A Potpourri of Glyphosate, Micronutrients, and Adjuvants

Mark Bernards
Extension Weed Specialist
Outline

- All the fuss about micronutrients
- What is yellow flash?
- Soybean response to manganese
- Glyphosate application with micronutrients
- Water conditioners and AMS dose
- Comments on glyphosate side-effects
2008
George Rehm
Univ of Minnesota
“This issue is not one we can paint with a broad brush.”

2010
Fabian Fernandez
Univ of Illinois
“We don’t really have a good recommendation system for micronutrients.”
Don Huber’s Arguments

- **Glyphosate:**
  - Changes soil microflora
  - Chelates micronutrients in the soil
  - Inhibits plant enzymes that regulate micronutrient uptake
  - Immobilizes Mn in plant tissues treated with glyphosate

- The glyphosate resistant gene reduces Mn efficiency

- **Micronutrient application will address these effects.**
• Projected need to double food supply by 2050.

• Industry targets to double corn and soybean yield in US from 2000 level.

• Will greater micronutrient use be necessary to reach yield potentials?

Source: U.S. Census Bureau, International Data Base, June 2010 Update.
Yellow flash in soybean

Chlorosis of newly emerging soybean leaves following application of glyphosate

Conditions

- Rapid soybean growth
  - Warm and moist
- Sprayer overlaps
- Areas prone to micronutrient deficiency

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Mechanism of Glyphosate-Resistance

- Identified gene from microbial source with an EPSP synthase enzyme that was insensitive to glyphosate
- Inserted gene encoding insensitive EPSP synthase into soybean
- GMO soybean has two copies of the EPSP synthase gene
  - 1 native (susceptible to glyphosate)
  - 1 introduced (insensitive to glyphosate)
Yellow Flash in Soybean

 важный: glyphosate temporarily chelates manganese and reduces chlorophyll production

**Fact 1:** One application of glyphosate temporarily reduced chlorophyll content in newly emerging soybean leaves compared to untreated control (Abendroth et al. 2005).

**Fact 2:** Chlorosis in soybean was caused by application of AMPA, a glyphosate degradation product (Reddy et al. 2004).
Table 2. Effect of Glyphosate-isopropylammonium (Glyphosate-Ipa) Treatment at 6.72 kg/ha on Glyphosate, Shikimate, and Aminomethylphosphonic Acid (AMPA) Concentration in Treated and New Leaves of Glyphosate-Resistant Soybean over Time

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Time after Treatment, days</th>
<th>Glyphosate, μg/g of tissue</th>
<th>Shikimate, ng/g of tissue</th>
<th>AMPA, μg/g of tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tween 20 only</td>
<td>1</td>
<td>0</td>
<td>139 a</td>
<td>0 e</td>
</tr>
<tr>
<td>glyphosate-IPA</td>
<td>1</td>
<td>527 a</td>
<td>131 a</td>
<td>42 a</td>
</tr>
<tr>
<td>glyphosate-IPA</td>
<td>3</td>
<td>336 b</td>
<td>146 a</td>
<td>19 b</td>
</tr>
<tr>
<td>glyphosate-IPA</td>
<td>5</td>
<td>167 c</td>
<td>135 a</td>
<td>10 c</td>
</tr>
<tr>
<td>glyphosate-IPA</td>
<td>7</td>
<td>149 c</td>
<td>141 a</td>
<td>8 cd</td>
</tr>
<tr>
<td>glyphosate-IPA</td>
<td>14</td>
<td>99 d</td>
<td>167 a</td>
<td>3 de</td>
</tr>
<tr>
<td>glyphosate-IPA</td>
<td>22</td>
<td>37 e</td>
<td>147 a</td>
<td>1 e</td>
</tr>
<tr>
<td>Tween 20 only</td>
<td>22</td>
<td>0</td>
<td>121 a</td>
<td>0 e</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher's protected LSD test. Treated leaves included first pair, and first, second, and third trifoliate leaves. New leaves included fourth trifoliate leaf and above. Tween 20 at 0.5% (v/v) was added to all treatment solutions.

Reddy et al. 2005
### Table 3. Effect of Aminomethylphosphonic Acid (AMPA) Treatment on Chlorophyll Content 4 Days after Treatment and Shoot Fresh Weight 14 Days after Treatment of Glyphosate-Resistant (GR) and Non-GR Soybean

<table>
<thead>
<tr>
<th>AMPA rate, kg/ha</th>
<th>GR soybean</th>
<th>non-GR soybean</th>
<th>GR soybean</th>
<th>non-GR soybean</th>
</tr>
</thead>
<tbody>
<tr>
<td>untreated control</td>
<td>100 a</td>
<td>100 a</td>
<td>100 a</td>
<td>100 a</td>
</tr>
<tr>
<td>Tween 20</td>
<td>86 b</td>
<td>83 ab</td>
<td>98 a</td>
<td>93 ab</td>
</tr>
<tr>
<td>0.12</td>
<td>72 c</td>
<td>84 ab</td>
<td>96 ab</td>
<td>93 ab</td>
</tr>
<tr>
<td>0.25</td>
<td>58 d</td>
<td>82 bc</td>
<td>91 bc</td>
<td>90 bc</td>
</tr>
<tr>
<td>0.50</td>
<td>59 d</td>
<td>66 c</td>
<td>90 cd</td>
<td>91 bc</td>
</tr>
<tr>
<td>1.00</td>
<td>50 de</td>
<td>41 d</td>
<td>88 cd</td>
<td>85 c</td>
</tr>
<tr>
<td>2.00</td>
<td>40 ef</td>
<td>36 d</td>
<td>86 d</td>
<td>84 c</td>
</tr>
<tr>
<td>4.00</td>
<td>40 ef</td>
<td>41 d</td>
<td>74 e</td>
<td>66 d</td>
</tr>
<tr>
<td>8.00</td>
<td>34 f</td>
<td>31 d</td>
<td>61 f</td>
<td>51 e</td>
</tr>
</tbody>
</table>

*Means within a column followed by the same letter are not significantly different at the 5% level as determined by Fisher’s protected LSD test. *a* Tween 20 at 0.5% (v/v) was added to spray solutions in all treatments except untreated control.

Reddy et al. 2005
Mn deficiency in soybean

- Where common?
  - Eastern Soybean Belt
  - High pH and/or high O.M. soils

- Interveinal chlorosis

- Deficiency symptoms often appear near time of postemergence herbicide applications

- Foliar and banded applications of Mn fertilizers are effective at alleviating symptoms
Hypotheses

On Mn-sufficient silt-loam or silty-clay loam soils in NE:

- GR and non-GR soybean varieties will respond similarly to foliar application of Mn
- Application of glyphosate will not affect GR soybean response to Mn
Field studies in 2007 and 2008

South Central Agricultural Laboratory (Clay Center, NE)
- Irrigated
- Hastings silt loam, 2.5% O.M. and pH 6.5
  - Soil Mn, 7.3-11.2 ppm

Lincoln Agronomy Farm (Lincoln, NE)
- Rainfed
- Sharpsburg silty clay loam, 3.1% O.M. and pH 6.7
Variety response

- Mainplot - varieties
  - 4 GR
  - 4 non-GR

- Subplot – Mn
  - 0 lbs Mn
  - 1 lb Mn (0.33 lb Mn/A applied at V4, V8, and R2)

- 4 replications

- Soybeans were planted mid-May

- 150,000 seeds/A

- 30 in row spacing
Glyphosate-resistant gene and yield

Average of 4 GR and 4 non-GR varieties

<table>
<thead>
<tr>
<th>Effect</th>
<th>P value</th>
<th>Site\ Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR gene</td>
<td>&lt;0.05</td>
<td>SCAL 08</td>
</tr>
<tr>
<td>Mn</td>
<td>n.s.</td>
<td>-</td>
</tr>
<tr>
<td>GR x Mn</td>
<td>&lt;0.05</td>
<td>Linc 08</td>
</tr>
</tbody>
</table>

Yield (bu/A)

- **Linc 07**
- **Linc 08**
- **SCAL 07**
- **SCAL 08**

- * indicates significant difference
- † indicates non-significant difference

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## Variety and Mn effect - Yield

<table>
<thead>
<tr>
<th>Effect</th>
<th>P value</th>
<th>Site</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>&lt;0.01</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>&lt;0.05</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Variety x Mn</td>
<td>n.s.</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing yield comparison between Mn and No Mn treatments across different sites and years.](weedscience.unl.edu)
Variety response – SCAL 2007

* p<0.05, within variety response to Mn only 2 times in 4 site years
**Glyphosate application effect on yield**

- 4 varieties
- Glyphosate
  - No glyphosate
  - Glyphosate at 0.75 lb ae/A applied at V6
- Mn
  - No Mn
  - Mn at 0.33 lb/A at V4, V8, and R2

<table>
<thead>
<tr>
<th>Effect</th>
<th>P value</th>
<th>Site Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>&lt;0.01</td>
<td>4</td>
</tr>
<tr>
<td>Mn</td>
<td>&lt;0.01</td>
<td>1</td>
</tr>
<tr>
<td>Glyphosate</td>
<td>&lt;0.05</td>
<td>2</td>
</tr>
<tr>
<td>Variety x Glyphosate</td>
<td>&lt;0.05</td>
<td>3</td>
</tr>
<tr>
<td>Mn x Glyphosate</td>
<td>n.s.</td>
<td>-</td>
</tr>
<tr>
<td>Variety x Mn</td>
<td>&lt;0.01</td>
<td>1</td>
</tr>
<tr>
<td>Var x Mn x Gly</td>
<td>n.s.</td>
<td>-</td>
</tr>
</tbody>
</table>

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Variety x Glyphosate interaction

Lincoln

SCAL

Glyphosate

No glyphosate

2007

2008

N2905R  P93M11R  H2811R  P92M71R

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Mn x Glyphosate interaction

![Graph showing yield comparison across different conditions.](weedscience.unl.edu)
Conclusions from NE study

- No consistent response to Mn fertilizer between glyphosate-resistant and non-glyphosate resistant soybean
- No consistent response to Mn application within varieties
- No consistent response to glyphosate application within varieties
- No interaction between glyphosate and Mn applications
Soybean response to Mn - Indiana

- Differential response between a GR and non-GR soybean on Mn-marginal soil in Indiana (Dodds et al. 2001)
  - Lower tissue Mn in GR soybean

- Chlorosis ratings and tissue Mn concentrations varied among several GR and non-GR soybean varieties (Dodds et al. 2002)

- Mn was not translocated when applied with or shortly after glyphosate (less than 7 days) (Huber et al. 2004)

- Neither IL nor IN reported problems with plants use of Mn after glyphosate appl. (Bernick 2010)
Yield of a GR-soybean increased with Mn application, but yield of non-GR isoleine did not change in Northeast Kansas (Gordon 2007).

Leaf tissue Mn concentration of GR-isoline was 60% less than of non-GR isoleine in absence of Mn application (Gordon 2007)

No difference in response to Mn application between GR and non-GR isolines in 3rd year of study (Gordon 2008)

Yield response to Mn among GR and non-GR varieties was inconsistent at 5 locations and 2 years across Kansas (Nelson 2008)
Soybean response to Mn - Ontario

- No yield benefit with Mn application (tested across several Mn formulations)
- Some Mn treatments resulted in a 10-15% yield reduction
  - Some due to plant injury from micronutrient application
- All but 2 Mn formulations reduced glyphosate activity (Soltani et al. 2011)
Table 1. Chlorophyll level and grain yield as affected by Mn fertilizer applied in glyphosate tank-mixtures to glyphosate-resistant soybean.

<table>
<thead>
<tr>
<th>Mn treatment</th>
<th>Mn rate</th>
<th>SPAD-502 reading</th>
<th>Yield -bu/A-</th>
</tr>
</thead>
<tbody>
<tr>
<td>no Mn</td>
<td>0.0</td>
<td>25.9 b</td>
<td>33 b</td>
</tr>
<tr>
<td>MnSO₄</td>
<td>2.5</td>
<td>37.1 a</td>
<td>57 a</td>
</tr>
<tr>
<td>Untreated</td>
<td>0.0</td>
<td>23.9 b</td>
<td>24 b</td>
</tr>
</tbody>
</table>
Mn antagonism in the field

Common lambsquarters control 28 DAT with glyphosate-AMS-Mn fertilizer tank-mixtures in soybean in 2001 and 2002. Glyphosate was applied at 0.5 lb ae/A.
Tank-mixing Micronutrient Fertilizers and Glyphosate
Glyphosate forms complexes with di- and tri-valent metal cations
Antagonism of herbicide efficacy occurs when adding a product to the spray solution causes a reduction in weed control.

antagonism of herbicide efficacy occurs when adding a product to the spray solution causes a reduction in weed control.

antagonism of herbicide efficacy occurs when adding a product to the spray solution causes a reduction in weed control.
Antagonistic Cations

Cations antagonistic to glyphosate activity:

- $\text{Al}^{3+}$
- $\text{Fe}^{3+}$
- $\text{Ca}^{2+}$
- $\text{Mn}^{2+}$
- $\text{Zn}^{2+}$
- $\text{Mg}^{2+}$
- $\text{Cu}^{2+}$
- $\text{Na}^{+}$
- $\text{K}^{+}$
Glyphosate efficacy and di-/tri-valent cations

- Reduced absorption
- Reduced translocation
- Reduced control
Water conditioners and adjuvants

- Water conditioners
  - ammonium sulfate (AMS)
  - EDTA
  - Citric acid
  - NTANK (NT)
  - N-Tense
  - CLASS ACT Next Generation (CANG)
  - Surfact
  - ReQuest
  - Choice
  - Bronc Max, etc.

- Fertilizer adjuvants
  - EDTA
  - HEDTA
  - Citric acid
  - Lignin sulfonates
  - Flavonols
  - Mannitol
  - iminodisuccinic acid
  - glucoheptonate
Objectives

1. Quantify the antagonism caused by various formulations of B, Cu, Fe, Mn, Zn, and micronutrient mixtures, on glyphosate efficacy.

2. Determine if the water conditioners AMS, CANG, and NT, can prevent antagonism from occurring.
Materials and Methods

- Greenhouse bioassays
  - Velvetleaf (*Abutilon theophrasti*)
  - Giant foxtail (*Setaria faberi*)
- Isopropylamine salt of glyphosate
  - 0.25 lb ae/A
- Single-tip track sprayer
- Spray volume: 10 gal/A
- Spray pressure: 25 psi
- All solutions were prepared in distilled water
Materials and Methods

**Micronutrient formulations (except Boron)**
- sulfate salt
- ammonium citrate salt
- EDTA or HEDTA chelate
- micronutrient charged catalyst flavonol
- lignosulfonic acid chelate (LSA)

**Water conditioner adjuvants**
- 2% AMS (w/w)
- 2.5% CANG (CLASS ACT® Next Generation) (v/v)
- 1.0% NT (NTANK™) (v/v)
Materials and Methods

Micronutrient application rates
- Boron, 0.25 lb/A (Boric acid and sodium borate)
- Copper, 0.45 lb/A
- Iron, 0.4 lb/A
- Manganese, 1.0 lb/A
- Zn, 0.5 lb/A

Micronutrient mixtures
- Chelated by EDTA and citric acid (MC)
- not chelated (MS)
  - in lb/A: N - 0.32, S - 0.16, B - 0.02, Fe - 0.05, Mn - 0.16, Zn - 0.11
# Micronutrient concentration in the tank-mixture

<table>
<thead>
<tr>
<th>Fertilizer rate</th>
<th>Analysis</th>
<th>Micronutrient rate</th>
<th>Spray volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 gal/A</td>
</tr>
<tr>
<td>4 gal/A</td>
<td>5% X</td>
<td>2 lb/A</td>
<td>24,000</td>
</tr>
<tr>
<td>2 gal/A</td>
<td>5% X</td>
<td>1 lb/A</td>
<td>12,000</td>
</tr>
<tr>
<td>1 gal/A</td>
<td>5% X</td>
<td>0.5 lb/A</td>
<td>6,000</td>
</tr>
<tr>
<td>0.5 gal/A</td>
<td>5% X</td>
<td>0.25 lb/A</td>
<td>3,000</td>
</tr>
<tr>
<td>0.25 gal/A</td>
<td>5% X</td>
<td>0.125 lb/A</td>
<td>1,500</td>
</tr>
<tr>
<td>0.25 gal/A</td>
<td>1% X</td>
<td>0.025 lb/A</td>
<td>300</td>
</tr>
</tbody>
</table>

---Nutrient, mg/L---
Boron (0.25 lb/A)

Table 1. Control of giant foxtail with glyphosate (0.25 lb/A) + boron tank-mixtures, 14 DAT.

<table>
<thead>
<tr>
<th>Boron salt</th>
<th>Water conditioner adjuvant in tank-mixture&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Control, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>AMS</td>
</tr>
<tr>
<td>None</td>
<td>100 a</td>
<td>99 a</td>
</tr>
<tr>
<td>Boric acid (HB)</td>
<td>93 a</td>
<td>99 a</td>
</tr>
<tr>
<td>Sodium borate (NaB)</td>
<td>88 a</td>
<td>100 a</td>
</tr>
</tbody>
</table>

<sup>a</sup> Means within a column followed by the same letter are not statistically different, p = 0.05.
Boron (0.25 lb/A)

FIG. 1 - Velvetleaf control, 14 DAT.

‘HB’ - Boric acid
‘NaB’ - Sodium borate
Table 2. *Control of giant foxtail with glyphosate (0.25 lb/A) + copper (Cu) tank-mixtures.*

<table>
<thead>
<tr>
<th>Cu formulation</th>
<th>Water conditioner adjuvant in tank-mixture&lt;sup&gt;a&lt;/sup&gt;</th>
<th>None</th>
<th>AMS</th>
<th>CANG</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>96&lt;sup&gt;a&lt;/sup&gt;</td>
<td>99&lt;sup&gt;a&lt;/sup&gt;</td>
<td>94&lt;sup&gt;a&lt;/sup&gt;</td>
<td>99&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Cu sulfate</td>
<td>56&lt;sup&gt;de&lt;/sup&gt;</td>
<td>67&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>64&lt;sup&gt;b&lt;/sup&gt;</td>
<td>89&lt;sup&gt;abc&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Cu citrate</td>
<td>63&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>68&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>74&lt;sup&gt;b&lt;/sup&gt;</td>
<td>83&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Cu EDTA</td>
<td>66&lt;sup&gt;c&lt;/sup&gt;</td>
<td>74&lt;sup&gt;b&lt;/sup&gt;</td>
<td>92&lt;sup&gt;a&lt;/sup&gt;</td>
<td>87&lt;sup&gt;bc&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Cu flavonol</td>
<td>80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>91&lt;sup&gt;a&lt;/sup&gt;</td>
<td>94&lt;sup&gt;a&lt;/sup&gt;</td>
<td>94&lt;sup&gt;ab&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Cu LSA</td>
<td>46&lt;sup&gt;e&lt;/sup&gt;</td>
<td>61&lt;sup&gt;c&lt;/sup&gt;</td>
<td>64&lt;sup&gt;b&lt;/sup&gt;</td>
<td>94&lt;sup&gt;ab&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Means within a column followed by the same letter are not statistically different, p = 0.05.
Copper (0.45 lb/A)

Cu sulfate: most antagonistic

Cu EDTA: least antagonistic

Tank-mixed with Cu fertilizer:

- glyphosate
- glyphosate + AMS
- glyphosate + 0.5% NT
- glyphosate + 1% NT
- glyphosate + CANG
- fertilize only
- No fertilizer (glyphosate)
Table 3. Control of velvetleaf with glyphosate (0.25 lb/A) + copper (Cu) tank-mixtures.

<table>
<thead>
<tr>
<th>Cu formulation</th>
<th>Water conditioner adjuvant in tank-mixture&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Control, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>AMS</td>
</tr>
<tr>
<td>None</td>
<td>78 a</td>
<td>90 a</td>
</tr>
<tr>
<td>Cu sulfate</td>
<td>19 d</td>
<td>53 c</td>
</tr>
<tr>
<td>Cu citrate</td>
<td>41 c</td>
<td>56 c</td>
</tr>
<tr>
<td>Cu EDTA</td>
<td>57 b</td>
<td>67 b</td>
</tr>
<tr>
<td>Cu flavonol</td>
<td>44 c</td>
<td>64 b</td>
</tr>
<tr>
<td>Cu LSA</td>
<td>41 c</td>
<td>56 c</td>
</tr>
</tbody>
</table>

<sup>a</sup> Means within a column followed by the same letter are not statistically different, p = 0.05.
Table 4. *Control of giant foxtail with glyphosate + Fe tank-mixtures.*

<table>
<thead>
<tr>
<th>Fe formulation</th>
<th>Water conditioner adjuvant in tank-mixture&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
</tr>
<tr>
<td>None</td>
<td>99 a</td>
</tr>
<tr>
<td>Fe sulfate</td>
<td>8 d</td>
</tr>
<tr>
<td>Fe citrate</td>
<td>21 c</td>
</tr>
<tr>
<td>Fe EDTA</td>
<td>68 b</td>
</tr>
<tr>
<td>Fe flavonol</td>
<td>69 b</td>
</tr>
</tbody>
</table>

<sup>a</sup> Means within a column followed by the same letter are not statistically different, p = 0.05.
Iron (0.4 lb/A)

**FIG. 4 - Velvetleaf control, 14 DAT.**

untreated  |  glypho.  |  glypho. + FeSO₄  |  glypho. + FeCl₂  |  glypho. + Fe flavonol  |  glypho. + Fe HEDTA  |  glypho. + Fe citrate

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Iron + glyphosate + AMS.

FIG. 5 – Control of velvetleaf, 14 DAT

Fe sulfate  Fe flavonol  Fe HEDTA  Fe citrate  no Fe

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Table 5. *Control of velvetleaf with glyphosate + Fe tank-mixtures.*

<table>
<thead>
<tr>
<th>Fe formulation</th>
<th>Water conditioner adjuvant in tank-mixture&lt;sup&gt;a&lt;/sup&gt;</th>
<th>None</th>
<th>AMS</th>
<th>CANG</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
<td>40 a</td>
<td>55 a</td>
<td>55 a</td>
<td>69 a</td>
</tr>
<tr>
<td>Fe sulfate</td>
<td>AMS</td>
<td>0 b</td>
<td>3 cd</td>
<td>0 c</td>
<td>4 bc</td>
</tr>
<tr>
<td>Fe citrate</td>
<td>AMS</td>
<td>0 b</td>
<td>0 d</td>
<td>3 c</td>
<td>0 c</td>
</tr>
<tr>
<td>Fe EDTA</td>
<td>AMS</td>
<td>5 b</td>
<td>11 bc</td>
<td>9 c</td>
<td>6 bc</td>
</tr>
<tr>
<td>Fe flavonol</td>
<td>AMS</td>
<td>1 b</td>
<td>19 b</td>
<td>23 b</td>
<td>11 b</td>
</tr>
</tbody>
</table>

<sup>a</sup> Means within a column followed by the same letter are not statistically different, p = 0.05.
**Table 6. Control of giant foxtail with glyphosate (0.28 kg/ha) + manganese (Mn) tank-mixtures.**

<table>
<thead>
<tr>
<th>Mn formulation</th>
<th>Water conditioner adjuvant in tank-mixture&lt;sup&gt;a&lt;/sup&gt;</th>
<th>None</th>
<th>AMS</th>
<th>CANG</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td></td>
<td>98 a</td>
<td>96 a</td>
<td>99 a</td>
<td>99 a</td>
</tr>
<tr>
<td>Mn sulfate</td>
<td></td>
<td>53 d</td>
<td>88 ab</td>
<td>70 c</td>
<td>91 a</td>
</tr>
<tr>
<td>Mn citrate</td>
<td></td>
<td>69 c</td>
<td>81 b</td>
<td>74 bc</td>
<td>95 a</td>
</tr>
<tr>
<td>Mn EDTA</td>
<td></td>
<td>83 b</td>
<td>93 a</td>
<td>82 b</td>
<td>94 a</td>
</tr>
<tr>
<td>Mn flavonol</td>
<td></td>
<td>91 ab</td>
<td>97 a</td>
<td>93 a</td>
<td>97 a</td>
</tr>
<tr>
<td>Mn LSA</td>
<td></td>
<td>44 d</td>
<td>71 c</td>
<td>58 d</td>
<td>74 b</td>
</tr>
</tbody>
</table>

<sup>a</sup> Means within a column followed by the same letter are not statistically different, p = 0.05.
Mn (1 lb/A)

No adjuvant

With NT

glypho. + MnSO₄

glypho. + Mn citrate

glypho. + Mn EDTA

glypho. + Mn LSA

glypho. + Mn flavonol

glypho. untreated

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Table 7. *Control of velvetleaf with glyphosate (0.28 kg/ha) + manganese (Mn) tank-mixtures.*

<table>
<thead>
<tr>
<th>Mn formulation</th>
<th>None</th>
<th>AMS</th>
<th>CANG</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>------</td>
<td>-----</td>
<td>------</td>
<td>----</td>
</tr>
<tr>
<td>None</td>
<td>68 a</td>
<td>79 a</td>
<td>74 a</td>
<td>84 a</td>
</tr>
<tr>
<td>Mn sulfate</td>
<td>9 d</td>
<td>50 bc</td>
<td>22 c</td>
<td>74 ab</td>
</tr>
<tr>
<td>Mn citrate</td>
<td>40 c</td>
<td>70 a</td>
<td>53 b</td>
<td>81 a</td>
</tr>
<tr>
<td>Mn EDTA</td>
<td>64 ab</td>
<td>56 b</td>
<td>62 b</td>
<td>69 bc</td>
</tr>
<tr>
<td>Mn flavonol</td>
<td>57 b</td>
<td>55 b</td>
<td>61 b</td>
<td>61 c</td>
</tr>
<tr>
<td>Mn LSA</td>
<td>10 d</td>
<td>41 c</td>
<td>24 c</td>
<td>67 bc</td>
</tr>
</tbody>
</table>

*a Means within a column followed by the same letter are not statistically different, p = 0.05.*
Table 8. *Control of giant foxtail with glyphosate (0.28 kg/ha) + zinc (Zn) tank-mixtures.*

<table>
<thead>
<tr>
<th>Zn formulation</th>
<th>Water conditioner adjuvant in tank-mixture&lt;sup&gt;a&lt;/sup&gt;</th>
<th>None</th>
<th>AMS</th>
<th>CANG</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Control, %</td>
<td>99 a</td>
<td>97 a</td>
<td>98 a</td>
<td>99 a</td>
</tr>
<tr>
<td>Zn sulfate</td>
<td>38 d</td>
<td>51 d</td>
<td>30 c</td>
<td>84 b</td>
<td></td>
</tr>
<tr>
<td>Zn citrate</td>
<td>53 c</td>
<td>86 ab</td>
<td>66 b</td>
<td>81 b</td>
<td></td>
</tr>
<tr>
<td>Zn EDTA</td>
<td>59 c</td>
<td>69 c</td>
<td>73 b</td>
<td>83 b</td>
<td></td>
</tr>
<tr>
<td>Zn flavonol</td>
<td>81 b</td>
<td>76 bc</td>
<td>88 a</td>
<td>91 ab</td>
<td></td>
</tr>
<tr>
<td>Zn LSA</td>
<td>14 e</td>
<td>46 d</td>
<td>23 c</td>
<td>81 b</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Means within a column followed by the same letter are not statistically different, p = 0.05.
Zinc

glypho. + ZnSO₄

glypho. + Zn citrate

glypho. + Zn EDTA

glypho. + Zn LSA

glypho. + Zn flavonol

glypho.
Zinc (0.5 lb/ A)

Table 9. Control of velvetleaf with glyphosate + Zn tank-mixtures.

<table>
<thead>
<tr>
<th>Zn formulation</th>
<th>None</th>
<th>AMS</th>
<th>CANG</th>
<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>66 a</td>
<td>78 a</td>
<td>70 a</td>
<td>76 a</td>
</tr>
<tr>
<td>Zn sulfate</td>
<td>20 c</td>
<td>40 c</td>
<td>1 d</td>
<td>54 b</td>
</tr>
<tr>
<td>Zn citrate</td>
<td>24 c</td>
<td>59 b</td>
<td>53 b</td>
<td>61 b</td>
</tr>
<tr>
<td>Zn EDTA</td>
<td>47 b</td>
<td>62 b</td>
<td>62 b</td>
<td>57 b</td>
</tr>
<tr>
<td>Zn flavonol</td>
<td>48 b</td>
<td>59 b</td>
<td>54 b</td>
<td>60 b</td>
</tr>
<tr>
<td>Zn LSA</td>
<td>5 d</td>
<td>54 b</td>
<td>13 c</td>
<td>58 b</td>
</tr>
</tbody>
</table>

\(^a\) Means within a column followed by the same letter are not statistically different, \(p = 0.05\).
Giant foxtail control with micronutrient mixtures

Tank-mixture partners with glyphosate:
- None + none
- None + AMS
- None + NT
- MC + none
- MC + AMS
- MC + NT
- MS + none
- MS + AMS
- MS + NT

Rate, lb/A
N – 0.3
S – 0.16
B – 0.02
Fe – 0.05
Mn – 0.16
Zn – 0.11

LSD = 9
Velvetleaf control with micronutrient mixtures

Tank-mixture partners with glyphosate:
- None + none
- None + AMS
- None + NT
- MC + none
- MC + AMS
- MC + NT
- MS + none
- MS + AMS
- MS + NT

LSD = 13

Rate, lb/A
- N - 0.3
- S - 0.16
- B - 0.02
- Fe - 0.05
- Mn - 0.16
- Zn - 0.11

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Summary - Micronutrient formulations

- Most Cu, Fe, Mn, and Zn formulations antagonized glyphosate on giant foxtail and velvetleaf
  - The EDTA, HEDTA, or flavonol formulations were the least antagonistic
  - The sulfate salt or lignosulfonic acid formulations were the most antagonistic
- Tank-mixtures containing NT overcame the antagonism more often than those containing AMS or CANG.
- Boron salts can also antagonize glyphosate efficacy
Antagonistic effect of multiple micronutrients in tank-mixture is at least additive

Increasing the glyphosate rate may overcome antagonism, but may also be cost-prohibitive on some species

Adding AMS or NT increased velvetleaf control for MC and MS tank-mixtures, but neither overcame the antagonism
Tank-mixing glyphosate and micros

**Efficient Solution**
- Nutrient deficiency
- Non-antagonistic fertilizer formulation
- Highest labeled rate of glyphosate
- Effective water conditioner
- Warm and humid

**Potential Problem**
- No nutrient deficiency
- Antagonistic fertilizer formulation
- Reduced glyphosate rate
- No water conditioner
- Large weeds, droughty conditions
More recent work on micronutrients

Penner et al. (2010, NCWSS)
- All micronutrient fertilizers antagonized glyphosate
- Some minor differences in water conditioners – but do not completely overcome the antagonism
Water conditioner variability
AMS Rate Matters

Control, %

AMS, % w/v

- Velvetleaf: $a=61.3$, $b=-3.0$, $x_0=0.40$, $R^2=0.98$
- Sunflower: $a=104.6$, $b=-2.3$, $x_0=0.46$, $R^2=0.99$
- Green foxtail: $a=89.6$, $b=-2.5$, $x_0=0.47$, $R^2=0.95$

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Evaluate commercial “water conditioners” in proposed test method to define water conditioners
Methods and Materials

- Glyphosate (0.28 lb ae/A)
  - ipa salt, 3 lb ae/gallon, 41% w/w, low load
- GPA 10
- Nozzles TT Jet 11001
- Pressure 40 psi
- Water Distilled
  - 1000 ppm hard water
Methods and Materials

Species:
- NE = Vele, wahe, fxtl.
- KS = Vele, ilmg, sorg, bygr, and corn.
- IL = Vele, ilmg, wahe, fxtl.
- MN = Vele, soy, cocb, bygr, and fxtl.
- ND = Flax, amar, tabw, and corn.

- Size at appl: 4 to 24 inches
- Replications: 4
- Evaluated: 14 and 28 DAT
Treatments

- Glyphosate - distilled water (DW)
- Glyphosate - hard water (HW)
- Glyphosate + AMS (DW)
- Glyphosate + AMS (HW)
- Glyphosate + 10 water conditioners at rec. rates (HW)
- All treatments applied:
  (-)
  (+) MON 0818 surfactant @ 0.25% v/v
Water Conditioner adjuvants

- Request = Water conditioner (WC) (0.5% v/v)
- Helfire = Acidic WC (0.5% v/v)
- N-Tense = WC + NIS (0.5% v/v)
- Array = AMS + Deposition + Defoamer (9 lb/100 gal)
- Bronc Max = AMS + WC (0.5% v/v)
- Choice Weather Master = AMS + WC (0.5% v/v)
- Cayuse Plus = AMS + NIS (0.5% v/v)
- Class Act NG = AMS + NIS (2.5% v/v)
- Bronc Plus Dry EDT = AMS + NIS (10 lb/100 gal)
- Flame = AMS + NIS (0.5% v/v)
Adjuvant Identity Protection Program
A material that reduces or eliminates the antagonism between a pesticide and ions in water and results in improved bioefficacy.

**Water conditioner**

Velvetleaf

- Glyt
- + NIS
- + AMS
- + AMS + NIS

Ave of 3 locations, 2010

[Graph showing % control with LSD = 8]
Water conditioner effectiveness

Ave of 3 locations, 2010 % control

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Average of 5 locations, 2010

Glyt + NIS = HW = DW + AMS + NIS

Glyt + NIS + AMS

Glyt + AMS + NIS

Broadleaf

Grass

LSD = 9

LSD = 10

% control

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Broadleaf species, 5 locations, 1000 ppm

Ave of broadleaf species

% control

0 10 20 30 40 50 60 70 80 90 100
Grass species, 5 locations, 1000 ppm

Ave of grass species

% control

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Response to NIS

Ave of broadleaf species

WC 1
WC 2
WC 3
WC 4
WC 5
WC 6
WC 7
WC 8
WC 9
WC 10

% control

ND, 2010

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AMS Rate Matters

AMS, % w/v

Control, %

- Velvetleaf
- Sunflower
- Green foxtail

Equations:
- Velvetleaf: $a=61.3$, $b=-3.0$, $x_0=0.40$, $R^2=0.98$
- Sunflower: $a=104.6$, $b=-2.3$, $x_0=0.46$, $R^2=0.99$
- Green foxtail: $a=89.6$, $b=-2.5$, $x_0=0.47$, $R^2=0.95$

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AMS rate in water conditioners

- **Approximate load**
  - 3.75 lb AMS/gal

- **Typical use rate**
  - 0.5% v/v

- **AMS in tank**
  - \((0.5 \text{ gal/100 gal}) \times (3.75 \text{ lb/gal}) = \)

  - 1.88 lb AMS/100 gal = 0.2% (w/v)
AMS Rate Matters

![Graph showing the effectiveness of AMS on control of various weeds.](weedsceunl.edu)

- **Velvetleaf**
  - Equation: $a=61.3$, $b=-3.0$, $x_0=0.40$, $R^2=0.98$

- **Sunflower**
  - Equation: $a=104.6$, $b=-2.3$, $x_0=0.46$, $R^2=0.99$

- **Green foxtail**
  - Equation: $a=89.6$, $b=-2.5$, $x_0=0.47$, $R^2=0.95$
Observations

- Water conditioner products vary widely in their effectiveness.
- Rates are often too low for extremely hard water scenarios.
  - 1000 ppm
    - Dry rates, minimum 8.5 lb/100 gal
    - Liquid rates, minimum 2.5% v/v
- Rates may be adequate if water quality is good.
Precipitation delayed herbicide applications

http://images.publicradio.org/content/2008/06/18/20080618_flooded_field_33.jpg
Why growth stage restrictions?

1. To not exceed allowable pesticide residues
2. To avoid crop injury
3. To guarantee good weed control
   a. Weeds too large
   b. Canopy too dense

http://hoegys.ca/cms/files/image/1195.jpg

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What is the maximum height for a broadcast application of glyphosate in RR2 corn?
Restrictions differ among glyphosate labels

- Drop nozzles recommended above 24”
- No applications allowed beyond 30” in RR corn
- Drop nozzles required above 30” (V8) in RR2
- No applications allowed beyond 48” in RR2
- Maximum in-crop applications totaled less than 64 fl oz K-salt or 96 fl oz IPA-salt
Glyphosate use in soybean

- Emergence through flowering (R2) stage
- Maximum weed height of 8 inches with a 22 fl oz/A application rate
- Maximum single use rate in crop:
  - 44 fl oz/A
- Maximum season-long in-crop use:
  - 64 fl oz/A
Drop nozzle spacing matters!

30” centers

20” centers

Ear leaf

V12 corn

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Where does the pesticide go?

- Translocated herbicides
  - Moves to the sink
    - Ear
    - Tassel
- Contact herbicide
  - Most stays in treated leaf
Arrested ears - NIS

Top: Normal ear
Bottom: Arrested ear
Irregular rows - glyphosate

http://www.kingcorn.org/news/articles.08/ArrestedEars-1209.html

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% abnormal ears caused by late appl.

http://www.kingcorn.org/news/articles.08/ArrestedEars-1209.html

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% Kernel number as affected by late application

http://www.kingcorn.org/news/articles.08/ArrestedEars-1209.html

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Late herbicide application – glyphosate + Cadet
Late herbicide application - Ignite
Glyphosate effects on corn pollen

Glyphosate applications at V8 or later reduced pollen viability 40%

Glyphosate applied at V10

At what corn growth stage do newly emerging weeds no longer reduce yield:

1. V2
2. V5
3. V8
4. V11
5. Tasseling
When do newly emerging weeds no longer reduce yield in corn?

- It depends!
  - Weed species
    - Sunflower vs. foxtail
  - Density
    - High vs low
  - Fertility
  - Moisture

- Range of growth stages from research
  - Earliest: V2
  - Latest: R1 – Silking
  - Average: V10
Summary

- Yellow flash is temporary toxicity caused by glyphosate degradation product.
- Mn applied to soybean should be targeted to locations with measurable deficiency.
- Tank-mixing glyphosate and micronutrients compromises glyphosate activity.
- AMS products vary, but most important factor is AMS rate in tank.
- Late applications of glyphosate can impact corn ear development.
Questions?

Thank you!