Sulfur uptake by corn from fall- or spring-applied $^{34}$S-labelled fertilizer

Fien Degryse, Rodrigo Coqui da Silva, Roslyn Baird and Mike McLaughlin
Sulfur fertilizers

- Sulfur is an essential major plant nutrient, but has received relatively little attention.
- S deficiency has become more common, because of reduced input (fertilizer, atmospheric) and increased output (yields).
- Inorganic S fertilizers:

<table>
<thead>
<tr>
<th>Sulfate</th>
<th>Elemental S</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Readily available</td>
<td>+ Lower transportation/application cost</td>
</tr>
<tr>
<td>- Susceptible to leaching losses</td>
<td>Sustained release</td>
</tr>
<tr>
<td>High transport/application cost on a nutrient basis ($SO_4^{2-}$)</td>
<td>- Only available when oxidised</td>
</tr>
</tbody>
</table>
Leaching of $\text{SO}_4^\text{-S}$

- Solid-liquid partitioning coefficient ($K_d$) in most soils <0.2 L/kg \[\Rightarrow\] little retardation
- 250 mm (10 in) of excess rainfall can leach $\text{SO}_4^\text{-S}$ to a depth of 60 cm (24 in) \[\Rightarrow\] high leaching losses of sulfate in high-rainfall environments may occur, particularly with fall-applied fertilizer, e.g.

Devine and Holmes, *J. Agric. Sci.* 1964
Oxidation of elemental S

• Oxidation of elemental S depends on:
  – environmental factors, mainly temperature (Q10 around 3.5);
  – soil chemical and biological factors; and
  – fertilizer properties (surface area)

• Oxidation of co-granulated ES is slower than for particulate ES due to reduced surface area, e.g.

<table>
<thead>
<tr>
<th>Fertiliser</th>
<th>$k_{\text{oxid}}$ (d$^{-1}$)</th>
<th>$t_{1/2}$ (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powdered ES</td>
<td>0.02</td>
<td>35</td>
</tr>
<tr>
<td>MAP+5%ES</td>
<td>0.006</td>
<td>120</td>
</tr>
<tr>
<td>ES pastille</td>
<td>0.0005</td>
<td>1400</td>
</tr>
</tbody>
</table>

Degryse et al, *under review*;
Similar oxidation rates estimated from pot trial (Degryse et al, Plant Soil 2015)
Aim

Assess contribution of fertilizer $\text{SO}_4^-$ and elemental S (ES) in MAP fertilizer (MESZ) to crop uptake in the Corn Belt region when fertilizer is fall or spring applied.

$\text{MESZ} \equiv \text{MAP} + 5\% \text{ES} + 5\% \text{SO}_4^- + 1\% \text{Zn}$

Source: [http://www.wrcc.dri.edu/precip.html](http://www.wrcc.dri.edu/precip.html)
Methods

\[^{34}\text{S} \text{labelling} – \text{principle}\]

ES labelled plots: \(^{34}\text{S} \star\)

SO\(_4\) labelled plots: \(^{34}\text{SO}_4 \bigstar\)

\%S in plant derived from

\[\text{Fert ES} \rightarrow \text{Fert SO}_4 \leftarrow \text{Soil S}\]

\[^{34}\text{S}\text{df} (\text{fert ES}) = \frac{\text{atom}\%^{34}\text{Sexcess}_{\text{plant}}}{\text{atom}\%^{34}\text{Sexcess}_{\text{fert ES}}} \times 100\]

\[^{34}\text{S}\text{df} (\text{fert SO}_4) = \frac{\text{atom}\%^{34}\text{Sexcess}_{\text{plant}}}{\text{atom}\%^{34}\text{Sexcess}_{\text{fert SO}_4}} \times 100\]
Experimental design and methods

- Champaign (Illinois, US) – humid continental climate
- MESZ applied at 280 kg/ha (=28 kg S/ha) in fall (25 Nov ‘13) or in spring at time of sowing (15 June ‘14);
  SO$_4$-S or ES labeled with $^{34}$S
- Corn manually sown in spring
- Early stage (20 Aug ‘14) and maturity harvest (31 Oct)
- $^{34}$S atom% in plant material analysed by IRMS (Isolytix)
Assessing sulfate leaching

• To estimate $SO_4$-S leaching:
  – plot with sulfate of potash (SOP) at 2630 kg/ha; applied at fall or spring
  – three cores sampled up to 90 cm (36 in) and analysed for $SO_4$-S (0.01 M $Ca(H_2PO_4)_2$ extraction)

• Weather during experimental period:

Precipitation
• Fall application to seeding 55 cm (21.6 in)
• Seeding to harvest 59 cm (23.3 in)
Yields and S uptake

<table>
<thead>
<tr>
<th>Stage</th>
<th>Whole plant yield (ton/ha)</th>
<th>S in plant (mg/kg)</th>
<th>S uptake (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT</td>
<td>11.3</td>
<td>821</td>
<td>9.3</td>
</tr>
<tr>
<td>R6</td>
<td>21.4 / 14.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>745 / 434&lt;sup&gt;a&lt;/sup&gt;</td>
<td>22.6</td>
</tr>
</tbody>
</table>

<sup>a</sup> grain/vegetative biomass
### % plant S derived from fertiliser

#### Spring applied

<table>
<thead>
<tr>
<th>Stage</th>
<th>SO₄-S</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT</td>
<td>13.7</td>
<td>&gt; 8.3</td>
</tr>
<tr>
<td>R6</td>
<td>10.6</td>
<td>ns 11.8</td>
</tr>
</tbody>
</table>

#### Fall applied

<table>
<thead>
<tr>
<th>Stage</th>
<th>SO₄-S</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT</td>
<td>5.6</td>
<td>ns 6.4</td>
</tr>
<tr>
<td>R6</td>
<td>4.1</td>
<td>&lt; 10.4</td>
</tr>
</tbody>
</table>

- **Spring applied:**
  - lower uptake from ES than SO₄-S at tasseling
  - similar uptake at maturity
- **Fall applied:**
  - similar uptake at tasseling
  - higher uptake from ES than SO₄-S at maturity
• Spring applied: ca 16% of fertilizer ES and SO$_4$-S recovered in crop at maturity

• Fall applied: recovery similar to spring-applied for ES but 2.5-fold lower for SO$_4$-S
Sulfate leaching

**Spring applied**

<table>
<thead>
<tr>
<th>VT</th>
<th>Mat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SO₄-S (mg/kg)</strong></td>
<td>337</td>
</tr>
<tr>
<td><strong>kg/ha</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Recovery (%)</strong></td>
<td><strong>61 (43-82)</strong></td>
</tr>
<tr>
<td><strong>Precip (cm)</strong></td>
<td>36</td>
</tr>
</tbody>
</table>

**Fall applied**

<table>
<thead>
<tr>
<th>VT</th>
<th>Mat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SO₄-S (mg/kg)</strong></td>
<td>152</td>
</tr>
<tr>
<td><strong>kg/ha</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Recovery (%)</strong></td>
<td><strong>22 (15-25)</strong></td>
</tr>
<tr>
<td><strong>Precip (cm)</strong></td>
<td>91</td>
</tr>
</tbody>
</table>
Leaching can be related to estimated infiltration (water use estimated based on Algoazany et al. JEQ 2007; same watershed)

Leaching in agreement with solute transport predictions (Hydrus-1D)
Sulfate leaching vs S fertilizer recoveries

- ES fully oxidized and no SO$_4$-S leaching
  $\Rightarrow$ circa equal recoveries

- ES fully oxidized and 50% SO$_4$-S leached below root zone
  $\Rightarrow$ ES/SO$_4$-S recovery = 2

- ES 50% oxidized and 50% SO$_4$-S leached below root zone
  $\Rightarrow$ circa equal recoveries
Sulfate leaching vs S fertilizer recoveries

⇒ From the recovery of ES relative to $SO_4$-S and the extent of sulfate leaching, it is estimated that:

- *ca* 30% of ES was oxidized at early stage; and
- *ca* 50% of ES was oxidized at maturity.
Conclusions

• Oxidation of elemental S in one season was estimated to be ca 50%

• Spring application of MESZ (5% SO$_4$-S and 5% ES):
  – About 50% of SO$_4$-S estimated to be leached below the root zone
  – Similar contribution of fertilizer SO$_4$-S and ES

• Fall application of MESZ:
  – About 85% of SO$_4$-S estimated to be leached below the root zone
  – 2.5 times more S in the plant derived from ES than from SO$_4$-S

➢ Benefit of a slow release S source in high-rainfall environments, especially with fall applications
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