Increasing Importance of Sulfur for Field Crops

John Sawyer, Professor
Brian Lang, Extension Field Agronomist
Daniel Barker, Assistant Scientist
Iowa State University
Sulfur Research History

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

- My first research project was on sulfur
  - Illinois 1977-1979 statewide with corn
    - Sulfur response at 5 of 81 site-years
      - 11 bu/acre mean increase at the 5 sites
  - Response with surface soils in greenhouse
    - One soil first plant harvest
    - 60% of soils second harvest
Sulfur Research History

- Southern IL - wheat (1990-1992)
  - No yield response – 2 research farms
- Recent University of Illinois research
  - Fernandez and Sutradhar, 2009-2011
  - 0 of 18 site-years small plot trial corn yield response
    - Mean of 9 sites: 11 bu/acre response
  - 2 of 22 site-years field strip trial corn yield response
Crop Sulfur Uptake

- Corn at 200 bu/acre (Iowa trials)
  - 8 lb S/acre grain (0.04 lb S/bu)
  - 5 lb S/acre vegetation (1.0 lb S/ton d.m.)
- Alfalfa (Iowa trials)
  - 5-6 lb S/ton d.m.
- Modern Corn and Soybean
  - Corn – 0.07 lb S/bu
  - Soybean – 0.10 lb S/bu
  - Alfalfa – 5 lb S/ton
Where does crop-available sulfur come from?

- Soil organic matter
  - Large pool of sulfur in most soils
- Subsoil sulfate
- Rock degradation/accumulated gypsum
- Atmospheric deposition
  - Volcanic emission
  - Marine gases
  - Coal/diesel burning
- Manure
- Fertilizers/byproducts containing sulfur
- Irrigation water
Sulfate Deposition 1985 – 2013

Sulfate ion wet deposition, 1985

Sulfate ion wet deposition, 2013

National Atmospheric Deposition Program (NADP)

10 kg SO$_4^{2-}$/ha = 3 lb S/acre
Things Changed in Iowa

Observation of poor alfalfa growth in Northeast Iowa

Photo from B. Lang, ISU
Visual Response in Alfalfa to S Application

S Fertilized

Check
### Alfalfa Response to S Application in Field Areas with Poor and Good Coloration of Alfalfa, 2005-2006

<table>
<thead>
<tr>
<th>Sulfur</th>
<th>Treatment</th>
<th>2005 Cuts 2+3 DM Yield</th>
<th>2005 Cut 2 Plant Top S</th>
<th>2006 Cut 1 DM Yield</th>
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<tbody>
<tr>
<td></td>
<td>Poor</td>
<td>Good</td>
<td>Poor</td>
<td>Good</td>
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<tr>
<td>None</td>
<td>1.18a</td>
<td>2.99b</td>
<td>0.14a</td>
<td>0.22b</td>
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<tr>
<td>Am. sulfate</td>
<td>2.76b</td>
<td>3.26b</td>
<td>0.40d</td>
<td>0.35c</td>
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<tr>
<td>Ca. sulfate</td>
<td>2.49b</td>
<td>3.21b</td>
<td>0.41d</td>
<td>0.37c</td>
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<tr>
<td></td>
<td><strong>6.6</strong></td>
<td><strong>7.4</strong></td>
<td><strong>Soil Sulfate-S (ppm)</strong></td>
<td></td>
</tr>
</tbody>
</table>

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 2005.
Treatment means followed by the same letter are not significantly different (p≤0.10).
Alfalfa Yield Increase to Applied S vs. Plant S Concentration (six-inch plant top)

R² = 0.52  p = 0.006
Linear-Plateau joins at 0.23% S

J.E. Sawyer, Iowa State Univ.
Things Changed
Visual Response in Corn to Sulfur Application

Photo from B. Lang, ISU
Waukon – 8/2006
Loess over bedrock or clay loam till

Loam and clay loam till

Loam till

Corn and soybean S trial sites, 2006-2013
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>
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<tr>
<td>Lamont 1</td>
<td>Sparta lfs</td>
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<td>123 a</td>
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<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>151 b</td>
</tr>
<tr>
<td>Lamont 2</td>
<td>Sparta lfs</td>
<td>No</td>
<td>154 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>198 b</td>
</tr>
<tr>
<td>Thorpe 1</td>
<td>Chelsa lfs</td>
<td>No</td>
<td>88 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>108 b</td>
</tr>
<tr>
<td>Thorpe 2</td>
<td>Kenyon l</td>
<td>No</td>
<td>196 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>204 a</td>
</tr>
<tr>
<td>Waukon</td>
<td>Fayette sl</td>
<td>No</td>
<td>96 a</td>
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<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>172 b</td>
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<tr>
<td>Waterville</td>
<td>Fayette sl</td>
<td>No</td>
<td>118 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>171 b</td>
</tr>
</tbody>
</table>

Sulfur applied as calcium sulfate at 40 lb S/acre.

J.E. Sawyer, Iowa State Univ.
Forty-Seven Corn S Rate Sites in 2007-2009 Northeast – North Central 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
- Soils: l, sil, fsl, lfs, sl, sicl, cl
Twenty-Eight Responsive S Rate Sites
2007-2008 North Central - Northeast Iowa
Soils: 21 fine texture (cl, sicl, sil, l); 7 coarse texture (fsl, lfs, sl)

S Response -- 2007-2008 (Responsive Sites)

<table>
<thead>
<tr>
<th>Sulfur Rate, lb S/acre</th>
<th>Corn Yield, bu/acre</th>
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</thead>
<tbody>
<tr>
<td>15 bu/acre</td>
<td>156</td>
</tr>
<tr>
<td>28 bu/acre</td>
<td>185</td>
</tr>
</tbody>
</table>

21 Fine-Textured Sites
23.4 lb S/acre, 181.1 bu/acre

7 Coarse-Textured Sites
16.9 lb S/acre, 188.7 bu/acre

Economic optimum rate is 0.125 price ratio ($0.50/lb S and $4.00/bu corn)

J.E. Sawyer, Iowa State Univ.
Phosphorus and Sulfur Product Evaluation

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

- Five sites in central to north-central Iowa
  - 2008 – 2010 (four loam and one loamy fine sand soils)
  - 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 two 2006 sites

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

Mean response across both sites, 2006.

- No S yield response at five 2008-2010 sites
  - Leaf S concentration increased with all products

- Across all sites (2006-2010)
  - Yield response to P with all products (17 bu/acre)
  - Leaf P concentration increase with all products
On-Farm Strip Trials  
Central and Northeast Iowa, 2009

<table>
<thead>
<tr>
<th>Site</th>
<th>County</th>
<th>Crop</th>
<th>Rate</th>
<th>Previous Sulfur</th>
<th>Sulfur Resp.</th>
<th>Corn Yield</th>
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<tr>
<td></td>
<td></td>
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<td>lb S/acre</td>
<td>- S</td>
<td>+ S</td>
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<td>3</td>
<td>Greene</td>
<td>corn</td>
<td>40</td>
<td>225</td>
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<tr>
<td>4</td>
<td>Greene</td>
<td>corn</td>
<td>40</td>
<td>210</td>
<td>215†</td>
<td>5</td>
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<tr>
<td>5</td>
<td>Greene</td>
<td>corn</td>
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<td>217</td>
<td>228†</td>
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<tr>
<td>6</td>
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<td>30</td>
<td>215</td>
<td>212</td>
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</tbody>
</table>

† Significantly different, P ≤ 0.10.  
Sulfur applied as gypsum.
### ISU FARM Strip Trials
NW-W-SW Iowa, 2012-2013

**ISU FARM On-Farm Strip Trials, 2012, 2013, and 2013 Residual Year**

| Site | County | Crop Yr 1 | Previous Sulfur Rate (lb S/acre) | 2012 Yield - S | + S | 2013 Yield - S | + S | Response '12 | '13 | Response
<table>
<thead>
<tr>
<th></th>
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<td>Mills</td>
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<tr>
<td>2c</td>
<td>Taylor</td>
<td>soybean</td>
<td>17</td>
<td>99</td>
<td>106*</td>
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<td>--</td>
<td>7</td>
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<td>15</td>
<td>157</td>
<td>160</td>
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<td>44.3*</td>
<td>3.8</td>
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<td>5c</td>
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<td>213</td>
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<td>79</td>
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<td>53.6</td>
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<td>45.0</td>
<td>49.1*</td>
<td>32</td>
<td>4.1</td>
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<td>64.3</td>
<td>63.3</td>
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<td>172</td>
<td>181*</td>
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<td>Taylor</td>
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<td>45.3</td>
<td>44.1</td>
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</table>

* Significant difference at P ≤ 0.10. Sulfur applied in spring as gypsum.

29% site positive response
Extractable Soil Sulfate-S (0-6 inch depth)

Yield Response to 40 lb S/acre

- Yield Increase (bu/acre)
- Extractable Soil Sulfate-S (ppm)
- 2007-2009 Sites
- 2000 Sites

N = 52

J.E. Sawyer, Iowa State Univ.
Soil Profile Extractable Sulfate-S

Yield Response to 40 lb S/acre

Three Foot Profile Extractable Sulfate-S (lb S/acre)
Corn Ear Leaf S Concentration (R1 Stage)

Yield Response to 40 lb S/acre

-30 -20 -10 0 10 20 30 40 50 60
0.10 0.12 0.14 0.16 0.18 0.20 0.22

Yield Increase (bu/acre)
Corn Ear Leaf S in Control (% S)

2007-2009 Sites
2000 Sites

N = 52

J.E. Sawyer, Iowa State Univ.
Soil Organic Matter (0-6 inch depth)

Yield Response to 40 lb S/acre

N=3

N=8

21% error

Soil Organic Matter (%)

J.E. Sawyer, Iowa State Univ.
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

J.E. Sawyer, Iowa State Univ.
Early Season Sulfur Deficiency Symptoms Can Disappear

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

<table>
<thead>
<tr>
<th>lb S/acre</th>
<th>Higher OM</th>
<th>Lower OM</th>
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<tbody>
<tr>
<td>0</td>
<td>192</td>
<td>187</td>
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<tr>
<td>5</td>
<td>184</td>
<td>188</td>
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<td>10</td>
<td>190</td>
<td>187</td>
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<td>20</td>
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<td>191</td>
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<tr>
<td>40</td>
<td>187</td>
<td>183</td>
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<tr>
<td>FLSD0.10</td>
<td>NS</td>
<td>NS</td>
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</table>

Dave Rueber
ISU Northern Farm, Kanawha

J.E. Sawyer, Iowa State Univ.
Sulfur Rate Trials – Northern Research Farm

<table>
<thead>
<tr>
<th></th>
<th>Higher OM Site (5.8%)</th>
<th>Lower OM Site (4.1%)</th>
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<tbody>
<tr>
<td>S Rate</td>
<td>SC   SC   SCC</td>
<td>SC   SC   SCC</td>
</tr>
<tr>
<td>lb S/acre</td>
<td>- - - bu/acre - - -</td>
<td>- - - bu/acre - - -</td>
</tr>
<tr>
<td></td>
<td>NDVI</td>
<td>NDVI</td>
</tr>
<tr>
<td>0</td>
<td>192  82  152  0.557</td>
<td>187  80  174  0.577</td>
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<td>5</td>
<td>184  100 171  0.591</td>
<td>188  99  192  0.619</td>
</tr>
<tr>
<td>10</td>
<td>190  105 180  0.657</td>
<td>187  109 191  0.649</td>
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<tr>
<td>20</td>
<td>191  105 179  0.629</td>
<td>191  113 179  0.663</td>
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<tr>
<td>40</td>
<td>187  111 181  0.638</td>
<td>183  104 185  0.671</td>
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<tr>
<td>Sign. (0.10)</td>
<td>NS  *  *  *</td>
<td>NS  *  *  *</td>
</tr>
</tbody>
</table>

Higher OM site Webster clay loam; lower OM site Clarion loam.
S rates (as gypsum) applied in spring 2011 and 2013 before corn.
Significance either rate, linear, quadratic, cubic, or +S vs. –S.
Dave Rueber, ISU Northern Research Farm, Kanawha, IA.
NDVI from Crop Circle at V10 corn growth stage.
# Sulfur Rate Trials

**Muscatine Island Research Farm**

<table>
<thead>
<tr>
<th>S Rate</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
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</thead>
<tbody>
<tr>
<td>lb S/acre</td>
<td>bu/acre</td>
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<tr>
<td>0</td>
<td>72.4</td>
<td>211</td>
<td>259</td>
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<tr>
<td>10</td>
<td>74.4</td>
<td>207</td>
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<td>20</td>
<td>69.6</td>
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<td>254</td>
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<td>40</td>
<td>72.2</td>
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<td>Sign. (0.05)</td>
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<td>NS</td>
<td>NS</td>
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</tbody>
</table>

Fruitfield coarse sand (1 to 1.5% OM), irrigated. S rates (gypsum) applied post-emergence. Leaf S concentrations increased each year with S application. 2013: 1.7 lb SO$_4^-$-S/acre-inch irrigation (27 lb S/acre in 16 inches). Vince Lawson, ISU Muscatine Island Research Farm, Fruitland.
Summary

- **Sulfur deficiencies an issue in Iowa**
  - 60% corn S rate sites responsive to S application
    - 68% sites responsive with l, sil, fsl, lfs, sl soils
    - 14% sites responsive with sicl, cl soils
  - Especially coarse textured, sideslope landscape, eroded, low organic matter soils; no-tillage, reduced-tillage, high crop residue, alfalfa prior crop, no manure application, no S applied in fertilizers or irrigation

- **47% S response frequency for 110 trials statewide from 2006 – 2013**
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 and soybean – ??
    - General field/soil characteristics
    - Visual coloration and growth response
    - Strip trials +/- S for multiple years

J.E. Sawyer, Iowa State Univ.
Sulfur Fertilizers

- Ammonium Sulfate (21-0-0-24S)
- Ammonium Thiosulfate (12-0-0-26S)
- Gypsum (Calcium Sulfate) (0-0-0-17S)
- Elemental Sulfur (0-0-0-90S)
- Magnesium Sulfate (0-0-0-14S)
- Potassium Magnesium Sulfate (0-0-22-23S)
- Potassium Sulfate (0-0-50-18S)
- N-P-S products (ex. 13-33-0-15S)
- Polyhalite (0-0-14-19S)

By-Products
  - Lysine manufacturing
  - Soybean soapstock refining process water (Plant Food Solution)
  - Wallboard (gypsum)
Research Support

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