Getting the Big Picture of Sulfur Fertilizer Needs for Minnesota Crops

Daniel Kaiser
Associate Professor
Department of Soil, Water and Climate
U of M Twin Cities
612-624-3482
dekaiser@umn.edu

2014 CPM Short Course
Sulfur in a Nutshell

- Sulfur is a plant Macronutrient
- Sulfur is a component of proteins and amino acids
- Sulfur is contained in soils in organic matter
- Sulfur is taken up by plants in the sulfate form
- Sulfate can leach like nitrate
The Sulfur Cycle

Atmospheric deposition

Animal manures and biosolids

Plant residues

Absorbed or mineral sulfur

Organic sulfur

Atmospheric sulfur

Crop harvest

SO₂ gas

Volatilization

Mineral fertilizers

Runoff and erosion

Reduced sulfur

Leaching

Immobilization

Mineralization

Plant uptake

Elemental sulfur

Oxidation

Bacterial oxidation

Bacterial reduction

Sulfate Sulfur (SO₄²⁻)

Source: IPNI
Sulfur Response

• Yield responses are increasing-Why?
  – Sulfate deposition have decreased
    • ~ 5-10 lb/ac/yr in the last 30+ years
  – Sulfur in fertilizer sources (other than S fertilizers) and pesticides have decreased
  – Less manure
  – More crop residues

• What is the most important factor?
  – Two key factors: soil temperature and organic matter concentration
Sulfur Timing and Rate Study 2009-2010

• Timing is less critical than rate as long as S is applied early (by V5)
• Most rate data indicates that 10 lbs of S is sufficient
• Some fields may respond to higher rates
  • Due to lower organic matter or more residue?
Relative Corn Yield (%)

RelYLD = 82.9 + 1.42(rate) - 0.0258(rate)^2

$R^2=0.98 \ P<0.02$

Plateau ~ 25 lbs

2009 Sulfur Application Rate (lbs. S ac\(^{-1}\))

0-24" Spring soil test Sulfur (ppm)
## Crop Response to Sulfur in Year 2

<table>
<thead>
<tr>
<th>Location</th>
<th>Crop</th>
<th>No Sulfur</th>
<th>+ Sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renville</td>
<td>Corn</td>
<td>209</td>
<td>216*</td>
</tr>
<tr>
<td>Theilman</td>
<td>Soybean</td>
<td>62</td>
<td>63</td>
</tr>
<tr>
<td>Montgomery</td>
<td>Soybean</td>
<td>42</td>
<td>41</td>
</tr>
<tr>
<td>Otisco</td>
<td>Corn</td>
<td>190</td>
<td>196*</td>
</tr>
<tr>
<td>Medford</td>
<td>Corn</td>
<td>202</td>
<td>200</td>
</tr>
</tbody>
</table>

* Crop responded to sulfur for 1 or more treatments were S was previously applied
Sulfur For Soybean

- Very limited recommendation for sulfur application for soybean
- Sulfur does play a role in proteins, which soybean has a higher content than corn
- Most research was conducted when responses were less likely
The graph shows the soybean grain yield (bu/ac) for different organic matter levels and starter treatments in three locations: Hanska 2008, Lewiston 2008, and Theilman 2009.

- **Hanska 2008**: The graph displays the grain yield for low organic matter (0-2%) with no starter, N starter, and N+P starter treatments. The yield values are indicated by bars with different patterns and letters (a, b, c) representing different levels of significance.

- **Lewiston 2008**: Similar to Hanska 2008, the graph for medium organic matter (2-4%) shows yield values for no starter, N starter, and N+P starter treatments. The bars are marked with letters (a, b, c) indicating significance.

- **Theilman 2009**: The graph for high organic matter (>4%) follows the same pattern as the previous years, with yield values for different starter treatments and significance letters.

The graph uses color and lettering to differentiate between treatments and their significance in achieving the highest soybean grain yield.
Sulfur for Soybean

• Decrease in the harvest index following sulfur application
  – More biomass relative to grain
• Is extra biomass good for soybean?
  – In dry years: probably not
  – In wet years: probably not
• Some data suggests yield increases are still possible following S application to corn
Effect of management practice and Sulfur on corn yield
U of M SWROC, Lamberton, MN 2009

F=5.01, p=0.0664
LSD 10% = 4.03 bu.
Effect of management practice and previous crop sulfur on soybean yield
U of M SWROC, Lamberton, MN 2009

F=23.97, p=0.0163
LSD 10% = 3.05 bu
How Does Sulfur Cycle

• Crop Residue
  – Crop residue must be decomposed to release sulfate
  – The amount of carbon relative to sulfur is important for recycling
  – Are other nutrients affected by sulfur application – residue quality

• In soil
  – Direct carryover from previous fertilizer application
P-K-S Interaction Studies

Split plot design with four replications
Treatment significance level: $P \leq 0.05$
Main Plot Factorial: 0 or 25 lb S ac$^{-1}$ and 0 or 120 lb P2O5 ac$^{-1}$
Sub-Plots: 0, 100, 200, and 300 lb K2O ac$^{-1}$
*All fertilizer applied before the corn crop
Triple superphosphate, KCl, and ammonium sulfate
Sub-plot Size: 15ft wide x 35ft long
Nitrogen fertilizer was kept at a non-limiting rate: 180 lb n ac$^{-1}$
# PKS Study Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Bray P1-P</th>
<th>NH4OAC-K</th>
<th>SOM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>YR 1</td>
<td>YR 3</td>
<td>YR 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>---------</td>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>---------</td>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>---------</td>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>---------</td>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>---------</td>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>Red Wing</td>
<td>2011</td>
<td>SiL</td>
<td>34</td>
<td>29</td>
</tr>
<tr>
<td>Rochester</td>
<td></td>
<td>L</td>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td>Becker</td>
<td>2012</td>
<td>LS</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>Lamberton</td>
<td></td>
<td>L</td>
<td>14</td>
<td>14</td>
</tr>
</tbody>
</table>

YR3 data represents the average value for the control (No P, K, or S)
Colors represent expected response to applied fertilizer
blue – low, green – moderate, red - high
Grain Yield Response to S Applied Prior to Corn in a C-SB Rotation

<table>
<thead>
<tr>
<th>Location</th>
<th>C1</th>
<th>SB1</th>
<th>C2</th>
<th>SB2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red Wing</td>
<td>7</td>
<td>0</td>
<td>22</td>
<td>5.7</td>
</tr>
<tr>
<td>Rochester</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>2.8</td>
</tr>
<tr>
<td>Becker</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>--</td>
</tr>
<tr>
<td>Lamberton</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>--</td>
</tr>
</tbody>
</table>

--Yield Increase bu ac⁻¹--

Responses of interest:
- Response at Lamberton (C1) was likely due to residue from the previous corn crop
- Lack of response at Becker may be due to sulfate in the irrigation water
Residue Levels and Sulfur Response

- **C:S ratios** *(source Soil Fertility and Fertilizers 7th ed.)*
  - <200:1 – mineralization
  - 200-400:1 no change
  - >400:1 - immobilization

- **Crop stover data**
  - Albert Lea, MN R6 Corn: 333:1
  - Clarkfield, MN R6 Corn: 151:1
  - Lewiston, MN R8 Soybean: 123:1
  - Hanska, MN R8 Soybean: 125:1
  - Strathcona, MN Wheat: 286:1
  - Perley, MN Wheat: 291:1
  - Red Wing, MN R6 Corn: 366:1
  - Rochester, MN R6 Corn: 301:1
Sulfur Cycling from Corn Residue
8 Site average 2009-2011

Stover C:S Ratio

Sulfur Fertilization Rate (lbs S/acre)

Does This Matter?
Sulfur and Stover Quality Impacts on P and K

Stover Phosphorus

<table>
<thead>
<tr>
<th>Phosphorus Uptake (lb P₂O₅/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
</tr>
<tr>
<td>Soybean</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sulfur Rate (lb S/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>25</td>
</tr>
</tbody>
</table>

Stover Potassium

<table>
<thead>
<tr>
<th>Potassium Uptake (lb K₂O/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
</tr>
<tr>
<td>Soybean</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>40</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>80</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>120</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sulfur Rate (lb S/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>25</td>
</tr>
</tbody>
</table>
Residue Recycling

• Little sulfur is likely mineralized from corn residue
  – Some potential for soybean residue to mineralize S – luxury S uptake by soybean?
• No effect of sulfur on uptake and recycling other nutrients in residue
• Residue impacts on soil temperature likely explain effects on S availability to crops
Relative Corn Yield (%)

RelYLD = 82.9 + 1.42(rate) - 0.0258(rate)^2
R^2=0.98 P<0.02
Plateau ~ 25 lbs

SoilS = 4.42 + 0.04x
R^2=0.89 P<0.02

* Sulfur applied spring 2009 prior to a corn crop
Red Wing, MN Silt Loam
Sulfate-S by Soil Depth

- Good internal drainage
- Low soil organic matter concentration
- Increased sulfate concentrations could be found after 1-2 cropping years

Soil Fertility
Becker, MN Loamy Sand
Sulfate-S by Soil Depth

- Rapid internal drainage – 95% sand
- Low organic matter
- No sulfate-S concentration differences between plots with and without sulfur
- Relatively high SO$_4$-S concentrations
Sulfur in the Soil

- Sulfur does not rapidly leach in some soils.
- Carryover effects can be seen 1-2 years post application in the top 2’.
- Carryover of sulfate-sulfur not utilized by past crops is the likeliest method of cycling on a year to year basis.
- Sulfate-S in the soil is likely at equilibrium with the management practices in a given field – rotation, tillage, fertilizer application.
Nitrogen x Sulfur Study

• Started in 2011
• 9 locations
  – 1 lost to wind damage
  – 1 had excessive rainfall that leached all the N
  – 1 planted late and had poor stand
  – Drought stress
  – 1 site responded to sulfur
• Funding provided by Dupont Pioneer as part of a CMRA grant
Red Wing 2013
Site 7

Corn Grain Yield (bu/ac)

- No Sulfur
- 25 lb S Broadcast
Sulfur Response – Putting it all Together

• Sulfur may affect the uptake and utilization of other nutrients, mainly nitrogen
  – S deficient plants commonly exhibit N stress symptoms late in the season
  – Effect of S is additive in the presence of P and K deficiency

• When deficient, the addition of sulfur fertilizer can result in highly profitable yield increases
Comments on Crop S Response

- Environment Influences Crop Response
  - 2008 and 2009 good response years
  - 2010 still showed some response
  - 2011 and 2012 fewer responses
    - Warmer spring
      - 2013: greater response potential
- Aggressiveness of tillage likely is a factor
- Length of growing season is important as well
- Greater response with poorly drained soils?
Method of Sulfur Application

• Broadcast has the least risk of damage
  – Foliar application can cause damage
• Ammonium Thiosulfate can be banded
  – Better if placed away from the seed
• Am Thio placed with UAN may have some inhibition effects for nitrate conversion
  – Not as big as other N inhibitors
  – Ammonium thiosulfate is not the same as ammonium sulfate (dry)
Sulfur Sources

**Readily Available**
- Ammonium sulfate
- Potassium sulfate
- Calcium sulfate (gypsum)
- Ammonium thiosulfate
- Potassium thiosulfate
- Manure S?

**Slowly/Not Available**
- Elemental S
- Organic S
- Manure S?
## Proposed Corn Sulfur Guidelines for Southern Minnesota

Broadcast sulfur to apply (lbs S per acre)

<table>
<thead>
<tr>
<th>Rotation</th>
<th>0-6” Soil Organic Matter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-2</td>
</tr>
<tr>
<td>Corn-Corn</td>
<td>10-25</td>
</tr>
<tr>
<td>Corn-Soybean</td>
<td>10-20</td>
</tr>
<tr>
<td>Sandy Soils</td>
<td>25</td>
</tr>
</tbody>
</table>

†For high residue corn on corn systems
Thank You
Questions?

SW&C Field Crew
Research and Field Crew from:
Southwest Research and Outreach Center
Sand Plains Research Center
Cooperators and Consultants

Daniel Kaiser
University of Minnesota
612-624-3482
dekaiser@umn.edu
http://z.umn.edu/nutmgmt
http://z.umn.edu/fbnutmgmt