SULFUR
Why it’s important?
When do we need it?

The Mosaic Company®, maker of MicroEssentials® SZ, is a sponsor of this publication and of the On-Farm Network®.
Sulfur: an essential element

S

ince its beginning, the On-Farm Network® has focused on using crop production data collected using newer technologies to improve management practices and profits. For several years, growers working through the On-Farm Network have been doing a few different types of trials and talking about these at group meetings.

A few have conducted trials studying the effect of supplemental sulfur. From the discussions of these trials in 2009, it became apparent that most growers would like to know more about this plant nutrient.

Most growers understand that sulfur is an important nutrient for crop production. However, few have deliberately added sulfur (S) to their fertilizer programs.

The reason for this is that the S in our soils has been adequate over the years and research has shown there was little need to add more. As on-farm testing increases, we’re beginning to see a few places where there is a response to applied S. These recent reports have more people wondering whether they need to supplement S.

As with most agronomic decisions, the answer is seldom a uniform yes or no. In order to identify where a response to S is likely, we need to understand the basics about it as a plant nutrient. When we apply that to current information about our crops, we can make an informed decision about using S.

As a simplified way, we think of soil fertility as a balance sheet. We know we have to have the right nutrients in the right amounts in the soil for a crop to grow. When we harvest a crop, we remove the nutrients (including S) it took from the soil along with the crop. In order to maintain balance, we need to replace those nutrients.

Sulfur (as well as N, P, and K) was naturally present in our soils when the ground was first farmed more than 150 years ago. When we grow crops and remove the grain and organic matter from the field, we remove some of this fertility from the soils. Over time, this net removal becomes significant.

We add N, P and K routinely now because the impact of removing grain from the fields year after year in increasingly higher amounts has depleted them from the soil.

To date, most growers have not included S in their nutrient management strategy, though it has been present in some of the fertilizers used.

Until recently, sufficient S for most crops has been added back to the soil, mostly deposited by rainfall (see S-Cycle illustration on page 4). Efforts to improve air quality in the U.S. have significantly reduced the amount of S in the air and, in turn, the amount of S deposited through precipitation. At the same time, though, crop yields are increasing, increasing their need for S. The trend is an increasing deficit of our S balance sheet. Knowing that we appear to be in a net mining condition in Iowa, the question is not if we will need to add S, but rather, when we will have to supply it.

Topics covered in this publication range from the basics of sulfur, to where we would expect to see S deficiencies first, what we can do to confirm a need for S, and our options for adding S back into our soils.
Basic questions about sulfur

Question: Why is sulfur important to a plant?
Answer: Sulfur is an essential component of proteins. 90% of plant sulfur is in proteins.

Question: What causes the yellow coloring in sulfur deficient plants?
Answer: Sulfur is needed for the synthesis of chlorophyll. When sulfur is limiting, there is less chlorophyll production which makes the plant appear yellow.

Question: Does sulfur affect other nutrient uptake or utilization?
Answer: Yes. Sulfur is a component of ferredoxins, which are important in nitrogen fixation in legumes such as alfalfa and soybeans.

Question: Does sulfur affect the feed quality of the crop?
Answer: Yes. The nitrogen to sulfur ratio is important in a feed ration so ruminants can utilize the nitrogen.

Question: How much sulfur is in a bushel of corn or soybeans?
Answer: Corn has about 0.08 lbs. S/bu. (200 bu. contains 16 lbs. S). Soybeans have about 0.18 lbs. S/bu. (60 bu. contains 11 lbs. S).

Question: How much S is in the soil?
Answer: The average amount of S in the soil ranges from .06 to .10%, which is similar to total phosphorus. More than 90% of the S in the soil is in the organic matter.

Question: Doesn’t sulfur acidify the soil?
Answer: While elemental sulfur does, the sulfate form (SO₄) does not. However, as the ammonium from ammonium sulfate fertilizer nitrifies, soil acidity is increased.

Question: Do we really have sulfur deficiencies in Iowa?
Answer: Yes. While not widely detected yet, several S deficient areas have been found while looking for areas thought most likely to be deficient.

Question: Is it possible that what I thought was N stress is actually S stress?
Answer: Yes. A S deficiency interferes with the N metabolism in the plant. S deficiencies are usually not as dramatic or localized on the plant as a N deficiency.

Question: Wouldn’t my soil tests have told me if I needed more S?
Answer: No. Soil tests are not considered reliable for detecting S.

Still have questions?

If we haven’t answered your questions about S in this publication or on our website (www.isafarmnet.com) please contact us by:

Email: info@isafarmnet.com
Phone: 800-383-1423
Mail: On-Farm Network
1255 SW Prairie Trail Parkway
Ankeny, IA 50023
The sulfur cycle

Overall, there are really four major forms of sulfur that are important to agriculture. They are sulfides, sulfates, organic sulfur and elemental sulfur. Most of the S that is present in the soil is tied up in the organic matter, so is not readily available for use by plants.

In many ways, sulfur (S) is like N in terms of the processes and transformations it undergoes. Comparisons of the S cycle to the N cycle show many similarities in the processes, inputs, losses and biological transformations.

The main form that plants can use is sulfate (SO₄), which is absorbed and taken up through plant roots.

The availability of sulfate is largely affected by carbon availability. Soil microorganisms get their energy from carbon. When carbon levels are high in the soil, the microorganisms will tie up much of the S (and N) while consuming the carbon sources. The net effect is less S is converted to an organic form that is not available for plant uptake. The process is called immobilization. A carbon-to-sulfur ratio of 400:1 will typically lead to S immobilization. If the C:S ratio is 200:1 or lower, mineralization of S will occur, which is the release of S from the organic form.

![Diagram of the sulfur cycle]

Basic Sulfur Facts

- Soils typically contain from 200 to 600 lbs. of sulfur per acre, most of which is unavailable for plant growth.
- Organic matter is the main reservoir for sulfur in the soil. Usually, the higher the organic matter content, the more sulfur the soil has in reserve.
- Sulfate (SO₄) is the main form of sulfur used by plants.
- The availability of sulfate in the soil is dependent on biological processes. Sulfur in organic matter is mineralized by soil microorganisms into SO₄. From 2.5 to 3 lbs. per acre of S are mineralized annually for each 1% soil organic matter.
- Sulfate, like nitrate, is easily leached (picked up and transported by water moving through the soil profile).

The illustration shows a simplified version of the sulfur cycle. Gaseous forms of sulfur can be released into the atmosphere through geologic activity (volcanos, hot springs, etc.) or through activities such as manufacturing or generating electricity. Sulfur gases combine with precipitation and are deposited onto soils, where they can be acted on by microorganisms. Soils typically contain more than enough sulfur for crops, but it must be mineralized by bacteria before it is available for plant growth. We can avoid sulfur deficiencies in crops by supplementing sulfur from precipitation and mineralization with fertilizer.

www.isafarmnet.com
Sources of sulfur

There are a number of different sources that can be used to supplement the soil S.

Manure is an excellent source of S (See sidebar). There are a number of commercial fertilizers that contain S. In addition to cost of the product, there are number of factors to consider. The length of time before it is available to a crop is one factor. Does it take an extra application cost to get it applied? Will it affect the soil pH? Can it be applied at the rate desired or will it burn the crop, or not mix with other sources?

Common sulfur fertilizer materials

**Elemental Sulfur 85-100% S**
- Yellow, solid, cheapest of all S sources
- Slow response
- Acid forming
- Takes time to dissolve
- Microorganisms must oxidize into sulfate

**Ammonium Sulfate (21-0-0-24)**
- Granular solid and liquid
- Expensive as a N source
- Fast availability – Sulfate

**Ammonium Thiosulfate (12-0-0-26)**
- Liquid, easily mixes with UAN
- Avoid direct seed contact
- Acid forming
- More expensive than elemental S, but readily available

**Potassium sulfate – 18% S**
- Expensive
- Easily blended with other dry fertilizers

**Gypsum – Calcium sulfate (0-0-0-18)**
- White solid
- Relatively cheap
- Relatively soluble

**Proprietary products** (Like Mosaic’s MicroEssentials SZ)
- Has half as sulfate (rapid availability) and half as elemental S (released slowly through microbial mineralization)
- MAP

Foliar fertilizers

A wide range of foliar fertilizers contain S in varying amounts. While plants can use S that is foliar applied, most of the S will come from the soil. Also the amount added from a foliar fertilizer is usually relatively small.

One of the factors to remember in nutrient management is that we tend to think of a single nutrient, but there are many nutrients that are all important. When applying fertilizers, it is important that all nutrients be adequately assessed and managed correctly. Applying only S when other nutrients are also deficient may not get the results desired.

**Manure as a sulfur source**

The amount of S in manure can vary greatly, depending upon the source and handling. There are a number of different livestock and poultry waste products that growers apply for various nutrient value including S. It should be noted, that not all waste products contain sulfur. Additionally, sources that are high in available C and low in S could create a situation that immobilizes some of the S that might have been available.

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<th>Animal type</th>
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<th>Solid (lb./ton)</th>
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<tr>
<td>Dairy</td>
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Source: University of Wisconsin Extension publication A2525, Emmett Schulte and Keith Kelling
Why sulfur; why now?

Looking at sulfur with a soil budget or mass-balance approach can give us some general insights into changes that have occurred in Iowa. The summary table below provides a simplified explanation of changes in a sulfur balance in our Iowa production fields.

From the table above, it is easy to see that of the six main factors that have changed in Iowa, only one has resulted in a favorable change in the soil sulfur (S) balance. While soil reserves do hold a fair amount of S, there is not an endless supply. Most factors that have changed are likely to lead to increasing depletion of our soil S supply. This means that moving into the future, there’s an increasing probability that our crop yields will be responsive to supplemental S.

Sulfur from precipitation
One of the biggest changes has been the reduction of S from the air/rain. The S Cycle diagram on page 4 shows that S gases in the air are absorbed by moisture and deposited by precipitation. The maps on page 7 show the amount of S deposited by precipitation in 2008 and, for comparison, 1986.

When the rates from the 2008 map are compared to the numbers in the table of crop removal, (on the right) you can see the current deposition of 3-12 lbs./acre is not enough to replenish the amount removed by crops.

Fertilizer use
Fertilizer use has also shifted over time, with a decrease in the use of ammonium sulfate as a source of N. In addition, there has been a decrease of S from other fertilizer materials that contained some S as a residue from the manufacturing process. For example, single super phosphate, which used to be the main source of supplemental phosphorus, contained some S. Since we’re now using more MAP or DAP to provide phosphorus, we’re adding less S to the soil.

Manure use has changed
Manured fields seldom show S deficiency. However, manure use has changed in Iowa. While livestock and poultry production has continued in roughly comparable amounts to the past, we’ve changed the way we handle manure and also the amount of ground that routinely receives manure. Manure is now used on less than 30% of the farm ground in the state. While some fields may receive significant amounts of S from the manure, most of our crop land does not receive manure regularly.

The two main factors that affect the rate of removal of S from our soil are crop rotation and overall yields.

Less forage in crop rotations
We’ve moved away from forage crops, which remove more sulfur than corn or soybeans. This decrease in forage production has been gradual in Iowa, taking place over the last 50 years, but the net effect is that S removal is not as great when we produce less forage.

Higher yields mean higher crop removal
Offsetting this slightly, however, is the fact that overall yields, the second factor affecting S removal, have increased over time. An increase of both grain and forage yields results in a more rapid depletion of nutrients, including S, from our soils.

Sulfate, like nitrate, is a negative ion that is easily leached with water moving through the soil. The increase in tile drainage in Iowa suggests an increase in S loss through leaching is
likely, but data documenting the actual amount of leaching is limited.

In summary, without the addition of S fertilizer or manure, there is a net decrease in a S budget for corn and soybean production in Iowa. The balance has not always been negative, but with the increase in production and the decrease in deposition from the air through precipitation, we would expect this deficit to only get larger. As we look into the future, with the potential of using residues for cellulosic ethanol production, etc., we would expect an even faster depletion of S from our soil.
When we think about fertilizer, we think nitrogen, phosphorus and potassium. But sulfur? We're not used to thinking about it as a crop nutrient or a necessary fertilizer. So if you’re like most growers, you probably don’t have a strategy for dealing with S.

There really are four different parts in a management strategy for S. First, determine where a S deficiency is most likely to first show up in your operation. Second, decide which diagnostic tools you can use to identify or confirm a sulfur deficiency. Third, find management practices (i.e., S additions) that you can use to correct the deficiency. Finally, evaluate the effectiveness of the correction strategy.

**Predicting the most likely place**

As stated in the preceding pages, the role of the general S budget can be used to help identify or prioritize areas of S deficiency. Some of the key factors are the organic matter content of the soil which indicates the amount of sulfur in the soil reservoir. Another key factor is the history of crop removal. Forage production removes considerably more S than grain production. So fields with low organic matter and long histories of forage/silage production with no manure additions would be more likely to exhibit a S deficiency. A high organic matter field with a history of grain production and routine application of manure would be less likely to be S deficient. For all scenarios, addition of other sources of S, such as ammonium sulfate would be an important consideration as well.

**Confirming a shortage**

The tool most often used when trying to determine if a soil is deficient is a soil test. However, as with N, it's difficult to get a reliable result. Because of the dynamics of S in the soil and trying to predict what is actually available to the crop, soil testing to predict a crop response to S is generally considered unreliable. A soil test can be used to identify high amounts of available S, but when S content of the soil is relatively low, the test has proven to be unreliable at predicting availability.

**Tissue testing**

Tissue testing is considered more reliable. There have been a number of papers quantifying the optimal concentrations of S. The tissue concentrations reported by John Sawyer, soil fertility specialist at Iowa State University, in his preliminary evaluations in Iowa were consistent with previous published results that showed an optimal concentration is approximately 0.21%. Often the ear leaf of the corn plant is sampled. Comparing samples in the same field/hybrid between poor and good areas may be the best strategy.

**Visual symptoms of stress**

Visual symptoms can be seen when S stress becomes severe enough. A S deficiency will result in a lighter green/yellow color. It will also affect plant growth. (See photos on right.) From a distance, S stress can easily be mistaken for N stress. (See photo on next page.) In corn, close examination of the leaves, however, will show that plants with severe deficiencies have yellow or white streaks along the leaf veins that may stretch the full length of the leaf. Notice in the photos above, there is a difference in the height of a crop between strips where S was deficient and where the deficiency was addressed using ammonium sulfate.

But probably the most reliable way to know whether a sulfur application will pay is to apply some S in strips
in fields where there is a concern, to see whether a difference can be measured with a difference in yield. (Pages 10-11 give examples of how this has been done.)

**Adding sulfur**
Several products—with sulfur in different forms—are available for correcting or preventing a sulfur deficiency. There are a variety of ways these products can be applied.

It is important to note that sulfur forms vary in their availability for plant growth. Plants can readily take up sulfate (SO₄), so a fertilizer product containing SO₄ would be appropriate where extreme stresses are visible. Elemental sulfur (S) must be mineralized into SO₄ by soil bacteria before plants can take it up. Elemental sulfur, then, is more of a slow release fertilizer, to be used as part of a soil maintenance program.

**Foliar fertilizer**
Because of the large volume of S taken up by a crop, sulfur is often added as a soil amendment, rather than as a foliar fertilizer. Plants can take up sulfate from a foliar fertilizer, but the SO₄ of most foliar fertilizers is less than the amount needed by the crop. So while there may be a fast response from a foliar fertilizer containing SO₄ applied to plants displaying a visible sulfur deficiency, a single foliar application may not contain enough S to meet the full amount needed to overcome the deficiency.

It is also important to consider that nutrition is complex and dependent on many of the plants’ other needs being met as well. If a plant is short on N, P, and/or K, there may not be a visible or a yield response to added S, or the response may not be as big as if the other nutritional needs have been met.

For this reason, responding to a sulfur deficiency by adding sulfur does not guarantee a yield increase. This is why it’s important to measure the yield response to the management solution you choose to correct the deficiency. In other words, it will help you see whether the rate, form or application method you chose for correcting the problem actually gave you a financial return on your investment.

Because there are cost differences between the various sulfur product options and types of application, it is important that we test not only the response of a practice but the relative effectiveness of each. And this is even more important with sulfur, because we have so little experience with directly managing it in Iowa.

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It’s easy to mistake sulfur deficiency for nitrogen deficiency. Both give the field a yellow look. Sulfur is immobile in the plant, so a deficiency is more likely to show up in younger leaves or throughout the plant. Nitrogen is mobile in the plant and when deficient, is transported from old leaves to younger ones. This means N deficiency shows up first in older leaves, while S deficiency shows up in newer leaves.
Replicated strip testing is a methodology for comparing yields from two different management practices across a field. These strips of alternating S management are harvested with combines equipped with GPS and yield monitors. Management practices tested may focus on differences in product application rate, timing, application method, product form, etc.

**Guidelines for On-Farm Network® replicated strip testing**

All On-Farm Network strip trials follow a simple protocol that assures they’re easy to put out and harvest, and that results are reliable for making decisions. A typical trial protocol example is shown on this page.

1. Keep it simple. Just compare two management practices in a given trial.
2. Keep all other practices the same (i.e., same hybrid, seed treatment, planting date).
3. Replicate at least three times, in side-by-side strips across the field at least the width of the combine header. More replications are better.
4. Mark strips with GPS (and flags where possible) so they can be recognized at harvest and yield data can be recorded separately.
6. Record yields with combine yield monitor, saving data separately for each strip.
7. Submit results to On-Farm Network for analysis immediately after harvest is complete.

**What can be tested?**

For several years now, growers have worked through the On-Farm Network to compare fungicides, insecticides, seed technologies and treatments, fertilizer products, and much more. They’ve tested management practices, application rates, timing, application methods, tillage practices, planting methods, and seeding rates. Anything you can imagine can be tested this way, as long as it lends itself to strips or swaths across the field.

**Selecting a field**

In small plot research where small test areas are randomized over a field, any field variability within the test area can skew the results. In replicated strip trials, variability can make a trial more valuable. Because GPS and yield monitors permit yield measurements in site-specific places, a single trial could characterize a number of different soil types or landscape positions.

Fields that have significant soil or landscape variation that lies perpendicular to the treatments are preferred. This way both treatments are affected relatively the same.

Fields with frequent terraces or point rows are less suitable for strip testing because it’s difficult to find an area large enough and similar enough to make multiple side-by-side passes.

**Yield summaries**

From the yield of each strip, the average yield difference between adjacent strips is easy to calculate. In addition, both yields and difference in yields between products or management practices can be calculated for each soil type, based on georeferenced soils maps overlaid on yield maps created from the yield monitor data.

More trial protocols at [www.isafarmnet.com/protocols.html](http://www.isafarmnet.com/protocols.html)
On-Farm Network® replicated strip trials of MicroEssentials® SZ on corn and soybeans

In the past, corn and soybeans in Iowa have rarely responded to sulfur (S) application. Recent Iowa State University reports suggest the potential for large corn yield responses to applied S in north-central and northeastern portions of the state. Increasingly higher grain yields and stringent government air quality regulations preventing use of high-sulfur coal by coal-fired power plants may have resulted in depletion of sulfur supplies from the soil, raising the potential for crop deficiencies.

Seven replicated strip trials were conducted in 2009 to evaluate MicroEssentials SZ fertilizer, a dry granular formulation containing mono-ammonium phosphate (MAP), S and zinc (12-40-0-10S-1Zn). The S in the blend is in both the sulfate (SO₄) and elemental forms.

In 2009, growers working with the On-Farm Network established three trials with soybeans following corn: three where corn was planted after soybeans, and one where corn followed alfalfa. Seven of the eight trials were located in north-central Iowa. The MicroEssentials SZ treatments were compared with DAP or MAP applied at the same rate of phosphorus (P) per acre: 70 lbs./acre for corn and 40 lbs./acre for soybean. Soil test values provided by the growers showed that the trial fields were in the High and Very High soil test P categories. None of the growers had observed S deficiencies or yield responses to S in recent years.

Across three corn trials (Table 1), the strips which received MAP or DAP yielded about 7 bu./acre more than the control where no P was applied. It is difficult to determine whether this yield response can be attributed to applied P, or whether it might be due, at least in part to the additional 17 lbs. of N per acre supplied by the MAP or the 27 lbs. of N/acre from the DAP. When comparing MicroEssentials SZ to the DAP or MAP, the yield response was about 3 bu./acre. The difference in the cost between MicroEssentials SZ and MAP was about $10/acre when the same amount of P was applied to corn. The corn-after-alfalfa (in Black Hawk Co.) had visual differences in plant growth early in the season, but the corn was damaged by hail and the final yields did not show a yield response to sulfur.

Across three soybean trials (Table 2), about 2 bu./acre of yield response was attributed to the MAP/DAP applications. The MicroEssentials SZ treated strips showed a 4 bu./acre yield response over the untreated strips, and a 2 bu. response compared with the DAP/MAP. The difference in the cost between MicroEssentials SZ and MAP was about $5/acre when the same amount of P was applied to the soybeans.

Based on this limited number of trials, yield responses to sulfur in both crops were slightly above the cost needed to pay for the S fertilizer. In future studies, it may be more reasonable to target row crops in northeastern Iowa planted after alfalfa where a S deficiency has been documented.

### Table 1. On-Farm Evaluations of MicroEssentials SZ on Corn in 2009

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<th>Trial ID</th>
<th>County</th>
<th>Previous Crop</th>
<th>Soil P Test Category</th>
<th>P Fertilizer Form</th>
<th>N applied with DAP or MAP, lb N/acre</th>
<th>Rainfall (inches)</th>
<th>Yield (bu./acre)</th>
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*ST2009060A was badly damaged by hail.

Table 1. On-Farm Evaluations of MicroEssentials SZ on Corn in 2009

Table 2. On-Farm Evaluations of MicroEssentials SZ on Soybeans in 2009

<table>
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<th>Trial ID</th>
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Table 2. On-Farm Evaluations of MicroEssentials SZ on Soybeans in 2009

40 lb./acre of P₂O₅ was applied with DAP, MAP, and MicroEssentials SZ (12-40-0-10S-1Zn).

Cost difference between MicroEssentials SZ and MAP was about $5/acre.

70 lb./acre of P₂O₅ was applied with DAP, MAP, and MicroEssentials SZ (12-40-0-10S-1Zn).

21 lb./acre of N was applied with MicroEssentials SZ.

Cost difference between MicroEssentials SZ and MAP was about $10/acre.
More information on sulfur as a crop nutrient

Websites

On-Farm Network®
- www.isafarmnet.com/tools.html
- www.isafarmnet.com/protocols.html
- www.isafarmnet.com/09STrial/09resulttrial.html

The Mosaic Company®
- www.mosaicco.com
- www.back-to-basics.net
- www.microessentials.com
- www.kmag.com

Publications

Soil and Applied Sulfur
University of Wisconsin Extension Publication A2525
Emmett Schulte and Keith Kelling
www.soils.wisc.edu/extension/pubs/A2525.pdf

Dealing with sulfur deficiencies in crop production: the northeast Iowa experience
Presented/published 2008 Indiana Crop Adviser Conference, Purdue University
John Sawyer, Brian Lang, and Daniel Barker
www.agronext.iastate.edu/soilfertility/info/2006LangICMCo
nfProcBL_11-16-06.pdf

Organizations

The Sulphur Institute
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www.sulphurinstitute.org/

International Plant Nutrition Institute
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www.ipni.net

For more information on the Iowa Soybean Association
On-Farm Network® go to www.isafarmnet.com. You can
email us at: info@isafarmnet.com Call toll-free: 800-383-1534. Or write to:

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