Increasing Importance of Sulfur for Field Crops

John Sawyer, Professor
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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

Study area
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
Sulfur Sources

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

National Atmospheric Deposition Program (NADP)

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

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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</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cuts 2+3</td>
<td>Cut 2</td>
<td>Cut 1</td>
</tr>
<tr>
<td></td>
<td>DM Yield</td>
<td>Plant Top S</td>
<td>DM Yield</td>
</tr>
<tr>
<td></td>
<td>Poor</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Poor</td>
<td>1.18a</td>
<td>2.99b</td>
<td>0.14a</td>
</tr>
<tr>
<td>Good</td>
<td>2.76b</td>
<td>3.26b</td>
<td>0.40d</td>
</tr>
<tr>
<td>Poor</td>
<td>2.49b</td>
<td>3.21b</td>
<td>0.41d</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 in 2005.

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

R^2 = 0.52  \( p = 0.006 \)
Linear-Plateau joins at 0.23% S

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Things Changed

Photo from B. Lang, ISU
Waukon – 6/26/2006
Visual Response in Corn to Sulfur Application

Photo from B. Lang, ISU Waukon – 8/2006
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>
</tr>
</thead>
<tbody>
<tr>
<td>Lamont 1</td>
<td>Sparta lfs</td>
<td>No</td>
<td>123 a</td>
</tr>
<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>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>172 b</td>
</tr>
<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.
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)

Fine-Textured Sites
- Maximum Response Rate: 16.9 lb S/acre, 188.7 bu/acre
- Economic Optimum Rate: 15.7 lb S/acre, 188.6 bu/acre

Coarse-Textured Sites
- Maximum Response Rate: 24.8 lb S/acre, 181.2 bu/acre
- Economic Optimum Rate: 23.4 lb S/acre, 181.1 bu/acre

0.125 price ratio ($0.50/lb S and $4.00/bu corn)

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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
  - Leaf S concentration increased with all products
  - Across all sites (2006-2010)
    - Mean response across both sites, 2006.

<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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<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>

- 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

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# 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>Sulfur Rate</th>
<th>Corn Yield</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>lb S/acre</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- S</td>
<td>+ S</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></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>
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<tr>
<td>4</td>
<td>Greene</td>
<td>corn</td>
<td>40</td>
<td>210</td>
<td>215†</td>
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<tr>
<td>5</td>
<td>Greene</td>
<td>corn</td>
<td>40</td>
<td>217</td>
<td>228†</td>
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<tr>
<td>6</td>
<td>Dallas</td>
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<td>40</td>
<td>201</td>
<td>200</td>
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<tr>
<td>9</td>
<td>Dallas</td>
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<td>40</td>
<td>147</td>
<td>152†</td>
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<tr>
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<td>Dallas</td>
<td>corn</td>
<td>40</td>
<td>135</td>
<td>134</td>
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<tr>
<td>1</td>
<td>Fayette</td>
<td>soybean</td>
<td>15</td>
<td>224</td>
<td>236†</td>
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<td>2</td>
<td>Howard</td>
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<td>20</td>
<td>186</td>
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<td>7</td>
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<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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<tr>
<td>11</td>
<td>Winneshiek</td>
<td>soybean</td>
<td>30</td>
<td>215</td>
<td>212</td>
</tr>
</tbody>
</table>

† Significantly different, P ≤ 0.10.

Sulfur applied as gypsum.

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55% site response

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

<table>
<thead>
<tr>
<th>Site</th>
<th>County</th>
<th>Crop Yr 1</th>
<th>Sulfur Rate</th>
<th>2012 Yield</th>
<th>2013 Yield</th>
<th>Response '12 '13</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- S</td>
<td>+ S</td>
<td>- S</td>
</tr>
<tr>
<td>1c</td>
<td>Mills</td>
<td>soybean</td>
<td>17</td>
<td>217</td>
<td>218</td>
<td>--</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>3c</td>
<td>Lyon</td>
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<td>157</td>
<td>160</td>
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<td>Osceola</td>
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<td>198</td>
<td>197</td>
<td>--</td>
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<tr>
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<td>Dickinson</td>
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<td>213</td>
<td>214</td>
<td>--</td>
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<td>Lyon</td>
<td>soybean</td>
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<td>134*</td>
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<td>88</td>
<td>79</td>
<td>55.5</td>
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<td>8c</td>
<td>Crawford</td>
<td>soybean</td>
<td>15</td>
<td>100</td>
<td>132*</td>
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<td>10c</td>
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<td>soybean</td>
<td>15</td>
<td>232</td>
<td>228</td>
<td>69.3</td>
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<tr>
<td>11c</td>
<td>Clay</td>
<td>soybean</td>
<td>15</td>
<td>231</td>
<td>235*</td>
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<tr>
<td>1s</td>
<td>Osceola</td>
<td>corn</td>
<td>15</td>
<td>50.2</td>
<td>52.4</td>
<td>201</td>
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<tr>
<td>2s</td>
<td>Monona</td>
<td>corn</td>
<td>15</td>
<td>64.3</td>
<td>63.3</td>
<td>230</td>
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<tr>
<td>1n</td>
<td>Taylor</td>
<td>soybean</td>
<td>17</td>
<td>--</td>
<td>--</td>
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<tr>
<td>1n</td>
<td>Taylor</td>
<td>corn</td>
<td>17</td>
<td>--</td>
<td>--</td>
<td>45.3</td>
</tr>
</tbody>
</table>

* Significant difference at P ≤ 0.10. Sulfur applied in spring as gypsum.
Extractable Soil Sulfate-S (0-6 inch depth)

Yield Response to 40 lb S/acre

Yield Increase (bu/acre) vs. Extractable Soil Sulfate-S (ppm)

2007-2009 Sites
2000 Sites

N = 52

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Soil Profile Extractable Sulfate-S

Yield Response to 40 lb S/acre

Three Foot Profile Extractable Sulfate-S (lb S/acre)

N = 19
Corn Ear Leaf S Concentration (R1 Stage)

Yield Response to 40 lb S/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

- Yield Increase (bu/acre)
- Soil Organic Matter (%)

2007-2009 Sites
2000 Sites

N=8
21% error

N = 52

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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

No Response or Small Response

Zero bu/acre Response
Ames Site 2001
Soybean Previous Crop
Clarion loam
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></th>
<th>Higher OM</th>
<th>Lower OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>lb S/acre</td>
<td>- - - bu/acre - - -</td>
<td></td>
</tr>
<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>
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<td>20</td>
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<td>40</td>
<td>187</td>
<td>183</td>
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<td>FLSD\textsubscript{0.10}</td>
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<td>NS</td>
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</table>

Dave Rueber
ISU Northern Farm, Kanawha
# 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>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S Rate</strong></td>
<td>SC      SCC   SCCC</td>
<td>SC      SCC   SCCC</td>
</tr>
<tr>
<td><strong>lb S/acre</strong></td>
<td>- - -   bu/acre - - -</td>
<td>NDVI    - - -   bu/acre - - -</td>
</tr>
<tr>
<td>0</td>
<td>192     82    152</td>
<td>0.557    187     80    174</td>
</tr>
<tr>
<td>5</td>
<td>184     100   171</td>
<td>0.591    188     99    192</td>
</tr>
<tr>
<td>10</td>
<td>190     105   180</td>
<td>0.657    187     109   191</td>
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<tr>
<td>20</td>
<td>191     105   179</td>
<td>0.629    191     113   179</td>
</tr>
<tr>
<td>40</td>
<td>187     111   181</td>
<td>0.638    183     104   185</td>
</tr>
<tr>
<td><strong>Sign. (0.10)</strong></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 (lb S/acre)</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>72.4</td>
<td>211</td>
<td>259</td>
</tr>
<tr>
<td>10</td>
<td>74.4</td>
<td>207</td>
<td>258</td>
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<tr>
<td>20</td>
<td>69.6</td>
<td>214</td>
<td>254</td>
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<tr>
<td>40</td>
<td>72.2</td>
<td>210</td>
<td>262</td>
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<tr>
<td>Sign. (0.05)</td>
<td>NS</td>
<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

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

Photo from B. Lang, ISU