ENVIRONMENTAL SULFUR SOURCES AS INPUTS FOR PREDICTING SULFUR NEEDS[1]

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Crop responses to sulfur fertilization have been demonstrated in most states in the midwest, but the frequency of these responses is relatively low. Sulfur deficiencies are usually confined to areas where one or more of the following conditions exist: (1) Sandy or shallow soils; (2) Low soil organic matter content; (3) No recent manure applications; (4) Low atmospheric sulfur deposition; (5) High crop sulfur requirement.

Although diagnostic tests to predict crop response to applied sulfur are an obvious need, the test procedures developed to date have shown only limited success in predicting the need for sulfur fertilization. The limited utility of sulfur soil test procedures is largely due to contributions of plant available sulfur from several sources that cannot be measured by the test procedure. Since the sulfur soil test usually measures only sulfate-S in the top six to eight inches of soil, significant contributions of plant-available sulfur from precipitation, soil profile sulfate, manure applications, and soil organic matter mineralization are not considered, but could markedly affect the amounts of sulfur available to crops. Therefore, soil test recommendations for sulfur are often modified to reflect the amounts of available sulfur contributed from sources not measured by the soil test procedure (Schulte, 1981).

The purpose of this paper is to present recent information on the amounts of plant available sulfur contributed from various sources and to suggest how this information might be used to improve current procedures for predicting crop response to sulfur fertilization in Wisconsin.

Sulfur in Precipitation

Significant amounts of sulfur are deposited annually in precipitation in much of the North Central Region (Tabatabai, et al., 1981). Recent revisions in air quality standards, which lowered the levels of sulfur permitted in industrial emissions, are expected to reduce the amounts of sulfur deposited in precipitation. This reduction in sulfur deposition has lead to speculation that the frequency of crop sulfur deficiency and the need for sulfur fertilization may increase.

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In 1969 through 1971, Hoeft et al. (1972), found that 14 and 38 lb S/acre were deposited annually in precipitation in rural and urban areas of Wisconsin, respectively, and a state-wide average sulfur deposition rate of 27 lb S/acre was estimated. To determine current sulfur levels in Wisconsin precipitation, sulfur deposition in bulk precipitation was determined at 10 sites in important agricultural areas for a 2-year period from November, 1985 through October, 1987. The locations of the monitoring sites and the average annual sulfur deposition in precipitation at each site are shown in Figure 1. Precipitation amounts, sulfur and inorganic nitrogen deposition, and volume-weighted pH values observed at each site in individual years is shown in Table 1. Inorganic nitrogen and pH levels in precipitation are shown for information purposes, but will not be discussed in this paper.

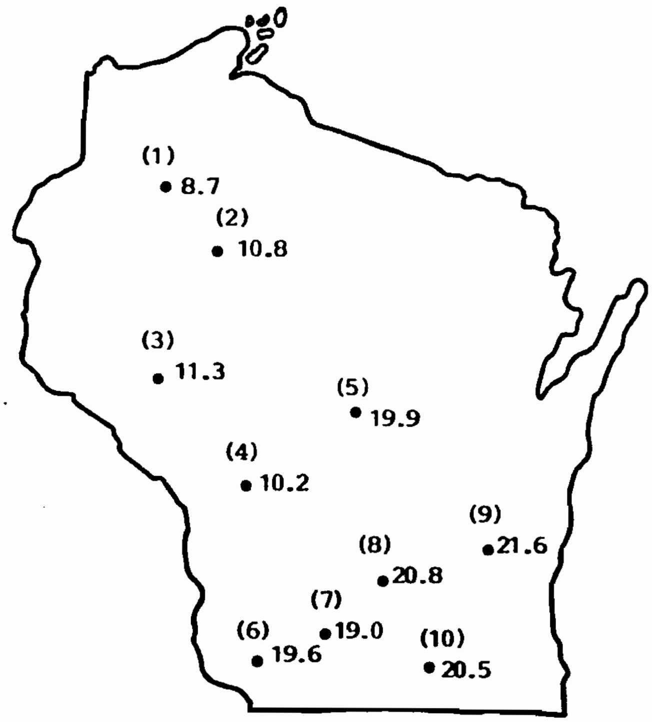

Figure 1: Annual average SO_4-S (lb/a) deposition in precipitation at ten sites in Wisconsin (1985-1987). Values in ( ) are site numbers.

Results in Figure 1 show that average annual sulfur deposition is 10.3 lb S/acre (sites 1-4), and 20.3 lb S/acre (sites 5-10) in northwestern and southeastern Wisconsin, respectively. These values indicate that current sulfur deposition rates are about 42% lower than those found during the

1969-1971 period (Hoeft et al., 1972). In addition, the geographical differences in sulfur deposition between the northwestern and southeastern regions of Wisconsin that were observed by Hoeft et al. (1972) are apparent in the current data.

Although the amounts of sulfur deposited in precipitation have decreased substantially since 1970, most of the sulfur requirements of corn and alfalfa are still likely to be provided by sulfur in precipitation in most areas of Wisconsin. Crop response to sulfur fertilization seems particularly unlikely in these areas when the sulfur added in precipitation is combined with contributions from other potential sulfur sources. If sulfur removal rates for moderate to high yields of alfalfa and corn are 19 and 10 lb S/acre, respectively (Hoeft and Fox, 1986), sulfur deposited in precipitation would be inadequate to replace these removals only in northwestern Wisconsin. Most of the significant crop responses to sulfur fertilization in Wisconsin have been obtained in the northwestern region (Rand et al., 1969; Hoeft and Walsh, 1975).

The amounts of sulfur deposited annually in precipitation were similar in each of the two years studied, although the total annual precipitation was well above normal in the first year and slightly below normal in the second (Table 1). Monthly precipitation and sulfur deposition values (data not shown) indicate that about 75% of the annual precipitation and sulfur deposition occurred during the April through September period. This period of highest deposition coincides with the crop growing season and crop sulfur uptake.

Soil Profile Sulfate-Sulfur

Although sulfate-sulfur is an anion and is subject to removal from the plant root zone through leaching, many studies indicate that sulfate can accumulate in soil profiles, particularly if the subsoils are acidic and high in clay. Where soil profile sulfate accumulates within the plant root zone, this sulfur can supply part or all of the crop sulfur requirement.

Warner (1986) found profile sulfate contents ranging from 17 to 166 lb S/acre in a variety of Wisconsin soils used for corn production. In this work, profile sulfate at various profile depths was negatively correlated with soil pH, indicating a greater tendency for sulfate accumulation in acidic subsoils. In addition, the cumulative amounts of profile sulfate-S to 36 inches was highly correlated to the soil organic matter content in the surface 12 inches of soil.

With the exception of the Plainfield loamy sand (a deep coarse-textured soil with low organic matter content), the soils studied by Warner (1986) contained relatively large amounts of plant-available sulfate within the root zone of most crops (Tables 2 and 3). These results suggest that many Wisconsin soils contain adequate amounts of profile sulfate to prevent sulfur deficiency and crop response to applied sulfur. Data in Table 3 illustrate that total profile sulfate content in some Wisconsin soils remains relatively constant during the periods within and between growing seasons. Although shifts in the distribution of sulfate with depth were noted in some soils, crop sulfur removal and loss of sulfate through leaching are apparently offset by sulfate additions from organic matter mineralization and precipitation.

Table 1. Annual precipitation amounts, sulfur and inorganic nitrogen deposition, and precipitation pH levels at 10 sites in Wisconsin, 1985 to 1987.

Site No.		Precipitation[1]/ amount		Deposition SO_4-S	NO_3-N	NH_4-N	pH[2]/
		inches		---------lb/acre---------			
				Year 1			
1		38.6	(+ 9.4)	7.7	3.0	5.4	5.1
2		41.7	(+ 9.1)	10.8	3.9	2.3	5.2
3		49.2	(+18.5)	11.1	4.0	9.7	5.5
4		44.1	(+12.6)	11.1	5.0	7.5	5.3
5		39.8	(+ 7.9)	23.5	7.5	3.9	5.3
6		33.5	(+ 0.4)	20.0	5.5	6.8	5.9
7		38.2	(+ 4.7)	19.8	8.7	9.0	5.1
8		48.8	(+16.9)	20.8	9.3	13.2	5.8
9		44.9	(+13.0)	25.6	7.7	4.7	5.4
10		38.9	(+ 6.7)	21.6	6.2	7.3	5.3
	mean	41.7	(+10.2)				
				Year 2			
1		23.6	(- 5.5)	9.7	3.9	5.0	4.1
2		--		--	--	--	--
3		32.3	(+ 1.6)	11.4	4.6	8.2	3.8
4		26.8	(- 4.7)	9.3	2.0	4.3	3.8
5		28.7	(- 3.1)	16.3	6.1	5.5	3.5
6		32.3	(- 0.8)	18.9	6.5	9.9	3.4
7		32.7	(- 0.8)	18.2	9.0	10.4	3.9
8		27.6	(- 4.3)	20.8	8.9	12.7	3.8
9		32.7	(+ 0.8)	17.6	7.4	5.9	3.9
10		23.2	(- 9.1)	19.9	7.0	10.1	4.5
	mean	28.7	(- 2.8)				

[1]/ Values in parentheses are departures from the 1951-1980 means for each site.
[2]/ Volume-weighted pH values.

Further evidence that profile sulfate is an important source of plant-available sulfur in Wisconsin is provided by data in Table 4 showing the influence of crop sequence on profile sulfate contents in a wide range of Wisconsin soils. In this work, profile sulfate was determined in spring, 1988, following corn or alfalfa at adjacent sites on each of the soils listed. Results show that soil profiles at most locations contained adequate amounts of sulfate to provide crop needs. However, profile sulfate contents following alfalfa were lower than those found after corn at several locations. This result may be due to the higher sulfur requirement of alfalfa or to more complete removal of sulfate from the root zone by the alfalfa crop. Previous work (Muir et al., 1976) indicates that alfalfa is very effective in depleting nitrate from soil profiles, and it seems possible that a similar process could occur with profile sulfate. The reasons for the unusually low profile sulfate values on the Plano silt loam soil following both corn and alfalfa is unknown.

Sulfur from Manure Applications

Sulfur contributions from manure are a significant source of plant available sulfur in Wisconsin since large quantities of manure are applied to cropland in the state. For example, dairy manure contains an average of 1.5 lb S/ton, and crop response to sulfur fertilization is usually not observed where manure has been applied within the past two years (Schulte, 1981).

Table 2. Sulfate-S in profiles of several Wisconsin soils, Spring, 1984.

	Sulfate-S, lb/a		
Depth (feet)	Withee sil	Plainfield lfs	Fayette sil
0-1	27	6	19
1-2	60	4	15
2-3	59	7	29
Total	146	17	63

(Warner, 1986)

Table 3. Sulfate-S in the profile of a Plano soil at various sampling times, Arlington, WI.

	1983		1984	
Depth (Inches)	Spring	Fall	Spring	Fall
	Sulfate-S, lb/a			
0-6	7	12	11	14
6-12	12	11	13	11
12-24	39	33	25	25
24-36	31	30	31	30
Total	89	86	80	80

(Warner, 1986)

Table 4. Effect of soil characteristics and previous crop on profile sulfate content in Wisconsin soils, Spring, 1988.

Soil region	Soil type	Previous Crop Corn	Previous Crop Alfalfa
		-Sulfate-S, lb/a[1]/-	
Western course textured soils	Meridian sandy loam	126	177
Northern silty soils	Withee silt loam	224	179
Eastern red soils	Kewaunee silt loam	190	36
Southern prairie soils	Plano silt loam	26	21
Southwestern loess soils	Dubuque silt loam	171	73

[1]/ Sulfate-S in 0-3 ft. soil profiles.

In a recent study to determine the effects of dairy manure applications on the amounts of plant available sulfate-sulfur in soil profiles, Warner (1986) found that high background sulfate levels at three study sites prevented direct assessment of the sulfur contributions from the manure applications. As shown in Table 5, although relatively high rates of liquid dairy manure were applied at each site, significant differences in profile sulfate content between the control treatment (no manure) and the manure treatments could not be detected.

Table 5. Effect of manure applications on profile sulfate in three Wisconsin soils, Fall, 1983.

Soil type	Manure rate[1]/ 1982	Manure rate[1]/ 1983	Sulfate-S, (0-5 ft) Control	Sulfate-S, (0-5 ft) Manure
	--tons/a--		---------lb/a---------	
Puchyan, lfs	57	74	108	119
Plano, sil	54	62	152	134
Tama, sil	44	54	128	148

[1]/ Manure was applied in Spring, 1982 and 1983 as injected liquid dairy manure.

Soil Organic Matter-Available Sulfur Relationships

Soil organic matter supplies plant available sulfate-sulfur through organic matter decomposition. Although only a small percentage of the organic sulfur in soil organic matter is mineralized in a single growing season, the amounts of available sulfur provided through this process are significant relative to crop sulfur needs. Where soil organic matter content exceeds 30 tons/acre, crop response to sulfur fertilization in Wisconsin is unlikely (Schulte, 1981).

Predicting the Need for Sulfur Fertilization

The previous sections of this paper have discussed the significance of various sources of plant available sulfur in Wisconsin. It seems likely that much of the current information on sulfur availability could be integrated to provide sulfur recommendations with greater reliability than those currently based on the sulfate content of surface soil samples. Some possibilities for this approach are suggested here.

The potential for improving sulfur soil test recommendations depends on more accurate accounting for available sulfur from all potential sources. The major contributions that need to be considered are sulfur in precipitation, profile sulfate and sulfur from manure. Recent precipitation monitoring studies (Figure 1) indicate that a substantial portion of southern, central, and eastern Wisconsin receives about 20 lb S/acre/year in precipitation. This deposition would likely eliminate crop response to sulfur fertilization. In addition, most of the soils in these areas have characteristics associated with profile sulfate retention, such as high organic matter and subsoil clay content and low subsoil pH. Better accounting for sulfur from recent manure applications would likely require solicitation of manure application information and manure analysis results (if available) from growers.

A mechanism is currently in place at Wisconsin soil testing laboratories for identifying samples submitted for sulfur analysis by soil type and geographical location (county). Therefore, it should be possible to estimate sulfur contributions from precipitation and the probability of significant profile sulfate contributions for most samples submitted for sulfur recommendations. In addition, an analysis for organic matter content in the sample submitted can be performed. If both precipitation sulfur and profile sulfate contributions are likely to be high, the recommendation should note that response to sulfur fertilization is unlikely at this location. Sites with organic matter contents sufficient to prevent probable response to added sulfur (over 30 tons/acre, or about 3% organic matter) can be identified through the organic matter test.

Localized areas within the southern, central, and eastern regions that might respond to applied sulfur could be identified based on soil characteristics, such as coarse texture, low organic matter content, and limited potential to accumulate profile sulfate. Profile sulfate measurements could also be used on a yes/no basis for predicting the need for sulfur fertilization. However, some calibration work to identify the critical profile sulfate content needed to prevent response to added sulfur may be needed.

In northwestern Wisconsin, where sulfur contributions from precipitation, soil organic matter, and profile sulfate can be low, a modeling effort to account for all sources of available sulfur at responsive and nonresponsive sites seems to be the most promising approach for improving sulfur recommendations. A model based on these results could then be used to predict the need for sulfur fertilization based on site-specific information on the amounts of sulfur available from all potential sources.

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