SULFUR IN MINNESOTA SOILS
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Sulfur (S), one of the 16 essential nutrients for plant growth, is classified as a secondary nutrient along with calcium (Ca) and magnesium (Mg). Secondary nutrients are required in smaller amounts than N, P, and K. But, requirements are larger than requirements for the micronutrients.

Sulfur, like nitrogen, is in a constant state of change in soil. Many of the reactions and transformations are similar. The magnitude however is different. So, if you have some understanding of the transformation of nitrogen in soils, it should not be difficult to grasp the dynamics of S.

1. NON-FERTILIZER SOURCES OF SULFUR

Plants use S in the sulfate form, designated as sulfate-sulfur (SO$_4$–S). Yet in most soils 90% to 95% of the total S present is found in the soil organic matter (SOM) component. Total S in some representative Minnesota soils is shown in Table 1.

Table 1. Total sulfur (S) content of some representative Minnesota soils (2).  

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Total S (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fayette</td>
<td>280</td>
</tr>
<tr>
<td>Estherville</td>
<td>450</td>
</tr>
<tr>
<td>Glencoe</td>
<td>763</td>
</tr>
<tr>
<td>Fargo</td>
<td>929</td>
</tr>
<tr>
<td>Nebish</td>
<td>352</td>
</tr>
<tr>
<td>Port Byron</td>
<td>455</td>
</tr>
<tr>
<td>Webster</td>
<td>607</td>
</tr>
</tbody>
</table>

Sulfur is incorporated into protein as a constituent of three amino acids; methionine, cystine and cysteine. Sulfur in proteins is converted to sulfate-sulfur (mineralized) by a wide variety of ubiquitous microorganisms. Because of the varying complexity of the proteins, some are more easily mineralized than others. Therefore, S mineralization takes place at different rates throughout the growing season. Sulfur from proteins that are less complex is released early in the growing season. Sulfur from proteins that are slowly degraded is released later in the season. The same concept applies to the release of N from the soil organic matter. As a microbial process, mineralization of organic S to SO$_4$–S is strongly affected by soil moisture and soil temperature. Since these two factors vary substantially throughout the growing season, it is difficult, if not impossible, to predict the amount of S released from the soil organic matter.

The amount of SO$_4$–S mineralized may also be directly related to soil type illustrated by the data in Table 2. The incubation study was conducted at the University of Minnesota Soil Testing Laboratory under ideal conditions of temperature and moisture. The data indicate that there is no relationship between S mineralization and soil texture.
Table 2. Sulfate – sulfur ($\text{SO}_4^{=}$ – S) mineralized in representative Minnesota soils (2).

<table>
<thead>
<tr>
<th>Location</th>
<th>Incubation Time (weeks)</th>
<th>Initial Value ppm $\text{SO}_4^=$-S*</th>
<th>ppm $\text{SO}_4^=$-S Mineralized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fayette silt loam</td>
<td>2</td>
<td>12.6</td>
<td>10.4</td>
</tr>
<tr>
<td>Webster clay loam</td>
<td>4</td>
<td>5.6</td>
<td>4.5</td>
</tr>
<tr>
<td>Menagha sandy loam</td>
<td>4</td>
<td>4.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Seaton silt loam</td>
<td>4</td>
<td>7.4</td>
<td>2.4</td>
</tr>
</tbody>
</table>

*SO$_4^=$-S extracted by the calcium phosphate analytical procedure.

In addition to S supplied from the soil, plants can get some, but not all, of the needed S from rainfall and sulfur dioxide ($\text{SO}_2$) in the atmosphere. The amount of S in precipitation at various locations in Minnesota is summarized in Table 3. The higher amounts in a metropolitan area are obvious. Concentrations of $\text{SO}_2$ in the atmosphere parallel the amount of S in rainfall. The values in Table 3 were measured in the mid 1960’s. Recent measurements from the same locations are not available.

Table 3. Sulfur in rainfall at various locations throughout Minnesota.

<table>
<thead>
<tr>
<th>Location</th>
<th>Precipitation</th>
<th>Total S Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inches*</td>
<td>lb. S/acre/year*</td>
</tr>
<tr>
<td>Park Rapids</td>
<td>23.7</td>
<td>3.7</td>
</tr>
<tr>
<td>St. Paul</td>
<td>22.2</td>
<td>14.0</td>
</tr>
<tr>
<td>Duluth</td>
<td>27.7</td>
<td>8.2</td>
</tr>
<tr>
<td>Lamberton</td>
<td>24.3</td>
<td>6.6</td>
</tr>
</tbody>
</table>

*Average for two years in the mid 1960’s

The $\text{SO}_2$ is absorbed by plant leaves and then metabolized within the plant. The concentration of $\text{SO}_2$ in the atmosphere has decreased in recent years leading to an expectation of more widespread S deficiencies in crop production.

Research has shown that atmospheric $\text{SO}_2$ can also be absorbed by soils, and then converted to $\text{SO}_4^{=}$-S. The use of S from this source for crop production, however, has not been documented in field research so the agronomic importance is unknown and may be minimal.

2. MOVEMENT IN SOIL

Plants absorb S from soils as the sulfate ($\text{SO}_4^{=}$) ion with two negative electrical charges is mobile in soils like nitrate ($\text{NO}_3^-$). Since the $\text{SO}_4^{=}$ ion has less environmental implications than nitrate, movement through soils has not been studied as extensively.

Sulfate movement is a concern when placement options are considered. This is especially true for banded applications in corn production. Studies have been conducted with soils of diverse textures to measure extent of movement of $\text{SO}_4^=$-S applied in a band at planting (Table 4). For this study, conducted in Minnesota from 1999 through 2001 ammonium sulfate (21-0-0-24) was applied with the seed (pop-up) at a rate to supply 18 lbs. S per acre. The soil samples were collected at about 4 weeks after emergence.
For the control treatment (no S applied), SO₄⁻⁻S concentrations were 1.0 to 1.5 ppm; 1.5 to 2.5 ppm; and 1.5 to 2.5 ppm for the loamy fine sand, silty clay loam, and silt loam respectively. The highest concentrations were directly below the seed with some lateral movement to 3 inches from the row. Soil samples were not collected from below 18 inches, so the extent of downward movement could not be determined but was anticipated to be minimal. Downward movement from broadcast S applications is expected to be similar to that from S applied in a band.

Table 4. Distribution of SO₄⁻⁻S placed in contact with the seed at planting in soils with diverse textures.

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Depth</th>
<th>0 ppm SO₄⁻⁻S</th>
<th>3 inches</th>
<th>6 inches</th>
<th>9 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy fine sand</td>
<td>0 to 3</td>
<td>47.5</td>
<td>5.8</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>loamy fine sand</td>
<td>3 to 6</td>
<td>48.0</td>
<td>29.0</td>
<td>3.3</td>
<td>1.0</td>
</tr>
<tr>
<td>loamy fine sand</td>
<td>6 to 12</td>
<td>22.3</td>
<td>10.8</td>
<td>3.0</td>
<td>1.0</td>
</tr>
<tr>
<td>loamy fine sand</td>
<td>12 to 18</td>
<td>5.8</td>
<td>1.3</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>silty clay loam</td>
<td>0 to 30</td>
<td>77.8</td>
<td>29.3</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>silty clay loam</td>
<td>3 to 60</td>
<td>52.3</td>
<td>29.3</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>silty clay loam</td>
<td>6 to 12</td>
<td>26.0</td>
<td>16.3</td>
<td>1.3</td>
<td>2.5</td>
</tr>
<tr>
<td>silty clay loam</td>
<td>12 to 18</td>
<td>8.3</td>
<td>9.0</td>
<td>1.8</td>
<td>2.5</td>
</tr>
<tr>
<td>silt loam</td>
<td>0 to 3</td>
<td>8.3</td>
<td>3.0</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>silt loam</td>
<td>3 to 6</td>
<td>14.3</td>
<td>3.3</td>
<td>2.3</td>
<td>2.0</td>
</tr>
<tr>
<td>silt loam</td>
<td>6 to 12</td>
<td>16.8</td>
<td>4.3</td>
<td>2.3</td>
<td>1.8</td>
</tr>
</tbody>
</table>

3. MANAGING SULFUR FERTILIZERS

Various fertilizers containing S are available for crop production. The preferred material varies primarily with the crop to be fertilized. For alfalfa, dry rather than liquid sources are more practical for broadcast application to established stands. The common dry materials on the market today are: 1) a product in which elemental S is mixed with clay, 2) the double salt of potassium and magnesium sulfate (0-0-22-22S-11 Mg), and 3) ammonium sulfate (21-0-0-24S).

Since S is absorbed by plants as SO₄⁻⁻ S, the elemental S must be converted to SO₄⁻⁻S by soil microorganisms. The rate of this conversion is affected by soil moisture and temperature with soil temperatures above 80°F being ideal. Conversion can take up to 30 days. Therefore, early spring application of the elemental S-clay mixture would be preferred. Sources containing S in the SO₄⁻⁻ form (0-0-22-22S-11Mg or 21-0-0-24S) can easily be applied in early spring or after the first cutting.

In contrast to alfalfa and other perennial crops, corn and small grains have the greatest need for S early in the growing season. So, sources with S in the SO₄⁻⁻ form are preferred placed in a band close to the seed. The appropriate dry materials are 0-0-22-22S-11Mg and 21-0-0-24S. Liquid sources of S are ammonium thiosulfate (ATS, 12-0-0-26S) and potassium thiosulfate (KTS, 0-0-22-17S) for those who use fluid fertilizers for corn or small grain at the time of planting.

The S in ATS and KTS exists in a form called thiosulfate-S. Thiosulfate is thought to be rapidly converted to SO₄⁻⁻S in soil. Therefore, both liquid and dry sources of S should have an equal effect on crop production. The corn yields in Table 5, taken from a study in Nebraska, show the benefit of SO₄⁻⁻S broadcast on corn at a rate of 25 lbs. S per acre. The elemental S+ clay product produced a yield increase; but not as large as from the use of SO₄⁻⁻S.
Table 5. Effect of sources of fertilizer S on yield of corn grown on irrigated sandy soil

<table>
<thead>
<tr>
<th>S Source</th>
<th>Yield (bu/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>163</td>
</tr>
<tr>
<td>elemental S + clay</td>
<td>176</td>
</tr>
<tr>
<td>21-0-0-24S</td>
<td>182</td>
</tr>
<tr>
<td>0-0-22-22S-11Mg</td>
<td>186</td>
</tr>
</tbody>
</table>

Application of fluid ATS and dry ammonium sulfate forms of S have been compared when placed in a band near the seed for corn production. Results from two years are summarized in Table 6. Yields are averages for rates of 6, 12, and 18lb. S/acre.

Table 6. Effect of S source placed in a band near the seed at planting on corn yield from a loamy fine sand soil (1).

<table>
<thead>
<tr>
<th>S Source</th>
<th>1999</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>167.3</td>
<td>141.9</td>
</tr>
<tr>
<td>21-0-0-24S</td>
<td>171.6</td>
<td>161.1</td>
</tr>
<tr>
<td>12-0-0-26S</td>
<td>177.2</td>
<td>161.5</td>
</tr>
</tbody>
</table>

Although similar comparisons have not been made with small grain, similar results are anticipate.

Rates of fertilizer S required for optimum yield are not complicated. For alfalfa, red clover, and other perennial forage legumes, an annual application of 25 lbs. S per acre is adequate. For corn and small grains, a rate of 12 lbs. S per acre in a band near the seed at planting is adequate. This rate increases to 25 lbs. per acre if pre plant broadcast applications are used.

3. SOIL TESTING FOR SULFUR

Soil testing for phosphorus (P), potassium (K), and zinc (Zn) is a well accepted management practice. So, the obvious question is “Is there a useful and reliable soil test for S?” At the present time, the answer to this question is: NO! The best explanation for this answer, is the statements made at the beginning of this lesson. The majority of SO$_4^{2-}$-S available for plant use and crop production originates with soil organic matter. Since we can’t predict mineralization (decomposition of the organic matter), we can’t reliably use a soil test. There have been numerous attempts over the past 50 years or more to develop a useful soil test and none have been successful.

4. SULFUR AND REDUCTION OF SOIL pH

Up to this point, the discussion has focused on S as an essential plant nutrient. In Minnesota, high soil pH is frequently a problem in crop production. Elemental S can be used to reduce soil pH. As mentioned previously, the conversion of elemental S to SO$_4^{2-}$-S is a biologically driven reaction. A result of the reaction is production of two hydrogen ions (H$^+$) for each sulfur atom converted.

This management practice appears to be one that would be easy to use. However, large amounts of S are needed to bring about a reduction in soil pH (see Table 7). The reduction in pH is not permanent and the practice is expensive. Therefore, the use of elemental S to reduce soil pH is not a recommended practice.
Table 7. Effect of soil texture on the amount of elemental S required to reduce pH to 6.5

<table>
<thead>
<tr>
<th>Initial pH</th>
<th>Sandy Soil</th>
<th>Fine Textured Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- - - - lb. Elemental S/Acre- - - -</td>
<td>- - - -</td>
</tr>
<tr>
<td>7.5</td>
<td>400 to 600</td>
<td>800 to 1,000</td>
</tr>
<tr>
<td>8.0</td>
<td>1,000 to 1,500</td>
<td>1,500 to 2,000</td>
</tr>
<tr>
<td>8.5</td>
<td>1,500 to 2,000</td>
<td>1,600 to 2,200</td>
</tr>
</tbody>
</table>

References
