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Sulfur deficiency

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In recent years, sulfur (S) deficiency has been diagnosed in corn, soybean, alfalfa, and wheat in the Midwest including Indiana. There are a number of reasons why S deficiency appears is becoming a more common occurrence, including reduced atmospheric S deposition, continued and increasing crop removal of S, greater use of no tillage, and high amounts of crop residues. It is wise to consider S deficiency when troubleshooting crop growth problems where yellowing of the crop is the primary symptom.

Atmospheric deposition of sulfur

Sulfur deficiency of crops may be more prevalent as of late because less S is deposited on the soil from the atmosphere **(Fig. 1),** due to reductions in power plant S emissions. As recently as 2001, soils in most of Indiana received more than 13 pounds of S per acre from the atmosphere. Extensive areas of southern Indiana received more than 18 pounds of S per acre. In 2015 (the most recent data summarized by EPA) S deposition was less than 10 pounds per acre throughout Indiana.

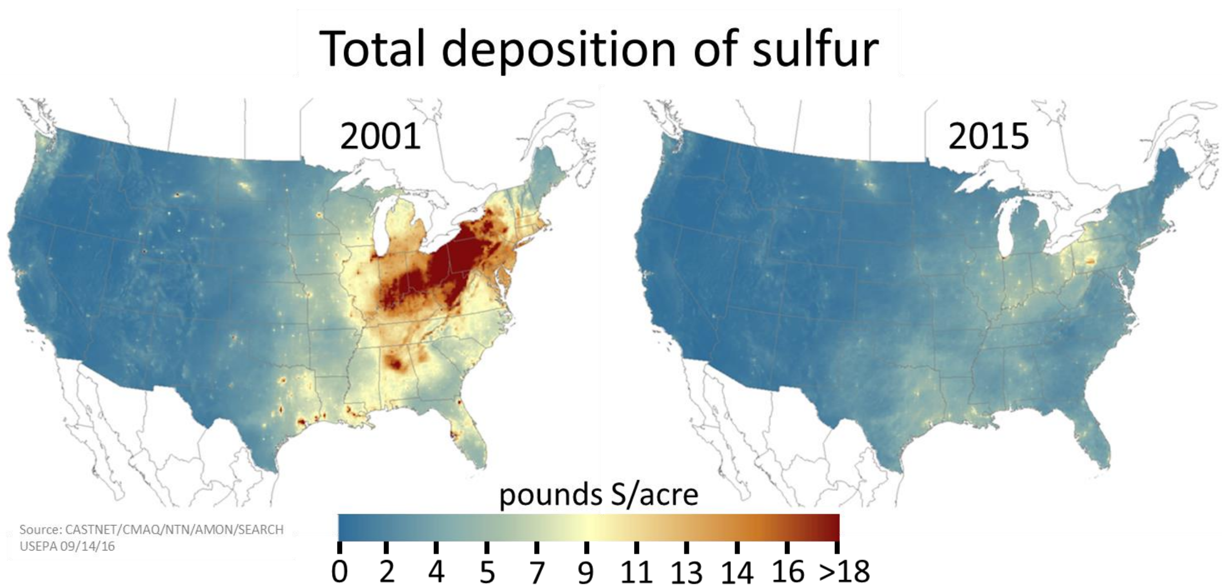

Fig. 1. The amount of sulfur deposited on the land is much less in 2015 than in 2001. Red colors indicate high deposition and blue low deposition. Data from: http://nadp.isws.illinois.edu/committees/tdep/tdepmaps/preview.aspx.
(URL accessed June 2017).

Crop sulfur removal

Crop harvest removes S from the field. Corn grain contains about 0.5 pound of S for every 10 bushels of grain, so about 10 pounds of S per acre is removed by corn that yields 200 bushel per acre. Soybean grain removes about 1.7 pounds of S per 10 bushels of grain – about 10 pounds of S per acre at 60 bushels per acre. Alfalfa hay removes about 5-7 pounds of S per ton of hay, so upwards of 20-30 pounds of S per acre per year. Ten years ago crop S removal was generally less than atmospheric S deposition, but now crop removal is equal to or greater than S deposition in most situations.

While deposition has decreased in the last 15 years, crop yield and S removal continue to increase. Over the past years, corn and soybean grain yields have increased about 1.8 and 0.4 bushels per acre per year, respectively. Increasing grain yield increases results in greater crop S removal from the field.

Soil properties and crop management affecting sulfur availability

If fertilizer S is not applied to the soil the main source of S in most soils arises from the mineralization of soil organic matter. Each percent organic matter in the upper 6 to 8 inches of soil contains about 100 pounds of sulfur per acre. Organic S must be mineralized to sulfate-S (SO_4-S) to be taken up by crop plants, in much the same way that organic N is made available to crop plants. Therefore, the lower the organic matter content of the soil the more likely S deficiency is to occur.

Since mineralization is a process carried out by microorganisms, soil temperature and moisture largely determine when and how much of the organic S is made available to the crop. Cold and excessively wet or dry conditions reduce microbial activity and reduce S availability from soil organic matter and crop residues. Thus, crops are more likely to be S deficient in the early spring before soil temperatures warm substantially, particularly with minimum tillage which results in colder soils.

Increases in no-till, early planting, and heavy residue from high yields have also been implicated in increasing the occurrence of S deficiency. Soybean and corn residues contain relatively low concentrations of S. During the decomposition of crop residues which are low in S, inorganic S from the soil may be preferentially utilized by the microorganisms making it temporarily unavailable to the crop – a process called immobilization. Thus S deficiency may occur more frequently with large amounts of crop residue early in the growing season.

Sulfate-S is relatively mobile in most soils (similar to nitrate) because it has a double negative charge and is repelled by the negative charge of the soil, unlike nutrients such as potassium, calcium, or magnesium. Although SO_4-S can bind to iron and aluminum in the soil, these elements are much more likely to bind phosphate at the exclusion of SO_4-S. As a result, SO_4-S is easily leached from soils, especially sandy soils.

At the field level the occurrence of S deficiency may be highly variable since soil S availability varies considerably with soil organic matter and texture. Sulfur deficiency is often seen in sandier, lower organic matter, and higher elevation areas of a field while lower lying, higher organic matter, and heavier textured areas typically have sufficient S.

Soil testing and sulfate-sulfur trends over time

There are several reasons why soil testing is not particularly useful for predicting S deficiency. First, soil sampling is usually performed in the fall or early spring of the year and second, only the upper 6 to 8 inches of soil is typically sampled. Soil testing may overestimate S availability if SO_4-S is leached below the crop root zone prior to crop need for S. Conversely, SO_4-S remaining in the crop root zone, but below the sampling zone and available to the crop, will not be measured with traditional sampling depths. Third, commonly utilized soil testing methods do not measure organic S which can be a significant source of crop S uptake after microbial mineralization. Sulfur deficiencies are notoriously transient because as the season progresses crops often access S deeper in the soil profile and warmer temperatures result in S mineralization from OM and crop residues.

Although traditional soil testing is not predictive of S deficiency it is useful for tracking changes in soil S levels over time. Summaries from A&L Great Lakes Laboratories (https://algreatlakes.com/pages/soil-test-summaries) indicate that the percentage of soil samples low in SO_4-S has increased over the past 10 years. In 2005-2007, less than 5% of soil samples tested in northern and southern Indiana had less than 8 ppm SO_4-S. The percentage of samples less than 8 ppm increased steadily over time to about 70% by 2016.

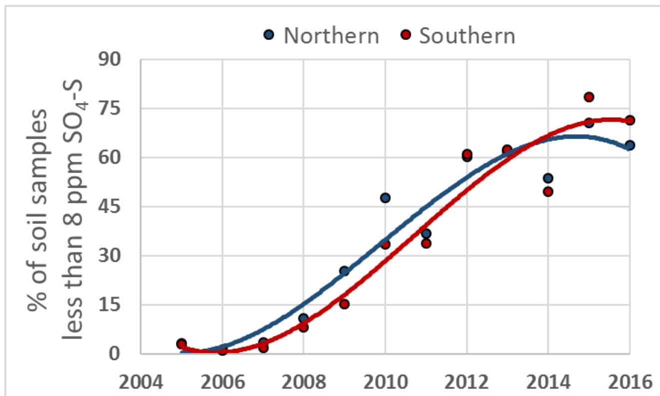

Fig 2. Soil samples testing lower than 8 ppm SO_4-S in northern and southern Indiana in the years 2005-2016. A&L Laboratory summary.

Diagnosing sulfur deficiency

Fig. 3. Soybeans without S and with 20 pounds sulfur per acre. ***Photos: Shaun Casteel.***

Sulfur deficient crops typically have an overall yellow appearance **(Fig. 3 & 4)** similar to N deficiency. However S is not as mobile in the plant as N, so lower leaves do not show more severe deficiency symptoms than the upper leaves. If a S deficiency is misdiagnosed as a N deficiency the application of fertilizer N will make the S deficiency worse, so tissue sampling is recommended to positively identify which nutrient is deficient. In corn, S deficiency may also cause leaf striping **(inset Fig. 4)** which is easily confused with magnesium, manganese, and zinc deficiency.

Fig. 4. Areas of sulfur deficiency (pale green) and sufficiency (dark green) in an Indiana corn field caused by variations in soil properties. Young corn that is sulfur deficient may show striping as well as an overall yellow color. ***Photos courtesy of Jeff Nagel.***

Tissue Sampling

The best way to identify a S deficiency is by tissue sampling from areas suspected of deficiency and healthy areas of the field for comparison.

For corn plants less than 4 leaf collars and soybeans less than 12 inches, sample the whole plant beginning about ½" above the soil surface. For larger corn and soybean plants, sample the youngest collared corn leaf or the most recently matured soybean trifoliate. Collect 15 to 25 corn or 20 to 30 soybean samples to represent each area.

Tissue samples contaminated with soil can be rinsed quickly in cold distilled water, but do not overdo it because some nutrients, especially potassium, may be leached out of the tissue. Wet samples should be air-dried before shipping to the laboratory in paper bags.

In the plant, S is a component of two amino acids and occurs in protein in a ratio of 1 part S to about 15 parts N. Therefore, the N:S ratio of plant tissue as well as the S concentration are used to identify S deficiency. The lower the S concentration and the higher the N:S ratio the more likely S is deficient in the plant.

Corn tissue S less than 0.15% and N:S ratio greater than 20:1 are most likely S deficient. Sulfur is most likely adequate when corn tissue S is greater than 0.20% and the N:S ratio is less than 12:1. Tissue S and N:S values in between these levels can go either way – deficient or adequate. Critical tissue S levels for soybean have been studied much less than for corn. Typically 0.2-0.3% S is considered adequate.

A soil analysis is always helpful for distinguishing among possible nutrient deficiencies. One should keep in mind that the soil test for sulfate-S is not the most accurate, because of the mobility of SO_4-S in the soil and the release of S from soil organic matter. The results of a soil analysis might be most useful for ruling out the possibility of other nutrient deficiencies, than identifying S deficiency.

Correcting Sulfur Deficiency

Sulfur fertilizer should be applied as close to crop need as possible to reduce the chance it will be lost from the root zone by leaching. Often including S in a fertilizer program to avoid S deficiency is more efficient and less costly than correcting a S deficiency once it occurs. If S deficiency is anticipated in corn, an application rate of 15 pounds of SO_4-S per acre is recommended on fine-textured soils and a rate of 25 pounds of SO_4-S per acre is recommended on coarse-textured soils, based on the most recent research conducted in Iowa **(see ref. 2)**. Although some carryover of S may occur in silt loam soils it likely will be necessary to make applications of S every year on sandy soils, particularly if irrigated and high yielding. Current research with soybean conducted by S. Casteel has found in-season soil and foliar applications of S to overcome S deficiency. Multiple foliar applications may be necessary to fully overcome S deficiency in some cases.

Fertilizer Materials

There are several fertilizers available for correcting a S deficiency **(Table 1)**. Adding ammonium thiosulfate to urea-ammonium nitrate solutions or blending ammonium sulfate with urea are convenient and cost effective ways to provide S in a timely manner to non-legume crops. Otherwise, sulfate-of-potash-magnesia (sul-po-mag or K-mag) or potassium sulfate can be blended with muriate of potash to provide S and K. The inclusion of magnesium in sul-po-mag may be an extra benefit compared to potassium sulfate if soil magnesium levels are low. Generally these fertilizers are spread prior to planting therefore the SO_4-S might be lost from sandy soils before the time of crop need. Spray-grade ammonium sulfate is usually the fertilizer of choice for foliar applications.

Naturally-occurring mined gypsum and several by-product sources of gypsum can be applied to provide S as well. Gypsum if pelletized can be blended with other fertilizers or if ground, applied with a lime spreader. Unless pelletized, however, higher than necessary rates of S will be applied with gypsum which is difficult to spread at rates less than 500 to 1000 pounds per acre (85 to 170 pounds of S per acre assuming 17% S). If carryover of S occurs, the S will be utilized in later years. However, in sandy soils, where leaching is likely, the benefit in future years may be minimal.

Table 1. Sulfur-containing fertilizers and their approximate composition **(see ref. 3)**. The actual nutrient concentration of a fertilizer should be expressed on the guarantee.

Fertilizer	%N	%K_2O	%S	%Mg	%Ca
Ammonium sulfate	21	0	24	0	0
Ammonium thiosulfate	12	0	26	0	0
Elemental sulfur	0	0	>90	0	0
Gypsum (calcium sulfate)	0	0	19	0	23
Potassium magnesium sulfate	0	22	23	11	0
Potassium sulfate	0	50	18	0	0

Elemental S must be oxidized by soil bacteria to SO_4 before becoming plant available. Warm temperatures and good moisture and aeration are required for S-oxidizing bacteria to function. Sulfur oxidation is minimal at soil temperatures less than 50° F. Even at 75° F the oxidation rate of S is about 15% of that at 85° F, so peak rates of S oxidation do not occur until late spring. Since the availability of elemental S may be minimal in early spring, a fertilizer containing all or at least some SO_4, in addition to elemental S, is preferred over a fertilizer with elemental S alone.

Effects of sulfur containing fertilizers on soil pH

Soil pH is lowered by elemental S, ammonium thiosulfate, and ammonium sulfate. The oxidation of elemental or chemically reduced S (thio-S for example) creates acidity which lowers soil pH. However, no acidity arises from the sulfate in any of the fertilizer materials including ammonium sulfate. With ammonium sulfate the conversion of ammonium to nitrate is the component that generates the acidity. When used to provide less than 30 pounds S per acre, the amount of acidity generated by each of these acid-producing fertilizers is equivalent to less than 100 pounds of limestone per acre. None of the S containing fertilizers in Table 1 increase soil pH. Gypsum, sulfate-of-potash-magnesia, and potassium sulfate do not affect soil pH.

References:

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(2) Camberato, J., S. Maloney, S. Casteel, and K. Johnson. 2012. Sulfur deficiency in alfalfa. https://www.agry.purdue.edu/ext/soilfertility/05-03-12Sulfur_deficiency_alfalfa.pdf. (URL accessed June 2017).

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(5) Crozier, C., D. Osmond, et al. 2017 North Carolina Agricultural Chemicals Manual - Fertilizer Use. https://content.ces.ncsu.edu/north-carolina-agricultural-chemicals-manual/fertilizer-use. (URL accessed June 2017).