Dealing with Sulfur Deficiency in Iowa Crop Production

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Iowa State University
Plant Essential Element Sulfur (S)

- Movement in plant
  - Relatively non-mobile
- Functions
  - Proteins, chlorophyll and photosynthesis
- Deficiency symptoms
  - Yellowing/chlorosis stripping of younger leaves
  - Plant yellowing, stunting, and spindly plants with severe deficiency
- Plant available form: sulfate (SO$_4^{2-}$)
Sulfur Deficiencies

- Situations aggravating deficiency
  - Soil
    - Sandy, low organic matter, eroded, no-tillage
    - Low profile sulfate
  - Climatic
    - Cold, dry – slow mineralization of S from organic matter
    - Low atmospheric deposition
    - No application from manure/fertilizers
    - Large crop use
Past Sulfur Research on Corn and Soybean in Iowa

- Prior 40+ years (before 2005) research across Iowa (approximately 200 site-years)
  - Three times statistically significant yield increase
  - One study with multi-year average yield decrease

- Why no response to sulfur?
  - High soil organic matter
  - High subsoil sulfate
  - Atmospheric deposition
  - Manure application
  - Low S demanding crops
Things Have Changed
Observation of poor alfalfa growth in Northeast Iowa

Slide from B. Lang, ISU
Visual Response in Alfalfa to Sulfur Application
Visual Response in Alfalfa to S Application
10 kg SO$_4$/ha = 3 lb S/acre

National Atmospheric Deposition Program (NADP)
### Alfalfa Response to S Application in Field Areas with Poor and Good Coloration of Alfalfa, 2005-2006

<table>
<thead>
<tr>
<th>Sulfur</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cuts 2+3 DM Yield</td>
<td>Cut 2 Plant Top S</td>
</tr>
<tr>
<td>Treatment</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>None</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Am. sulfate</td>
<td>1.18a</td>
<td>2.99b</td>
</tr>
<tr>
<td>Ca. sulfate</td>
<td>2.76b</td>
<td>3.26b</td>
</tr>
<tr>
<td></td>
<td>2.49b</td>
<td>3.21b</td>
</tr>
</tbody>
</table>

| Soil Sulfate-S (ppm) | 6.6 | 7.4 |

Three field sites in 2005, Elgin, Gunder and West Union, IA (Fayette & Downs sil soils).

Two field sites in 2006, Elgin and Gunder, IA.

Sulfur materials were applied at 40 lb S/acre after first cut in in 2005.

Treatment means followed by the same letter are not significantly different ($p \leq 0.10$).
## Alfalfa Dry Matter Response to S Rate, 2006

<table>
<thead>
<tr>
<th>Sulfur rate(^1)</th>
<th>Wadena</th>
<th>Waucoma(^2)</th>
<th>Nashua</th>
<th>Waukon</th>
<th>West Union</th>
<th>Lawler</th>
</tr>
</thead>
<tbody>
<tr>
<td>lb S/acre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.32</td>
<td>1.85</td>
<td>6.73</td>
<td>1.39</td>
<td>0.78</td>
<td>2.14</td>
</tr>
<tr>
<td>15</td>
<td>2.59</td>
<td>3.06</td>
<td>6.98</td>
<td>2.97</td>
<td>1.05</td>
<td>2.11</td>
</tr>
<tr>
<td>30</td>
<td>2.76</td>
<td>3.14</td>
<td>6.85</td>
<td>3.33</td>
<td>1.07</td>
<td>2.11</td>
</tr>
<tr>
<td>45</td>
<td>2.92</td>
<td>3.24</td>
<td>7.14</td>
<td>3.58</td>
<td>1.07</td>
<td>2.07</td>
</tr>
<tr>
<td>Significant (90%)</td>
<td>*</td>
<td>*</td>
<td>NS</td>
<td>*</td>
<td>*</td>
<td>NS</td>
</tr>
<tr>
<td>Max rate, lb S/ac</td>
<td>25</td>
<td>22</td>
<td>0</td>
<td>29</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Cut harvested</td>
<td>2+3</td>
<td>2+3</td>
<td>1+2+3+4</td>
<td>2+3</td>
<td>3</td>
<td>2+4</td>
</tr>
</tbody>
</table>

\(^1\) Sulfur applied as calcium sulfate in April at Nashua and May at other sites.

\(^2\) Waucoma site had 10 lb/ac elemental S applied in spring across the entire field.
### Alfalfa Plant S Concentration Response, 2006

<table>
<thead>
<tr>
<th>Sulfur rate&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Wadena</th>
<th>Waucoma&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Nashua</th>
<th>Waukon</th>
<th>West Union</th>
<th>Lawler</th>
</tr>
</thead>
<tbody>
<tr>
<td>lb S/acre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.14</td>
<td>0.21</td>
<td>0.33</td>
<td>0.18</td>
<td>0.18</td>
<td>0.27</td>
</tr>
<tr>
<td>15</td>
<td>0.20</td>
<td>0.30</td>
<td>0.35</td>
<td>0.29</td>
<td>0.24</td>
<td>0.36</td>
</tr>
<tr>
<td>30</td>
<td>0.30</td>
<td>0.43</td>
<td>0.34</td>
<td>0.40</td>
<td>0.29</td>
<td>0.39</td>
</tr>
<tr>
<td>45</td>
<td>0.39</td>
<td>0.36</td>
<td>0.37</td>
<td>0.41</td>
<td>0.28</td>
<td>0.37</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil S, ppm&lt;sup&gt;4&lt;/sup&gt;</th>
<th>7</th>
<th>3</th>
<th>7</th>
<th>1</th>
<th>6</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil OM, %&lt;sup&gt;4&lt;/sup&gt;</td>
<td>3.1</td>
<td>2.1</td>
<td>4.2</td>
<td>3.8</td>
<td>3.3</td>
<td>2.6</td>
</tr>
<tr>
<td>Soil type</td>
<td>Fayette silt loam</td>
<td>Wapsie loam</td>
<td>Clyde-Floyd loam</td>
<td>Fayette silt loam</td>
<td>Fayette silt loam</td>
<td>Ostrander loam</td>
</tr>
</tbody>
</table>

1. Sulfur applied as calcium sulfate in April at Nashua and May at other sites.
2. Waucoma site had 10 lb/ac elemental S applied in spring across the entire field.
3. Sulfur concentration (%S) for 6-inch plant tops collected before second cut.
4. Soil samples collected in check plots after first cut, 0 to 6 inch depth.
Alfalfa Yield Increase to Applied S vs. Plant S Concentration (six-inch plant top)

Yield Increase per Cut (%) vs. Plant Analysis (% S)

- $R^2 = 0.52$, $p = 0.006$
- Linear-Plateau joins at 0.23% S
2010-2011 Alfalfa Sulfur Trial
Nashua Research Farm

<table>
<thead>
<tr>
<th>Trt</th>
<th>Forage Yield</th>
<th>Soil S Test</th>
<th>Plant Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>------</td>
<td>--------</td>
<td>--------</td>
<td>------</td>
</tr>
<tr>
<td>None</td>
<td>6.15a</td>
<td>6.44a</td>
<td>6.30a</td>
</tr>
<tr>
<td>B</td>
<td>6.10a</td>
<td>6.68a</td>
<td>6.39a</td>
</tr>
<tr>
<td>S</td>
<td>6.91b</td>
<td>7.85b</td>
<td>7.38b</td>
</tr>
<tr>
<td>B + S</td>
<td>6.67ab</td>
<td>8.07b</td>
<td>7.37b</td>
</tr>
</tbody>
</table>

Means followed by the same letter are not different, $p \leq 0.05$.
S applied at 40 lb S/acre as gypsum (calcium sulfate).
B applied at 2 lb B/acre as Borate-48.
Fertilizers applied for each year.
Readlyn loam, 3.3% organic matter.
Three harvests in 2010 and four harvests in 2011.

B. Lang and K. Pecinovsky, ISU
Things Have Changed
Things Have Changed
Visual Response in Corn to Sulfur Application
# Sulfur Fertilizer Trials on Corn in Problem Field Areas, Northeast Iowa, 2006

<table>
<thead>
<tr>
<th>Location</th>
<th>Soil type</th>
<th>Sulfur</th>
<th>Yield</th>
<th>Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>bu/acre</td>
<td>%</td>
</tr>
<tr>
<td>Lamont 1</td>
<td>Sparta lfs</td>
<td>No</td>
<td>123 a</td>
<td>24.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>151 b</td>
<td>22.6</td>
</tr>
<tr>
<td>Lamont 2</td>
<td>Sparta lfs</td>
<td>No</td>
<td>154 a</td>
<td>22.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>198 b</td>
<td>18.8</td>
</tr>
<tr>
<td>Thorpe 1</td>
<td>Chelsa lfs</td>
<td>No</td>
<td>88 a</td>
<td>14.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>108 b</td>
<td>13.5</td>
</tr>
<tr>
<td>Thorpe 2</td>
<td>Kenyon l</td>
<td>No</td>
<td>196 a</td>
<td>19.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>204 a</td>
<td>19.3</td>
</tr>
<tr>
<td>Waukon</td>
<td>Fayette sl</td>
<td>No</td>
<td>96 a</td>
<td>- -</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>172 b</td>
<td>- -</td>
</tr>
<tr>
<td>Waterville</td>
<td>Fayette sl</td>
<td>No</td>
<td>118 a</td>
<td>33.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>171 b</td>
<td>30.7</td>
</tr>
</tbody>
</table>

Sulfur applied as calcium sulfate at 40 lb S/acre.
Forty-Seven Corn S Rate Sites in 2007-2009
North Central – Northeast Iowa

❖ Sulfur (gypsum) at 0, 10, 20 and 40 lb S/acre
❖ 2007
   ➢ 17 of 20 sites responded to S application
     • 18 bu/acre average yield increase across all sites
❖ 2008
   ➢ 11 of 25 sites responded to S application
     • 7 bu/acre average yield increase across all sites
❖ 2009
   ➢ 2 sites with no response to S application
Twenty-Eight Responsive S Rate Sites
2007-2009 North Central - Northeast Iowa
Soils: 21 fine texture (cl, sicl, sil, l); 7 coarse texture (fsl, lfs, sl)

Sulfur Rate, lb S/acre
Corn Yield, bu/acre

<table>
<thead>
<tr>
<th>Sulfur Rate, lb S/acre</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Yield, bu/acre</td>
<td>120</td>
<td>140</td>
<td>160</td>
<td>180</td>
<td>200</td>
</tr>
</tbody>
</table>

Maximum Response Rate
- Fine-Textured: 16.9 lb S/acre, 188.7 bu/acre
- Coarse-Textured: 24.8 lb S/acre, 181.2 bu/acre

Economic Optimum Rate
- Fine-Textured: 15.7 lb S/acre, 188.6 bu/acre
- Coarse-Textured: 23.4 lb S/acre, 181.1 bu/acre

0.125 price ratio ($0.50/lb S and $4.00/bu corn)
Phosphorus, Sulfur, and Zinc Product Evaluation

- Two sites in northeast Iowa
  - 2006
  - Simplot 13-33-0-15S (SEF)

- Five sites in central to north-central Iowa
  - 2008 – 2010
  - Mosaic 13-33-0-15S (MES15)
  - Mosaic 12-40-0-10S (MES10)

- Compared to AMS and MAP

- Sulfur applied at 10 and 30 lb S/acre
  - N and P equalized at rate with highest S rate
Phosphorus and Sulfur Product Evaluation

- Sulfur response at 2006 sites

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ear Leaf S</th>
<th>Grain Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>bu/acre</td>
</tr>
<tr>
<td>S-CON</td>
<td>0.15a</td>
<td>196a</td>
</tr>
<tr>
<td>SEF-10</td>
<td>0.18b</td>
<td>211b</td>
</tr>
<tr>
<td>AMS-10</td>
<td>0.18b</td>
<td>211b</td>
</tr>
</tbody>
</table>

Mean response across both sites, 2006.

- No S yield response at 2008 – 2010 sites
  - Leaf S concentration increased with all products
Phosphorus and Sulfur Product Evaluation Across Seven Sites

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ear Leaf S</th>
<th>Ear Leaf P</th>
<th>Grain Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP-CON</td>
<td>0.14d</td>
<td>0.24b</td>
<td>194b</td>
</tr>
<tr>
<td>S-CON</td>
<td>0.15c</td>
<td>0.28a</td>
<td>209a</td>
</tr>
<tr>
<td>MES/SEF-10</td>
<td>0.17b</td>
<td>0.28a</td>
<td>213a</td>
</tr>
<tr>
<td>AMS-10</td>
<td>0.16b</td>
<td>0.28a</td>
<td>211a</td>
</tr>
<tr>
<td>MES/SEF-30</td>
<td>0.19a</td>
<td>0.28a</td>
<td>208a</td>
</tr>
<tr>
<td>AMS-30</td>
<td>0.18a</td>
<td>0.28a</td>
<td>212a</td>
</tr>
<tr>
<td>MAP-30</td>
<td>0.18a</td>
<td>0.28a</td>
<td>212a</td>
</tr>
</tbody>
</table>

Mean response across all seven sites, 2006-2010. Letters indicate significant difference at \( p=0.05 \).
Six of Eleven Sulfur Strip Trials in Northeast and Central Iowa Responsive, 2009

<table>
<thead>
<tr>
<th>Site</th>
<th>County</th>
<th>Crop</th>
<th>Sulfur Rate</th>
<th>Corn Yield - S</th>
<th>Corn Yield + S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>lb S/acre</td>
<td>bu/acre</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Greene</td>
<td>corn</td>
<td>40</td>
<td>225</td>
<td>229</td>
</tr>
<tr>
<td>4</td>
<td>Greene</td>
<td>corn</td>
<td>40</td>
<td>210</td>
<td>215†</td>
</tr>
<tr>
<td>5</td>
<td>Greene</td>
<td>corn</td>
<td>40</td>
<td>217</td>
<td>228†</td>
</tr>
<tr>
<td>6</td>
<td>Dallas</td>
<td>soybean</td>
<td>40</td>
<td>201</td>
<td>200</td>
</tr>
<tr>
<td>9</td>
<td>Dallas</td>
<td>corn</td>
<td>40</td>
<td>147</td>
<td>152†</td>
</tr>
<tr>
<td>10</td>
<td>Dallas</td>
<td>corn</td>
<td>40</td>
<td>135</td>
<td>134</td>
</tr>
<tr>
<td>1</td>
<td>Fayette</td>
<td>soybean</td>
<td>15</td>
<td>224</td>
<td>236†</td>
</tr>
<tr>
<td>2</td>
<td>Howard</td>
<td>soybean</td>
<td>20</td>
<td>186</td>
<td>192†</td>
</tr>
<tr>
<td>7</td>
<td>Dubuque</td>
<td>soybean</td>
<td>30</td>
<td>216</td>
<td>229†</td>
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<tr>
<td>8</td>
<td>Floyd</td>
<td>---</td>
<td>20</td>
<td>199</td>
<td>203</td>
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<td>11</td>
<td>Winneshiek</td>
<td>soybean</td>
<td>30</td>
<td>215</td>
<td>212</td>
</tr>
</tbody>
</table>
Extractable Soil Sulfate-S

Yield Response to 40 lb S/acre

Yield Increase (bu/acre)

Extractable Soil Sulfate-S (ppm)

2007-2009 Sites

2000 Sites
Corn Ear Leaf S Concentration

Yield Response to 40 lb S/acre

Yield Increase (bu/acre)

Corn Ear Leaf S in Control (% S)

- 2007-2009 Sites
- 2000 Sites
Soil Organic Matter

Yield Response to 40 lb S/acre

Yield Increase (bu/acre)

Soil Organic Matter (%)

-30
-20
-10
0
10
20
30
40
50
60
012345678

2007-2009 Sites
2000 Sites

IOWA STATE UNIVERSITY
University Extension
Soil Organic Matter

Yield Response to 40 lb S/acre

Yield Increase (bu/acre) vs. Soil Organic Matter (%)

- 2007-2009 Sites: N=3
- 2000 Sites: N=6

21% error

Iowa State University
University Extension
76 bu/acre Response
Site WK 2006
Alfalfa Previous Crop
Fayette sil

42 bu/acre Response
Site D 2007
Soybean Previous Crop
Sparta lfs

20 bu/acre Response
Site T1 2006
Soybean Previous Crop
Chelsa lfs
Zero bu/acre Response
Site Mason City 2008
Soybean Previous Crop
Readlyn loam

Zero bu/acre Response
Ames Site 2001
Soybean Previous Crop
Clarion loam

No Response or Small Response
Early Season Sulfur Deficiency Symptoms Can Disappear

2011 Continuous Corn
10 replicated strips
+/- 12.2 lb S/acre as ammonium thiosulfate, incorp.
No S: 217 bu/acre
With S: 216 bu/acre

Doug Johnson; Central IA; Picture 6/7/2011
Early Season Sulfur Deficiency Symptoms Can Disappear

2011 Soybean-Corn
0, 5, 10, 20, 40 lb S/acre as gypsum
“High OM” site: 5.8%; “Low OM” site: 4.1%

<table>
<thead>
<tr>
<th>lb S/acre</th>
<th>High OM</th>
<th>Low OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>192</td>
<td>187</td>
</tr>
<tr>
<td>5</td>
<td>184</td>
<td>188</td>
</tr>
<tr>
<td>10</td>
<td>190</td>
<td>187</td>
</tr>
<tr>
<td>20</td>
<td>191</td>
<td>191</td>
</tr>
<tr>
<td>40</td>
<td>187</td>
<td>183</td>
</tr>
<tr>
<td>FLSD&lt;sub&gt;0.10&lt;/sub&gt;</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

Dave Rueber
ISU Northern Farm, Kanawha

2011/06/10
Soybean Sulfur Trials

- **2000-2001**
  - Six S rate trials each year across Iowa
    - No yield response

- **2008**
  - Two S rate trials in central-northeast Iowa
    - Yield increase at the northeast Iowa site

- **2011**
  - One S rate trial on a sandy soil in southeast Iowa
    - No yield response
Summary

- Sulfur deficiencies an issue in Iowa (esp. northeast)
  - 60% corn S rate sites responsive to S application
  - Especially coarse textured, sideslope landscape, low organic matter, eroded soils, no-tillage, reduced-tillage, alfalfa prior crop, no manure application, no S applied in fertilizers
    - 68% sites responsive with l, sil, fsl, lfs, sl soils
    - 14% sites responsive with sicl, cl soils
  - For responsive sites, 19 bu/acre yield increase

- Not as likely in rest of state (fine textured - higher organic matter soils)?
Summary

- **Sulfur application rate when needed**
  - Alfalfa: topdress 20 to 30 lb S/acre
  - Corn: 15 lb S/acre fine textured soils
    - 25 lb S/acre coarse textured soils

- **Tools to indicate S deficiency**
  - Alfalfa – top six-inch plant growth at early bud
  - Corn – ?? needs more investigation
  - Visual coloration and growth response
Research Support

- Honeywell International, Inc.
- J.R. Simplot Company
- Mosaic Fertilizer, LLC
- Foundation for Agronomic Research
- Calcium Products, Inc.
- Iowa State University Extension