A STATE UNIVERSITY

AGRONOMY
• Crops
• Soils
• Climate

Sulfur—An Essential Nutrient

Sulfur (S) has long been known to be an essential plant nutrient. It was observed as early as 1674 that, under some conditions, additions of sulfur salts to cropland increased plant growth.

Since the 1970s high yielding crops have hastened the removal of native soil S. At the same time, additions of S to cropland decreased. Until the 1970s considerable quantities of S were applied to croplands in the form of impurities in various fertilizers, herbicides, and pesticides. However, advances in technology have virtually eliminated S impurities in those materials. This dual assault on soil S reserves led to speculation that economic responses to S fertilizers would soon be widespread.

Before 1970, the Iowa State University Soil Testing Laboratory did not analyze soils for S; however, the number of analyses at all laboratories that analyzed samples from Iowa increased from approximately 5,000 in 1970 to almost 82,000 in 1979.

Soil Sulfur

Sulfur is unique among essential plant nutrients because it exists in a wide variety of forms. It has been estimated that total S in the earth's crust ranges from 30 to 10,000 parts per million (ppm) and averages 700 ppm. This S can be found as deposits of elemental S, as gypsum ($CaSO_4 \cdot 2H_2O$), as sulfides (S^{2-}) in anaerobic conditions, as a constituent of soil organic matter, and as the sulfate ion (SO_4^{2-}) in the soil solution.

Sulfur is also present in the atmosphere, predominantly as sulfur dioxide (SO_2). Sulfur dioxide is oxidized in air to sulfur trioxide (SO_3). Sulfur trioxide then can react with water to form sulfuric acid (H_2SO_4), a principal component of acid rain.

Plants can absorb SO_2 directly from the air. A study in Wisconsin showed that 44 percent of the S in alfalfa came from atmospheric sources. On the other hand, excessive concentrations of SO_2 in the air can be toxic to plants. There have been isolated instances in Iowa of SO_2 toxicity in plants growing close to a source of SO_2 emission.

Significant concentrations of SO_4^{2-} are often found in both ground and surface waters. Water for irrigation should be analyzed for sulfate sulfur (SO_4-S) content.

Most S in soil is in the soil organic matter. Research has shown that 95 to 98 percent of the total S in Iowa soils is in the soil organic matter. The form of S available to plants is sulfate (SO_4^{2-}), which is formed during the decomposition of soil organic matter by sulfur oxidizing bacteria that are present in all agricultural soils.

Sulfate is an anion. Since it is not attracted to the cation exchange sites on soils, it is subject to leaching. Consequently, it is possible that significant quantities of S may be present in subsoils. Low organic matter content and coarse texture are conditions that may lead to sulfur deficiencies.

Soil tests for available S determine extractable sulfate S. These tests are fairly reliable but do not appear to be as precise as soil tests for phosphorus and potassium. The soil test does not take into account the amount of S that will mineralize from soil organic matter during the growing season, and must be interpreted carefully.

Sulfur in Plants

Sulfur is an essential component of several amino acids, the building blocks of proteins. Over 90 percent of the S in plants is in the amino acids cysteine, cystine, and methionine. Plants require adequate supplies of S for nitrogen (N) metabolism, since both S and N are required for protein synthesis.

Sulfur is required for the activation of some enzymes, for example, nitrate reductase, which is involved in converting nitrates to amino acids in plants.

Lack of adequate available S results in a decrease in soluble protein accompanied by an increase in nitrate in plants. These changes can be detected by chemical analysis of plant tissue. Several researchers have suggested that the ratio of total N to total S in plants be used as a diagnostic tool for determining S deficiencies. An N:S ratio of 15:1 has been suggested as a critical value for nonlegumes and a ratio of 11:1 for legumes.

Prepared by Randy Killorn, extension agronomist.

Cooperative Extension Service
Iowa State University
Ames, Iowa 50011

Pm-1126 | November 1983

Sulfur in Iowa

Figure 1 shows that 49 percent of all soils tested for available S by the ISU lab from 1974 to 1979 were in the low to marginal range. Despite this, there have been no yield increases attributable to fertilizer S in Iowa except on some low organic matter, sandy soils.

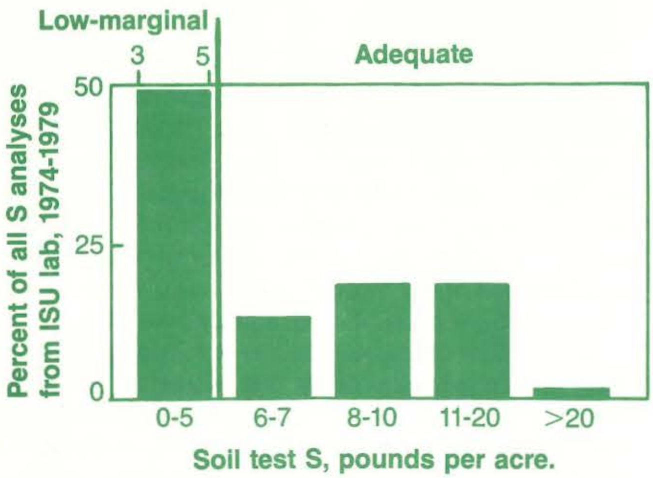

Figure 1. Concentration and interpretation of S in all soil samples from ISU lab, 1974-1979. (Data provided by Kalju Eik, ISU Soil Testing Lab).

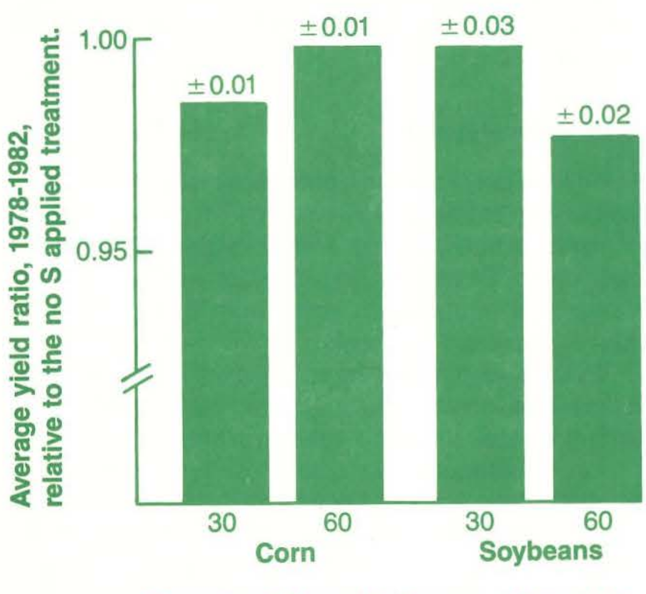

Figure 2. Effect of S fertilizer on average corn and soybean yields at five locations in Iowa.

Figure 2 is a summary of sulfur experiments on corn and soybeans conducted by ISU researchers from 1978 to 1982 at five locations in Iowa. The data are presented as yield relative to the no S treatment—a value of one indicates a yield equal to that of the no S treatment. Taking experimental variability into account, additions of S have not affected corn or soybean yields. The lack of response to added S can be explained if S from the atmosphere, the subsoil, and mineralized from soil organic matter are considered.

Studies conducted from 1971 to 1973 showed that 12 to 15 pounds of S per acre are added to Iowa soils annually in precipitation. Most of this comes during the growing season.

Sulfur mineralization from soil organic matter is a biological process that is influenced by such factors as temperature, moisture, pH, and availability of a food source for the microorganisms. In Iowa, pH and temperature are often the most important factors limiting S mineralization. Sulfur deficiency symptoms may be seen early in the spring when soil temperatures are unfavorable for biological activity. Low (acid) pH will reduce biological activity and S mineralization rates. Sulfur mineralized in 13 representative Iowa surface soils in a 70-day greenhouse study ranged from 1.4 to 18.8 pounds per acre, and averaged 6.6 pounds per acre.

Table 1. Available S in the top 5 ft. of selected profiles of Iowa soil.[1]

Soil series	Available sulfur (lbs/acre 5 ft. of soil)
Edina	262
Clarinda	317
Haig	247
Pershing	258
Marshall	117
Sharpsburg	125
Fayette	188
Ida	56
Monona	135
Tama	196
Muscatine	279
Readlyn	269
Webster	148
Nicollet	161
Clarion	174
Primghar	249
Galva	151
Weller	158
Taintor	124
Otley	195
Clinton	169

[1]Alesii, B.A. 1982. How much sulfur is in Iowa soils? *Proceedings 34th Annual Fertilizer and Ag Chemical Dealers Conference.* January 12-13, Des Moines, Iowa.

Estimates of the amount of available S in Iowa subsoils vary. In one study of five representative Iowa soils an average of 18.4 pounds S per acre was measured in the 1 to 2 foot depth of soil. However, analysis of soil profiles from numerous locations (table 1) indicates that available S may range from 56 to 317 pounds in the top 5 feet of soil.

The amount of S removed annually from the soil by various crops is listed in table 2. Using even the most conservative estimates of S available in Iowa subsoil, total available S from mineralization of soil organic matter, precipitation, and the subsoil ranges from 37 to 40 pounds per acre. This is more than enough to supply the needs of most crops grown in Iowa.

Deficiency Symptoms

Sulfur deficiency symptoms are easily confused with N deficiency. Generally, S deficiency symptoms are: light green to yellowish leaves, with even lighter yellow veins; retarded growth rates and delayed maturity; and spindly plants with short, slender stalks.

Misidentifying S deficiency as N deficiency can result in limited crop yields and poor crop quality, even though more N fertilizer is applied.

A general rule to follow in distinguishing between S and N deficiencies is that yellowing appears first on the young upper leaves with S deficiency, while most N-deficiency symptoms appear first on the older bottom leaves.

Probably the best indicator of S deficiency is the total N:total S ratio in the plants. It is generally agreed that this ratio should be about 15:1 in healthy plants. High quality forage probably requires a total N:total S ratio of 10:1. If ratios are larger than these, S is required.

Since no responses to applied S have been noted by ISU researchers, actual rates of S required for various total N:total S ratios for various crops have not been determined. However, if the N:S ratio indicates that S is required, 20 to 30 pounds of S per acre for legumes or 20 pounds of S per acre for corn should be adequate. Sulfur containing fertilizers are listed in table 3.

If S deficiency is suspected, and tissue analysis is not available, foliar spray or ground application of a soluble S source applied to test strips in fields will help verify if S deficiencies are present.

Table 2. Sulfur removed from the soil by field crops.

Crop	Yield/acre	Sulfur removed, lbs. S/acre
Corn grain	100 bu	8-10
Corn silage	13 tons	20-25
Soybeans	40 bu	5-8
Alfalfa	4 tons	20-24
Oat grain	80 bu	5
Oat straw	2 tons	9

Summary

Anticipated S deficiencies caused by increased uptake of S by high yielding crops coupled with decreased S inputs to soil have not been realized in Iowa. Sulfur supplied by mineralization from soil organic matter, subsoil S, and S from precipitation apparently provide enough S to meet plant requirements.

Sandy soils with low organic matter content can be suspected to be low in available S. If an S deficiency is suspected, it can be verified by a tissue analysis for total N and total S. If the N:S ratio is wider than 15:1 for nonlegumes or 10:1 for legumes, S deficiency can be verified by applying water soluble S to test strips in the suspect field.

Table 3. Sulfur-containing fertilizers. [1]

Source	Chemical Formula	Percent S
Elemental sulfur	S	30-100
Ammonium polysulfide	NH_4S_x	40-45
Ammonium bisulfite	NH_4HSO_3	17-32
Ammonium thiosulfate	$(NH_4)_2S_2O_3$	26-43
Ammonium sulfate	$(NH_4)_2SO_4$	10-25
Gypsum	$CaSO_4 \cdot 2H_2O$	15-18
Normal superphosphate	$Ca(H_2PO_4)_2 + CaSO_4$	10-14
Epsom salt	$MgSO_4 \cdot 7H_2O$	11-14
Potassium-magnesium sulfate	K_2SO_4-$2MgSO_4$	20-23
Potassium sulfate	K_2SO_4	16-18
Copper sulfate	$CuSO_4 \cdot 5H_2O$	12-14
Ferrous sulfate	$FeSO_4 \cdot 7H_2O$	10-14
Manganese sulfate	$MnSO_4 \cdot 4H_2O$	12-16
Zinc sulfate	$ZnSO_4 \cdot H_2O$	12-18

[1] From: Mortvedt, J. J. 1981. Identifying and correcting sulfur deficiencies in crop plants. *Crops and Soils*. 8:11-14.

File: Agronomy 7-2

Cooperative Extension Service, Iowa State University of Science and Technology and the United States Department of Agriculture cooperating. Robert L. Crom, director, Ames, Iowa. Distributed in furtherance of the Acts of Congress of May 8 and June 30, 1914.