Is Sulfur is the “S” in Soybean?

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Intentional Soybean Management
Maturity Group 2

S Accumulation: 1960s vs. 2010s
• Atmospheric Deposition
• Organic S
• Plant Residue
- Organic Matter
- Plant Residue
- N Fixation
High Yielding Soybeans!
Sulfur: Who Needs It...Maybe You?

Total deposition of sulfur

2001

2015

Source: CASTNET/CMAQ/NTN/AMON/SEARCH USEPA 09/14/16

EPA, 2016

Which Crops Should Be the Most Responsive to Sulfur?
Supplying Sulfur to Our Fields

• ~3-5 lb S/ac mineralized per 1% OM per year

• Plant Residue – Mineralized or Immobilized?
  – C:S Ratio < 200:1 → MINERALIZED SO₄-S
  – C:S Ratio > 400:1 → IMMOBILIZED SO₄-S
  – Corn Stover ~350:1
  – Soybean Stover ~125:1
  – Wheat Straw ~300:1
  – Cover Crop? Other Factors?
# How Much S Does CORN Remove?

<table>
<thead>
<tr>
<th>Grain</th>
<th>lb/bu</th>
<th>180 bu</th>
<th>220 bu</th>
<th>260 bu</th>
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<tbody>
<tr>
<td>Nitrogen</td>
<td>0.67</td>
<td>121</td>
<td>147</td>
<td>174</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.35</td>
<td>63</td>
<td>77</td>
<td>91</td>
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<tr>
<td>K₂O</td>
<td>0.25</td>
<td>45</td>
<td>55</td>
<td>65</td>
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<tr>
<td>Sulfur</td>
<td>0.08</td>
<td><strong>14</strong></td>
<td><strong>18</strong></td>
<td><strong>21</strong></td>
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<tr>
<td>Total S</td>
<td>0.15</td>
<td>27</td>
<td>33</td>
<td>39</td>
</tr>
</tbody>
</table>

IPNI, 2014
# How Much S Does Soybean Need?

<table>
<thead>
<tr>
<th>Grain</th>
<th>lb/bu</th>
<th>50 bu</th>
<th>75 bu</th>
<th>100 bu</th>
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<tbody>
<tr>
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<td>3.30</td>
<td>165</td>
<td>248</td>
<td>330</td>
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<tr>
<td>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>0.73</td>
<td>37</td>
<td>55</td>
<td>73</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>1.20</td>
<td>60</td>
<td>90</td>
<td>120</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.18</td>
<td>9</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td>Total S</td>
<td>0.35</td>
<td><strong>18</strong></td>
<td><strong>26</strong></td>
<td><strong>35</strong></td>
</tr>
</tbody>
</table>
## Doing the Math: **Sulfur Needs (lb S/ac)**
(Rough Mass Balance)

<table>
<thead>
<tr>
<th>Yield (bu)</th>
<th>Need (lb S/ac)</th>
<th>Sky</th>
<th>1%</th>
<th>2%</th>
<th>3%</th>
<th>4%</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>18</td>
<td>~5</td>
<td>9</td>
<td>5</td>
<td>1</td>
<td>+3</td>
</tr>
<tr>
<td>75</td>
<td>26</td>
<td>~5</td>
<td>17</td>
<td>13</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>100</td>
<td>35</td>
<td>~5</td>
<td>26</td>
<td>23</td>
<td>18</td>
<td>14</td>
</tr>
</tbody>
</table>

**Soil Organic Matter**
No Sulfur  20 lb S/acre
## Flowering (aka R2)

Leaf Nutrient Sufficiency Ranges

<table>
<thead>
<tr>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.25 to 5.0</td>
<td>0.30 to 0.60</td>
<td>1.5 to 2.25</td>
<td>0.8 to 1.4</td>
<td>0.25 to 0.70</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>S</th>
<th>Manganese</th>
<th>Zinc</th>
<th>Copper</th>
<th>Boron</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25 to 0.60</td>
<td>17 to 100</td>
<td>21 to 80</td>
<td>4 to 30</td>
<td>20 to 60</td>
</tr>
</tbody>
</table>
Sulfur Season Treatments

• **Untreated**

• **Broadcast @ 20 lb S/ac with MES10 or AMS** prior to emergence

• **Single foliar @ 5 lb S/ac with spraygrade AMS:**
  - V4, R2, R4, R6

• **Sequential foliar combos @ 5 lb S/ac per pass**
  - V4 + R2 \(\Rightarrow 5 + 5 = 10\) lb S/ac
  - V4 + R4 \(\Rightarrow 5 + 5 = 10\) lb S/ac
  - R4 + R6 \(\Rightarrow 5 + 5 = 10\) lb S/ac
  - V4 + R2 + R4 + R6 \(\Rightarrow 5 + 5 + 5 + 5 = 20\) lb S/ac
2016 Sulfur @ R3 (18 d after R2)

Fisher’s Protected LSD

Soybean Station
Delivering First Class Information

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2016 N:S @ R3 (18 d after R2)

Fisher’s Protected LSD

0.05

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2016 Sulfur Season @ LaCrosse
+ 8.5 to 12.5 bu with broadcast

Yield (bu/ac)

UTC    MES10   AMS    V4    R2    R4    R6    V4+R2    V4+R4    R4+R6    All Foliar

d    abc    a    c    abc    c    c    ab    bc    c    d

+ 6 to 10 bu with foliar AMS

Fisher’s Protected LSD 0.05
2016 Sulfur Season @ SWPAC
+ 6 bu with broadcast at V3

Yield (bu/ac)

UTC  MES10  AMS  V4  R2  R4  R6  V4+R2  V4+R4  R4+R6  All Foliar  urea  urea + ESN

c  a  ab  abc  c  c  d  bc  c  d  d  abc  abc

Fisher’s Protected LSD

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2017 Sulfur Response
No Sulfur

20 lb S/acre
No Sulfur

20 lb S/acre
No Sulfur
31 pods
17 nodes
1 branch

20 lb S/acre
45 pods
18 nodes
2 branches
2017 Sulfur Responsiveness

• **Broadcast** @ 20 lb S/ac: + 13 bu
  – Similar to 2016

• **Single foliar** @ 5 lb S/ac: + 4 to 7 bu
  – Not as good as 2016

• **Sequential foliar combos**: + 5 to 7.5 bu
  – No response (i.e., crop phytotoxicity) with foliar applications at all four timings (V4, R2, R4, R6)
  – Not as good as 2016
## Doing the Math: Sulfur Needs (lb S/ac) 
(Rough Mass Balance)

### Soil Organic Matter

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<tr>
<th>Yield (bu)</th>
<th>Need (lb S/ac)</th>
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<td>50</td>
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<td>~5</td>
<td>~4</td>
<td>~8</td>
<td>~12</td>
<td>~16</td>
</tr>
<tr>
<td>75</td>
<td>26</td>
<td>~5</td>
<td>~4</td>
<td>~8</td>
<td>~12</td>
<td>~16</td>
</tr>
<tr>
<td>100</td>
<td>35</td>
<td>~5</td>
<td>~4</td>
<td>~8</td>
<td>~12</td>
<td>~16</td>
</tr>
</tbody>
</table>

What is the RIGHT RATE?
Sulfur Rate x Source: 2016-17

- **Untreated** control to be zero S rate
- **Sulfur Rates:** 5, 10, 20, 30 lb S/ac
- **Sources:**
  - AMS (21-0-0-24S), Ammonium Sulfate (Sulf-N®)
  - MES10 (12-40-0-10S), MicroEssentials MES10S™
  - TigerAMS (50:50 blend of bentonite elemental sulfur and ammonium sulfate)
- Phosphorus was balanced for all fertilizer treatments with triple super phosphate (0-45-0)
- Broadcast applied to the soil surface within a few days of planting
Sulfur Rate x Source: 2016-17

Yield (bu/ac) vs. Sulfur (lb S/ac)

- AMS
- MES10
- TigerAMS

LaCrosse, IN
Sulfur Rate x Source: 2016-17

AMS ~10 lb S/ac

AMS

R^2 = 0.99

MES10

TigerAMS

0
5
10
15
20
25
30

Yield (bu/ac)

AMS

Sulfur (lb S/ac)

LaCrosse, IN
Sulfur Rate x Source: 2016-17

MES10 ~20 lb S/ac

Sulfur (lb S/ac)

Yield (bu/ac)

AMS  \( R^2 = 0.99 \)

MES10  \( R^2 = 0.98 \)

TigerAMS

LaCrosse, IN
Sulfur Rate x Source: 2016-17

TigerAMS ~20 lb S/ac

AMS \( R^2 = 0.99 \)

MES10 \( R^2 = 0.98 \)

TigerAMS \( R^2 = 0.88 \)

Yield (bu/ac)

Sulfur (lb S/ac)
~10 lb S/ac in SULFATE FORM optimized yield for all three sources:

- AMS @ 10 lb S/ac
- MES10 / TigerAMS @ 20 lb S/ac

- Higher Yield Levels?
- Application Timings?
- Other Sources?
18 New Sulfur Sources: Early R3
## 18 Sulfur Sources: LaCrosse

<table>
<thead>
<tr>
<th>Source</th>
<th>Yield (bu/ac)</th>
</tr>
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<tr>
<td>UTC</td>
<td>62.4</td>
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<tr>
<td>AMS</td>
<td>72.0</td>
</tr>
<tr>
<td>MES10</td>
<td>73.4</td>
</tr>
<tr>
<td>Gypsum</td>
<td>72.8</td>
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<tr>
<td>K-Mag</td>
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<td>Tiger90CR</td>
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<td>AMS:Tiger</td>
<td>68.8</td>
</tr>
<tr>
<td>spray.ATS</td>
<td>68.6</td>
</tr>
<tr>
<td>R3.Foliar.AMS</td>
<td>69.4</td>
</tr>
</tbody>
</table>
18 Foliar Sulfur Rate x Timing

- Pre-AMS @ 20 lb S/ac
- Growth Stage Targets: V4, R3, V4 + R3
- Sulfur Rates: 0, 1, 2, 4, 6 lb S/ac
- Spray grade AMS
- 15 GPA
- LaCrosse, IN
18 Foliar Sulfur Rate x Timing

Yield (bu/ac)

Foliar S Rate (lb S/ac)

V4_AMS
R3_AMS
AMS_V4R3

LaCrosse, IN
18 Foliar Sulfur Rate x Timing

V4 @ ~4 lb S/ac

Yield (bu/ac)

0 10 20 30 40 50 60 70

Foliar S Rate (lb S/ac)

0 2 4 6 8 10 12 14

V4_AMS
R3_AMS
AMS_V4R3

LaCrosse, IN
18 Foliar Sulfur Rate x Timing

R3 @ ~4 lb S/ac

Yield (bu/ac)

- V4_AMS
- R3_AMS
- AMS_V4R3

LaCrosse, IN

Soybean Station
Delivering First Class Information

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18 Foliar Sulfur Rate x Timing

- ~4 lb S/ac optimized yield regardless of stage (V4 or R3)
- Foliar applications still short of Pre-AMS → 68.9 bu/ac
TIMELY PLANTING of Soybeans
TIMELY PLANTING of Soybeans

• Best combination of **heat unit accumulation** and **light interception** to maximize:
  – Nodes
  – Pods
  – Reproductive branches
  – Canopy closure
  – Reproductive duration

• **Late April to Early May**: general sweet spot

• **Loss of yield potential 0.3 to 0.4 bu/ac/day after mid-May** (even early May occasionally)
18 Preliminary N+S Findings

- **N+S x Planting Date**
  - **ACRE**: West Lafayette
  - 2 x 10 Factorial arranged in RCBD with 5 reps
  - Variety: AG 34x6
  - 2 Planting Dates: **May 11th, June 5th**
  - 10 N-S Based Treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Timing</th>
<th>Nitrogen</th>
<th>Sulfur</th>
<th>May 11</th>
<th>June 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTC</td>
<td></td>
<td>.</td>
<td>.</td>
<td>62.4</td>
<td>59.2</td>
</tr>
<tr>
<td>AMS</td>
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<td>17.5</td>
<td>20</td>
<td>69.5</td>
<td>60.7</td>
</tr>
<tr>
<td>ATS</td>
<td>PRE-Emerge</td>
<td>9.3</td>
<td>20</td>
<td>71.5</td>
<td>61.9</td>
</tr>
</tbody>
</table>
# 18 Preliminary N+S Findings

- **N+S x Variety**
  - Pinney PAC: **Wanatah, IN**
  - 2 x 10 Factorial arranged in RCBD with 5 reps
  - 2 Varieties: **AG24x7, AG34x6 planted May 25th**
  - 10 N-S Based Treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Timing</th>
<th>Nitrogen</th>
<th>Sulfur</th>
<th>AG 24X7</th>
<th>AG 34X6</th>
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</thead>
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<tr>
<td></td>
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<td>lb N/ac</td>
<td>lb S/ac</td>
<td>bu/ac</td>
<td>bu/ac</td>
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<td>66.0</td>
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<td>17.5</td>
<td>20</td>
<td>69.3</td>
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<td>PRE-Emerge</td>
<td>9.3</td>
<td>20</td>
<td>60.2</td>
<td>67.0</td>
</tr>
</tbody>
</table>
18 INField Advantage: Untreated Leaf Samples

Leaf N:S vs Leaf Sulfur Concentration (%)

0.25% S

18:1
18 INFA Tipton

AMS 24 lb S/ac

No Sulfur

66 pods/plant
18.4 nodes

84 bu

44 pods/plant
16.6 nodes

73 bu
Concluding Thoughts on Sulfur

• **Soil test? Not Really.**

• **Soybean is the integrator**
  – Late Spring Broadcast of ~20 lb S/ac with soluble source (e.g., AMS, MES10, Gypsum, ATS)
  – **Leaf Nutritional Snapshots then Apply Sulfur**
    • “Close” to *critical S levels* (0.25%)
    • N:S ~18:1 or higher
  – Foliar S → ~4 lb S/ac

• **Management x Fertility Considerations?**
  – Field conditions that affect sulfur availability and nodulation + N fixation (e.g., soil temp, planting, residue)
Thanks for the support!

[logos of Indiana Soybean Alliance and United Soybean Board]
Highlighter Green Soybeans
Seep Hydrology

a) Soil Surface
   Permeable Layer
   Restrictive Layer

b) 

c) 

b) 

d) Crop Stress
A New Pest in 2018?
Shelby County
Shelby County
Good
18.8 nodes
43.1 pods
~60 bu

Poor
16.7 nodes
28.7 pods
~40 bu
Good

Poor
Good

Poor
Advancing the INField Advantage Soy + Sulfur Program

• Yield maps so data can be queried
• PDF yield maps are at the mercy of the legend’s scale with no way of quantifying the yield response unless it is dramatic
  – How much of a yield response is break-even for 20 lb of S/ac via AMS? ~2 to 2.5 bu/ac
  – Can you tell the difference between 2, 3, or 4 bu pixels on a yield map?
Firm Foundations For Yield

• Varieties are taking up more N and S
• Timely Planting sets the stage
• Fertility for yield potential
• Sulfur (and Nitrogen)
  – Sulfur-Deficient Fields
  – Sulfur can be *Situationally Deficient* (and N?)
  – Sulfur ➔ Nodulation, N Fixation, N Utilization
## Yield Map Legend Example

<table>
<thead>
<tr>
<th>May 11</th>
<th>June 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>bu/ac</td>
<td>bu/ac</td>
</tr>
<tr>
<td>62.4</td>
<td>59.2</td>
</tr>
<tr>
<td>69.5</td>
<td>60.7</td>
</tr>
<tr>
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<td>61.9</td>
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<td>58.0</td>
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<td>76.1</td>
<td>57.6</td>
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<td>59.9</td>
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<tr>
<td>72.8</td>
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<table>
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<th>May 11</th>
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<tr>
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<tr>
<td>AMS</td>
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</tr>
<tr>
<td>AMS + Urea</td>
<td>PRE-Emerge</td>
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<td>10</td>
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<td>62.8</td>
</tr>
<tr>
<td>AMS + Urea</td>
<td>V4</td>
<td>40</td>
<td>10</td>
<td>75.9</td>
<td>58.0</td>
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<tr>
<td>V4 + R3</td>
<td>V4 + R3 Direct</td>
<td>80</td>
<td>20</td>
<td>76.1</td>
<td>57.6</td>
</tr>
<tr>
<td>AMS + UAN</td>
<td>R3 Direct</td>
<td>40</td>
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<td>UAN</td>
<td>R3 Direct</td>
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<td>72.8</td>
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<tr>
<td>AMS</td>
<td>R3 Direct</td>
<td>8.75</td>
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</tr>
<tr>
<td>R3 + Feed</td>
<td>R3 + R5, 5.5, 6, 6.5</td>
<td>80</td>
<td>20</td>
<td>72.4</td>
<td>57.2</td>
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</tbody>
</table>

**Legend:**
- UTC: Untreated Control
- AMS: Ammonium Sulfate
- ATS: Ammonium Thiosulfate
- AMS + Urea: Ammonium Sulfate + Urea
- AMS + UAN: Ammonium Sulfate + UAN
- V4: V4 Stage
- V4 + R3: V4 + R3 Direct
- AMS + UAN: Ammonium Sulfate + UAN
- R3 + Feed: R3 + R5, 5.5, 6, 6.5
## Yield Map Legend Example

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<td>9.3</td>
<td>20</td>
<td>71.5</td>
<td>61.9</td>
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<tr>
<td>AMS + Urea</td>
<td>PRE-Emerge</td>
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<td>20</td>
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<tr>
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<tr>
<td>UAN</td>
<td>R3 Direct</td>
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<tr>
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<tr>
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<td>R3 + R5, 5.5, 6, 6.5</td>
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<td>20</td>
<td>72.4</td>
<td>57.2</td>
</tr>
</tbody>
</table>
Good

18.8 nodes
43.1 pods
~60 bu

Poor

16.7 nodes
28.7 pods
~40 bu
Good

Poor
Good

Poor
## 18 Preliminary N+S Findings

### N+S x Planting at West Lafayette, IN

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Timing</th>
<th>Nitrogen</th>
<th>Sulfur</th>
<th>May 11</th>
<th>June 5</th>
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<td>PRE-Emerge</td>
<td>17.5</td>
<td>20</td>
<td>69.5</td>
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</tr>
<tr>
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<td>9.3</td>
<td>20</td>
<td>71.5</td>
<td>61.9</td>
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</tbody>
</table>

### N+S x Variety at Wanatah, IN: May 25th Planting

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Timing</th>
<th>Nitrogen</th>
<th>Sulfur</th>
<th>AG 24X7</th>
<th>AG 34X6</th>
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<td>65.4</td>
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<tr>
<td>ATS</td>
<td>PRE-Emerge</td>
<td>9.3</td>
<td>20</td>
<td>60.2</td>
<td>67.0</td>
</tr>
</tbody>
</table>
Future: Planting Date x Source

- Planting Date: 5 small, but 2 to 3 at PACs?
- Sources:
  - ATS Burndown
  - ATS in Starter 0x2
  - AMS Broadcast
  - Other Soluble Sources
Future: Field Residue x Source

• Field Residue:
  – Corn Stalks
  – Corn Residue levels
  – Cover Crop: C. Rye, Others

• Sources:
  – ATS Burndown
  – ATS in Starter 0x2
  – AMS Broadcast
  – Other Soluble Sources
Future: Incubation Studies

- 2 Soils
- Residues
  - C. Rye
  - Corn Stover
  - Corn Stover + C. Rye
- C:N Ratios
- C:S Ratios
- Fertilizer additions?
Future: App Timing x Source

• Application: 5 to 6 timings
  – Fall
  – Feb-March (~60 d prior to planting)
  – March-April (~30 d prior to planting)
  – Planting (within 1 week)
  – V2 (~30 d after planting)
  – V6/R1 (~60 d after planting)

• Sources: 4 to 6?
  – AMS Broadcast
  – Gypsum
  – MES10
  – Elemental S
  – ATS?
  – Any Blends?

• Rates?
  – 12 lb, 24 lb S/ac

• Untreated