158	164	148	147	113	117	141	138	175	177	--	--
40	155	153	147	147	118	108	143	144	180	166	--	--
	NS‡		NS		NS		NS		NS		--	
Soybean												
0	40.3	41.1	46.7	43.9	54.8	54.5	44.8	44.2	53.5	53.7	44.3	43.0
10	43.3	40.2	44.7	45.0	54.7	54.5	43.2	43.4	52.6	52.3	44.5	46.5
20	39.4	41.1	45.5	46.5	56.5	57.1	42.3	43.6	51.4	52.7	42.5	47.3
40	39.4	39.5	45.8	46.4	54.3	54.2	40.9	44.6	51.8	52.3	44.0	40.3
	NS		NS		NS		NS		NS		NS	

† CaS = calcium sulfate; S = elemental sulfur. Sulfur fertilizers applied spring 2000.

‡ No significant effect due to S rate, source, or interaction (P = 0.05).

Table 8. Mean effect of sulfur source and rate across sites in 2000 and 2001.

	Corn								Soybean					
	Grain Yield		Chlorophyll Meter Reading		Leaf S		Grain Protein		Grain Yield		Leaf S		Grain Protein	
S Rate	CaS[†]	S[†]	CaS	S	CaS	S	CaS	S	CaS	S	CaS	S	CaS	S
lb S/acre	bu/acre				%		%		bu/acre		%		%	
2000														
0	162	159	60	60	0.18	0.18	8.0	8.0	50.0	50.1	0.26	0.27	35.5	35.7
10	158	160	60	60	0.19	0.18	7.9	8.1	49.3	49.6	0.27	0.26	35.6	35.4
20	158	159	60	60	0.19	0.18	8.0	8.0	48.9	49.7	0.28	0.28	35.5	35.6
40	158	159	60	60	0.20	0.20	8.0	8.0	49.0	49.6	0.29	0.27	35.4	35.5
	NS[‡]		NS		SS[§]		NS		NS		SS[¶]		NS	
2001														
0	147	146	62	62	0.15	0.15	8.0	8.1	48.0	47.8	0.25	0.25	35.4	35.3
10	143	147	62	62	0.16	0.15	8.1	8.2	48.1	47.6	0.25	0.25	35.3	35.3
20	147	149	61	62	0.17	0.17	8.1	8.1	47.0	48.5	0.24	0.25	35.2	35.5
40	149	144	62	61	0.17	0.17	8.1	8.1	46.6	46.9	0.24	0.26	35.1	35.2
	NS		NS		SS[§]		NS		NS		NS		NS	

[†] CaS = calcium sulfate; S = elemental sulfur. Sulfur fertilizers applied spring 2000.

[‡] No significant effect due to S rate, source, or interaction (P = 0.05).

[§] Significant mean effect due to S rate (P = 0.05).

[¶] Significant S rate x source interaction (P = 0.05).

Table 9. Effect of sulfur source and rate on corn and soybean leaf S concentration, 2000.

	Ames		Atlantic		Crawfordsville		Doon		Kanawha	
S Rate	CaS[†]	S[†]	CaS	S	CaS	S	CaS	S	CaS	S
lb S/acre	%									
Corn										
0	0.21	0.22	0.18	0.18	0.17	0.18	0.18	0.19	0.17	0.17
10	0.22	0.21	0.19	0.17	0.17	0.18	0.18	0.19	0.18	0.17
20	0.21	0.21	0.19	0.18	0.19	0.19	0.18	0.18	0.19	0.17
40	0.22	0.24	0.21	0.18	0.19	0.20	0.20	0.19	0.20	0.18
	NS[‡]		SS[§]		SS[¶]		NS		SS[#]	
Soybean										
0	0.23	0.23	0.23	0.25	0.31	0.32	0.25	0.28	0.28	0.28
10	0.26	0.24	0.24	0.23	0.32	0.31	0.26	0.25	0.29	0.28
20	0.26	0.25	0.24	0.24	0.31	0.31	0.28	0.28	0.30	0.29
40	0.28	0.26	0.23	0.24	0.33	0.31	0.29	0.27	0.30	0.29
	SS[#]		NS		NS		NS		NS	

[†] CaS = calcium sulfate; S = elemental sulfur. Sulfur fertilizers applied spring 2000.

[‡] No significant effect due to S rate, source, or interaction (P = 0.05).

[§] Significant S rate x source interaction (P = 0.05).

[¶] Significant mean effect due to S rate (P = 0.05).

[#] Significant mean effect due to S rate and source (P = 0.05).

Table 10. Effect of sulfur source and rate on corn and soybean leaf S concentration, 2001.

	Ames		Atlantic		Crawfordsville		Doon		Kanawha	
S Rate	CaS†	S†	CaS	S	CaS	S	CaS	S	CaS	S
lb S/acre	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - % - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -
Corn										
0	0.13	0.14	0.16	0.15	0.19	0.18	0.15	0.14	0.14	0.15
10	0.12	0.14	0.17	0.16	0.18	0.18	0.15	0.15	0.14	0.14
20	0.16	0.15	0.19	0.18	0.18	0.19	0.16	0.16	0.16	0.16
40	0.16	0.15	0.21	0.20	0.19	0.18	0.17	0.17	0.15	0.16
	SS‡		SS‡		NS§		SS‡		SS‡	
Soybean										
0	0.25	0.25	0.24	0.24	0.26	0.27	0.26	0.25	0.25	0.25
10	0.24	0.24	0.24	0.24	0.25	0.26	0.25	0.25	0.26	0.26
20	0.23	0.24	0.25	0.22	0.26	0.27	0.21	0.25	0.26	0.26
40	0.24	0.25	0.24	0.25	0.25	0.27	0.25	0.27	0.24	0.26
	NS		NS		NS		NS		NS	

† CaS = calcium sulfate; S = elemental sulfur. Sulfur fertilizers applied spring 2000.

‡ Significant mean effect due to S rate (P = 0.05).

§ No significant effect due to S rate, source, or interaction (P = 0.05).

Table 11. Effect of sulfur source and rate on corn and soybean grain protein, 2000.

	Ames		Atlantic		Crawfordsville		Doon		Kanawha	
S Rate	CaS†	S†	CaS	S	CaS	S	CaS	S	CaS	S
lb S/acre	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - % - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -
Corn										
0	8.5	8.5	7.9	8.0	8.3	8.3	8.5	8.3	7.4	7.4
10	8.6	8.6	7.7	7.9	8.3	8.3	8.2	8.8	7.3	7.3
20	8.4	8.5	7.9	7.8	8.6	8.2	8.1	8.3	7.3	7.5
40	8.5	8.4	8.0	7.8	8.1	8.5	8.2	8.4	7.4	7.3
	NS‡		NS		NS		SS§		NS	
Soybean										
0	35.4	35.4	36.7	37.3	38.0	38.2	34.5	34.6	33.8	34.0
10	36.5	35.5	37.0	36.7	38.0	38.0	34.1	34.3	33.6	33.5
20	35.9	36.4	36.8	36.9	38.1	37.8	34.4	34.3	33.5	33.6
40	35.7	36.3	36.6	36.6	37.7	37.9	34.4	34.6	33.5	33.3
	SS§		NS		NS		NS		NS	

† CaS = calcium sulfate; S = elemental sulfur. Sulfur fertilizers applied spring 2000.

‡ No significant effect due to S rate, source, or interaction (P = 0.05).

§ Significant S rate x source interaction (P = 0.05).

Table 12. Effect of sulfur source and rate on corn and soybean grain protein, 2001.

S Rate	Ames CaS[†]	Ames S[†]	Atlantic CaS	Atlantic S	Crawfordsville CaS	Crawfordsville S	Doon CaS	Doon S	Kanawha CaS	Kanawha S
lb S/acre					%					
Corn										
0	8.1	8.4	7.5	7.8	7.3	7.6	8.6	8.4	8.5	8.4
10	8.0	8.3	7.8	7.9	7.4	7.7	8.6	8.5	8.6	8.6
20	8.3	8.2	7.5	7.7	7.6	7.6	8.5	8.5	8.5	8.4
40	8.2	8.3	7.6	7.7	7.6	7.7	8.6	8.5	8.4	8.5
	NS[‡]		SS[§]		NS		NS		NS	
Soybean										
0	36.8	36.6	35.1	34.5	36.4	36.5	37.1	37.0	33.0	33.0
10	36.6	36.8	34.5	34.8	36.6	36.3	36.9	37.2	33.1	32.8
20	36.1	36.4	34.4	34.7	36.8	36.7	36.5	37.2	33.1	33.1
40	36.2	36.4	34.3	34.6	36.3	36.5	36.9	36.9	32.9	33.0
	NS		NS		NS		NS		NS	

[†] CaS = calcium sulfate; S = elemental sulfur. Sulfur fertilizers applied spring 2000.

[‡] No significant effect due to S rate, source, or interaction (P = 0.05).

[§] Significant mean effect due to S rate and source (P = 0.05).

Table 13. Extractable S concentration by the monocalcium phosphate sulfate-S soil test method, spring 2000 and 2001.

Sample Depth	Ames Crn[†]	Ames Sb[†]	Atlantic Crn	Atlantic Sb	Crawfordsville Crn	Crawfordsville Sb	Doon Crn	Doon Sb	Kanawha Crn	Kanawha Sb	Castana Crn	Castana Sb
inches						ppm						
2000[‡]												
0-6	9	5	8	11	6	7	2	4	7	7	4	--
6-12	6	6	11	5	2	4	2	4	4	7	5	--
12-24	9	5	7	7	2	5	8	7	10	15	2	--
24-36	13	11	7	10	3	2	--	--	9	10	4	--
2001[§]												
0 lb S/acre												
0-6	10	10	8	12	3	8	2	3	8	6	--	6
6-12	5	9	1	4	6	3	2	3	12	7	--	6
40 lb S/acre												
0-6	15	14	18	14	6	6	2	6	9	7	--	8
6-12	9	11	4	5	3	10	7	10	13	6	--	5

[†] Crn = Corn, Sb = Soybean. Extractable-S for soil samples collected in the spring before the indicated crop.

[‡] Soil sampled before sulfur application, spring 2000.

[§] Composite sample from both S sources, spring 2001.