Glyphosate Effects on Diseases of Plants

Symposium: Mineral Nutrition and Disease Problems in Modern Agriculture: Threats to Sustainability

N-(phosphonomethyl)glycine

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Glyphosate Effects on Diseases of Plants

- **Background - review**
  - Interacting factors for disease
  - Some cultural factors affecting nutrition and disease

- **Glyphosate**
  - Characteristics
  - Glyphosate resistance
  - Reported effects of glyphosate

- **Effect of glyphosate on disease**
  - Take-all root and crown rot of cereals
  - Corynespora root rot
  - Marasmius root rot of sugarcane
  - Fusarium head scab of cereals
  - Citrus variegated chlorosis (CVC)
  - Rust diseases
  - Rice blast

- **Mechanisms to reduce disease**

- **Conclusions**
INTERACTING FACTORS DETERMINING DISEASE SEVERITY

PLANT
- Nutrients
- Moisture
- Temperature
- pH (redox potential)
- Density, gases

PATHOGEN
- Population
- Virulence
- Activity

BIOTIC ENVIRONMENT
- Antagonists, Synergists
- Oxidizers, Reducers
- Competitors, Mineralizers
  - [Fe, Mn, N, S]

ABIOTIC ENVIRONMENT
- Nutrients
- Moisture
- Temperature
- pH (redox potential)
- Density, gases

TIME

Vigor, Stage of Growth, Root Exudates
- Resistance
- Susceptibility

Antagonists, Synergists
- Oxidizers, Reducers
- Competitors, Mineralizers
  - [Fe, Mn, N, S]
Changes in Agricultural Practices Change the Interactions

**Crop Sequence**
- Biotic environment
- Nutrition
- Nitrification
- Organic matter

**Tillage/No-till**
- Residue break down
- Soil density/aeration
- Pathogen survival
- Nutrient distribution
- Denitrification

**Fertilization**
- Rate/form
- Time applied
- Source/assoc. ions
- Inorganic
- Organic

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**Effect of crop residue on nitrification**

<table>
<thead>
<tr>
<th>% NO₃</th>
<th>Alfalfa</th>
<th>Soya</th>
<th>Pea</th>
<th>Corn</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>4</td>
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</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>100</td>
<td>0</td>
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<td>0</td>
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</tbody>
</table>

**Crop sequence effect on Mn⁺²**

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Extractable Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Corn</td>
<td>130 ppm</td>
</tr>
<tr>
<td>Continuous soybeans</td>
<td>64 ppm</td>
</tr>
<tr>
<td>Soybean, wheat, corn</td>
<td>91 ppm</td>
</tr>
<tr>
<td>Wheat, corn, soybean</td>
<td>79 ppm</td>
</tr>
<tr>
<td>Fall chissel, soybean</td>
<td>126 ppm</td>
</tr>
<tr>
<td>No-till</td>
<td>80 ppm</td>
</tr>
</tbody>
</table>

**Metabolism of different forms of nitrogen**

- Deficient
- Sufficient
- Excess

**Diagram: Rhizosphere**

- PHOTOSYNTHESIS
- Amino Acids
- Acid
- Alkaline
- NO₃
- Rhizosphere

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**Legend:**
- CHO
- NH₄
- Amino Acids
- Acid
- Alkaline
- NO₃
Factors Affecting N Form, Mn Availability and Severity of Some Diseases*

<table>
<thead>
<tr>
<th>Soil Factor or Cultural Practice</th>
<th>Nitrification</th>
<th>Effect on:</th>
<th>Effect on:</th>
<th>Effect on:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mn Availability</td>
<td>Disease Severity</td>
<td></td>
</tr>
<tr>
<td>Low Soil pH</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
<td></td>
</tr>
<tr>
<td>Green Manures(some)</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
<td></td>
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<tr>
<td>Ammonium Fertilizers</td>
<td>Decrease</td>
<td>Increase</td>
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<td></td>
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<td>Irrigation (some)</td>
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<td>Firm Seed bed</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
<td></td>
</tr>
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<td>Nitrification Inhibitors</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
<td></td>
</tr>
<tr>
<td>Soil Fumigation</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
<td></td>
</tr>
<tr>
<td>Metal Sulfides</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
<td></td>
</tr>
<tr>
<td>High Soil pH</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
</tr>
<tr>
<td>Lime</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
</tr>
<tr>
<td>Nitrate Fertilizers</td>
<td>----</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
</tr>
<tr>
<td>Manure</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
</tr>
<tr>
<td>Low Soil Moisture</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
</tr>
<tr>
<td>Loose Seed bed</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
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*Potato scab, Rice blast, Take-all, Phymatotrichum root rot, Corn stalk rot
Glyphosate Started Changing Agriculture 30+ Years Ago

The most widely used agricultural chemical!

- Broad-spectrum (non-selective) weed control
  - Paraquat, Tordon, Spike, salt
- Short “direct” residual activity
- Low direct mammalian toxicity
- Economical use
- TRANSGENIC PROTECTION - selectivity

A very strong metal chelator with potential interaction with all life through mineral deprivation

“All flesh is grass”
Isaiah 40:6, 800 BC
Some Characteristics of Glyphosate

- A chemical chelator
  - Small amount needed
  - Tightly bind mineral elements
  - Immobilizes Mn, Fe

- Non-specific herbicidal effect

- Tank mix impairs herbicidal activity

Chelating stability constants of glyphosate

<table>
<thead>
<tr>
<th>Metal ion</th>
<th>[ML]</th>
<th>[M][L]</th>
<th>[M][H][L]</th>
<th>[M][L2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg2+</td>
<td>3.31</td>
<td>12.12</td>
<td>5.47</td>
<td></td>
</tr>
<tr>
<td>Ca2+</td>
<td>3.25</td>
<td>11.48</td>
<td>5.87</td>
<td></td>
</tr>
<tr>
<td>Mn2+</td>
<td>5.47</td>
<td>12.30</td>
<td>7.80</td>
<td></td>
</tr>
<tr>
<td>Fe2+</td>
<td>6.87</td>
<td>12.79</td>
<td>11.18</td>
<td></td>
</tr>
<tr>
<td>Cu2+</td>
<td>11.93</td>
<td>15.85</td>
<td>16.02</td>
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<tr>
<td>Fe3+</td>
<td>16.09</td>
<td>17.63</td>
<td>23.00</td>
<td></td>
</tr>
</tbody>
</table>

Glyphosate + Zn tank mix
Some Chemical Chelators in Agriculture

- **Mn, Fe chelating compounds**
  - Piricularin, alpha-picolinic acid - rice blast toxin
  - Glyphosate - non-specific herbicide
  - Reducing activity - photosynthesis

- **Cu chelating compounds**
  - Nitrapyrin, methyl pyrazole - inhibit nitrification
  - Tordon herbicide - specific to broad-leaved plants
  - Oxidizing activity - (lacases, oxidases)

- **Various plant root exudates**
  - Induced with nutrient deficiency
Source of Chelators

- **Natural metabolites**
  - Plant root exudates - organic acids, siderophores
  - Microbial metabolites - organic acids, toxins
  - Soil organic matter

- **Synthetic compounds**
  - Herbicides - glyphosate, Tordon
  - Nitrification inhibitors - nitrapyrin
  - EDTA, DTPA, citric acid, amino acids

- **Important because micronutrients are the**:
  - Activators
  - Inhibitors
  - Regulators of plant physiological functions
Characteristic Effects of Glyphosate

- **Systemic in plants**
  - A modified essential amino acid
  - Concentrates in meristematic tissues
    - Shoot and root tips
    - Reproductive structures

- **Distributed throughout the rhizosphere in root exudates**

- **Non-specific herbicidal effect**

- **Toxic to some soil microbes; stimulates others**
  - Changes nutrient availability
  - Changes virulence of some pathogens
Some Microbial Interactions with Glyphosate

- Changes the soil microbial “balance”
- Toxic to beneficial organisms:
  - Rhizobium, Bradyrhizobium
    - Inhibits N-fixation
  - Mn reducing organisms (Biocontrol)
    - *Trichoderma* spp, *Bacillus* spp
  - Mychorrhizae
    - *Glomus mossea* - Zn, P uptake
- Stimulates:
  - Mn oxidizing organisms
  - *Fusarium*, other fungi
    - K sink immobilization
- Increases pathogens:

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**Manganese Availability**

pH 5.2 to pH 7.8

Rhizosphere biology

- Root nodules reduced with glyphosate
- Fungal Mn oxidation in soil
- Mn oxidizers from soil
Roundup Ready® Gene

Confers “tolerance” to glyphosate
Alternate metabolic pathway introduced
Slows down some physiologic processes
Provided selective herbicidal activity
There are several “modifiers” possible

Changes physiology of the plant (N metabolism)

Incomplete “protection” of meristematic and reproductive tissues - depends on:
Time of application
Method of application
Crop species

Often causes a “Yield Drag”
## “Glyphosate” Gene Effect on Mn Uptake

### Mn Efficiency of Isogenic soybeans - after Gordon, 2007

<table>
<thead>
<tr>
<th>Isoline:</th>
<th>KS4202</th>
<th>KS4202 RR</th>
<th>Difference*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield</td>
<td>Tissue Mn</td>
<td>Yield</td>
</tr>
<tr>
<td></td>
<td>(bu/a)</td>
<td>(ppm)</td>
<td>(bu/a)</td>
</tr>
<tr>
<td>Mn applied (lb./a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>76.9</td>
<td>75</td>
<td>64.9</td>
</tr>
<tr>
<td>2.5</td>
<td>76.1</td>
<td>80</td>
<td>72.8</td>
</tr>
<tr>
<td>5.0</td>
<td>74.9</td>
<td>92</td>
<td>77.6</td>
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<tr>
<td>7.5</td>
<td>72.6</td>
<td>105</td>
<td>77.6</td>
</tr>
</tbody>
</table>

* Difference compared with 0 Mn of normal
Residual Chelation Effect of Glyphosate on Mn

<table>
<thead>
<tr>
<th>Time Mn Applied Relative to Glyphosate (UltraMax®)</th>
<th>PPM Mn in tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>- 4 days</td>
<td>40</td>
</tr>
<tr>
<td>Same time</td>
<td>30</td>
</tr>
<tr>
<td>+ 4 days</td>
<td>25</td>
</tr>
<tr>
<td>+9 days</td>
<td>20</td>
</tr>
</tbody>
</table>

Mn "sufficient" soil

PPM Mn in tissue range:
- None: 0
- 4 days: 40
- Same time: 30
- + 4 days: 25
- +9 days: 20

Low Mn soil
REPORTED EFFECTS OF GLYPHOSATE

• Reduced Mn & Fe uptake*
  Root & foliage
  [K reduced also]

• Immobilization of Mn*
  Translocation
  Reduced physiological efficiency

• Reduced root nodulation & N-fixation*

• Soil Microflora changes - Root exudates
  Stimulatory to *Fusaria*, oxidizers, etc.
  Toxic to manganese reducers and *Rhizobium*

• Increased drought stress*

• Earlier maturity*

• Interaction with some diseases*

*Can be modified by Mn or other micronutrient application
Some Diseases Increased by Glyphosate

<table>
<thead>
<tr>
<th>Host plant</th>
<th>Disease</th>
<th>Pathogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>Canker</td>
<td><em>Botryosphaeria dothidea</em></td>
</tr>
<tr>
<td>Banana</td>
<td>Panama</td>
<td><em>Fusarium oxysporum f.sp. cubense</em></td>
</tr>
<tr>
<td>Barley</td>
<td>Root rot</td>
<td><em>Magnaporthe grisea</em></td>
</tr>
<tr>
<td>Beans</td>
<td>Root rot</td>
<td><em>Fusarium solani f.sp. phaseoli</em></td>
</tr>
<tr>
<td>Bean</td>
<td>Damping off</td>
<td><em>Pythium</em></td>
</tr>
<tr>
<td>Bean</td>
<td>Root rot</td>
<td><em>Thielaviopsis bassicola</em></td>
</tr>
<tr>
<td>Canola</td>
<td>Crown rot</td>
<td><em>Fusarium</em></td>
</tr>
<tr>
<td>Canola</td>
<td>Wilt (New)</td>
<td><em>Fusarium oxysporum, F. avenaceum</em></td>
</tr>
<tr>
<td>Citrus</td>
<td>CVC</td>
<td><em>Xylella fastidiosa</em></td>
</tr>
<tr>
<td>Cotton</td>
<td>Damping off</td>
<td><em>Pythium</em></td>
</tr>
<tr>
<td>Cotton</td>
<td>Bunchy top</td>
<td>Manganese deficiency</td>
</tr>
<tr>
<td>Cotton</td>
<td>Wilt</td>
<td><em>F. oxysporum f.sp. vasinfectum</em></td>
</tr>
<tr>
<td>Grape</td>
<td>Black goo</td>
<td><em>Phaeomoniella chlamydiospora</em></td>
</tr>
<tr>
<td>Melon</td>
<td>Root rot</td>
<td><em>Monosporascus cannonbalus</em></td>
</tr>
<tr>
<td>Soybeans</td>
<td>Root rot</td>
<td><em>Corynespora cassicola</em></td>
</tr>
<tr>
<td>Soybeans</td>
<td>Target spot</td>
<td><em>Corynespora cassicola</em></td>
</tr>
<tr>
<td>Soybeans</td>
<td>SDS</td>
<td><em>Fusarium solani f.sp. glycines</em></td>
</tr>
<tr>
<td>Sugarcane</td>
<td>Decline</td>
<td><em>Marasmius</em></td>
</tr>
<tr>
<td>Tomato</td>
<td>Wilt (New)</td>
<td><em>Fusarium oxysporum f.sp. pisi</em></td>
</tr>
<tr>
<td>Various</td>
<td>Canker</td>
<td><em>Phytophthora</em></td>
</tr>
<tr>
<td>Weeds</td>
<td>Biocontrol</td>
<td><em>Myrothecium verucaria</em></td>
</tr>
<tr>
<td>Wheat</td>
<td>Bare patch</td>
<td><em>Rhizoctonia solani</em></td>
</tr>
<tr>
<td>Wheat</td>
<td>Glume blotch</td>
<td><em>Septoria</em></td>
</tr>
<tr>
<td>Wheat</td>
<td>Root rot</td>
<td><em>Fusarium</em></td>
</tr>
<tr>
<td>Wheat</td>
<td>Head scab</td>
<td><em>Fusarium graminearum</em></td>
</tr>
<tr>
<td>Wheat</td>
<td>Take-all</td>
<td><em>Gaeumannomyces graminis</em></td>
</tr>
</tbody>
</table>
## Some Diseases Reduced by Glyphosate

<table>
<thead>
<tr>
<th>Host plant</th>
<th>Disease</th>
<th>Pathogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean</td>
<td>Rust</td>
<td><em>Phycopsora pakyrhiza</em></td>
</tr>
<tr>
<td>Wheat</td>
<td>Rust</td>
<td><em>Puccinia graminis</em></td>
</tr>
</tbody>
</table>
# Plant Pathogens Affected by Glyphosate

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Pathogen</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Increase:</strong></td>
<td><strong>Decrease (obligate pathogens):</strong></td>
</tr>
<tr>
<td>Botryospheara dothidea</td>
<td>Monosporascus cannonbalus</td>
</tr>
<tr>
<td>Corynespora cassicola</td>
<td>Myrothecium verucaria</td>
</tr>
<tr>
<td>Fusarium avenaceum</td>
<td>Phaeomoniella chlamydospora</td>
</tr>
<tr>
<td>F. graminearum</td>
<td>Phytophthora spp.</td>
</tr>
<tr>
<td>F. oxysporum f. sp. cubense</td>
<td>Pythium spp.</td>
</tr>
<tr>
<td>F. oxysporum f.sp (canola)</td>
<td>Rhizoctonia solani</td>
</tr>
<tr>
<td>F. oxysporum f.sp. glycines</td>
<td>Septoria nodorum</td>
</tr>
<tr>
<td>F. oxysporum f.sp. vasinfectum</td>
<td>Thielaviopsis bassicola</td>
</tr>
<tr>
<td>F. solani f.sp. glycines</td>
<td>Xylella fastidiosa</td>
</tr>
<tr>
<td>F. solani f.sp. phaseoli</td>
<td></td>
</tr>
<tr>
<td>F. solani f.sp. Pisi</td>
<td></td>
</tr>
<tr>
<td>Gaeumannomyces graminis</td>
<td></td>
</tr>
<tr>
<td>Magnaporthe grisea</td>
<td></td>
</tr>
<tr>
<td>Marasmius spp.</td>
<td></td>
</tr>
</tbody>
</table>

**Abiotic increase:** Mn deficiency diseases
**Physiologic Roles of Manganese**

Photosynthesis
- Glycolysis (energy reactions)
- Carbohydrate, hormone & Amino Acid Synthesis
- Phenylalanine ammonia-lyase

Shikimic Acid
- Mn

Amino Acids
- Mn

COUMARINS
- Mn

LIGNINS
- Mn

FLAVANOIDS = Defense materials

Root Growth

Cyanoglycosides

“Lignituber” formed in response to cell penetration.
- Wheat Triticale

(After Skou, 1975)
Take-all of Cereals

- the Pathogen

- *Gaeumannomyces graminis var tritici*
- Common soilborne fungus - endemic world-wide
  - 600 “world” isolates were almost identical in peptidase profiles
  - Can distinguish *Gaeumannomyces graminis var tritici* from *G. graminis var graminis*
- Virulence associated with manganese oxidation
- Very high tolerance for Mn

<table>
<thead>
<tr>
<th>Temperature</th>
<th>15°C</th>
<th>25°C</th>
</tr>
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<tbody>
<tr>
<td>Isolate X</td>
<td>A</td>
<td>+</td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>+</td>
</tr>
<tr>
<td>B</td>
<td>C</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
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</tbody>
</table>

VIRULENCE AND MANGANESE OXIDATION

Mn oxidation: Virulent to Avirulent
No oxidation: 25°C to 15°C
The Pathogen

*Gaeumannomyces graminis*

A. Ectotrophic growth on root
   “Runner” hyphae on wheat root

B. Extracellular oxidation of Mn

C. Dispersive X-ray microanalysis
   of ectotrophic mycelium on root

Ectotrophic growth of Ggt on wheat root
Hyphal networks in soil

**Gaeumannomyces** oxidizes Mn in Soil, rhizosphere, and root tissue

**XANES - MnO₂** distribution

More intense with high soil moisture

**MnO₂** in wheat root hair cell

Severe take-all spots in wheat

Severe Mn deficiency in double-crop Spybeans after severe take-all
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<td>Decrease</td>
<td>Decrease</td>
</tr>
<tr>
<td>Soil Fumigation</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
<td>Decrease</td>
</tr>
<tr>
<td>Metal Sulfides</td>
<td>Decrease</td>
<td>Increase</td>
<td>Decrease</td>
<td>Decrease</td>
</tr>
<tr>
<td>High Soil pH</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
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<tr>
<td>Lime</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
</tr>
<tr>
<td>Nitrate Fertilizers</td>
<td>----</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
</tr>
<tr>
<td>Manure</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
</tr>
<tr>
<td>Low Soil Moisture</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
</tr>
<tr>
<td>Loose Seed bed</td>
<td>Increase</td>
<td>Decrease</td>
<td>Increase</td>
<td></td>
</tr>
</tbody>
</table>

*Potato scab, Rice blast, Take-all, Phymatotrichum root rot, Corn stalk rot*
Effect of N form & inhibiting nitrification on take-all and rhizosphere Mn oxidizers

A. N form on Take-all
B. Manganese oxidizers
C. -/+ Nitrification inhibitor
## Effect of Cultural Practices on Tissue Mn and Take-all

<table>
<thead>
<tr>
<th>Cultural Condition</th>
<th>Mn*</th>
<th>TA index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose Seedbed</td>
<td>11.2</td>
<td>3.0</td>
</tr>
<tr>
<td>Firm Seedbed</td>
<td>19.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Nitrification (normal)</td>
<td>8.9</td>
<td>3.2</td>
</tr>
<tr>
<td>Inhibiting Nitrification</td>
<td>17.2</td>
<td>2.0</td>
</tr>
<tr>
<td>Wheat-wheat-wheat</td>
<td>20.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Wheat-oats-wheat</td>
<td>55.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Oats-oats-wheat</td>
<td>76.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

*Wheat tissue Mn, PPM; Take-all index = 1-5 (severe

No press wheel | Press wheel
Take-all and Populations of Mn-oxidizing Rhizosphere Bacteria

Cattle dung (manure)
Impact of Glyphosate on Take-all

Take-all of wheat after glyphosate to RR beans

After glyphosate | No glyphosate

Transient Mn immobilization in tissue with glyphosate

Soybean herbicide plots

Wheat after soybeans

After glyphosate | No glyphosate
Corynespora Root Rot of Soybeans

- Caused by *Corynespora cassiicola*
- Dark brown to black rotted small lateral roots & hypocotyl
- Generally considered “root nibbler” - limited economics
- Can be severe & also as a foliage pathogen (target spot)
Predisposing Effect of Glyphosate on Corynespora Root Rot of Soybean

Control           Inoculated           Inoculated + foliar glyphosate
Effect of Glyphosate from Root Exudates

- Stunted soybean plants adjacent to glyphosate-killed giant ragweed plants
- Very severe Corynespora root rot
- Dead ragweed is not a host for Corynespora

Dead ragweed plant   Surviving ragweed plant

4-6”   18” away
Citrus Variegated Chlorosis
Predisposition to CVC (Xylella fastidiosa) by glyphosate

After T. Yamada

Typical glyphosate weed control

CVC with the glyphosate program

Alternative mulch program of T. Yamada

Tissue nutrients

Mn: 12.3
Zn: 13.3
49.0 mg kg\(^{-1}\) DW
57.3 mg kg\(^{-1}\) DW
Fusarium Head Scab and Root Rot

- Caused by *Fusarium graminearum* & other *F. spp.*
  - Soilborne fungi
  - Stimulated by glyphosate

- Disease “requires” three “cardinal” conditions
  - Flowering (center of head outwards)
  - Moisture
  - Temperature > 26 C

- Temperature changes C:N ratio (physiology)

- Glyphosate induces similar changes (Mn, Fe, etc.)

- New “Cardinal” conditions:
  - Flowering
  - Moisture
  - Previously applied glyphosate

These changes also affect rust for “resistance”
Predisposition of Bean to Root Rot

- Non-nodulating isolines of beans are more resistant to root rot
- Glyphosate reduces nodulation and increases root rot
- Glyphosate increases manganese deficiency
Rice blast, caused by *Pyricularia grisea* (Magnaporthe grisea)

Only oxidized Mn in lesion area
Magnaporthe grisea is a strong Mn oxidizer

A. Mycelium on leaf surface
B. Micro XANES of MnO$_2$ in A
C. Blast lesion on leaf
D. XANES of MnO$_2$ in lesion
E. Lesion produced by toxin
Glyphosate is Reported to Control Rust Diseases

- Increases resistance
  - Specific N nutrients withheld
    - Glycine, phenylalanine, etc.
  - Amino acid inhibitors increased

- Provides a 20-25 day effect

- Blocks specific peptidase activity

- May account for the more limited damage from soybean rust than anticipated in the U. S.
Mechanisms by which Nutrients Reduce Disease

- Increased Plant Resistance
  - Physiology - phytoalexin, CHO, phenolic production
  - Defense- callus, lignituber, cicatrix formation

- Disease Escape, Increased Plant Tolerance
  - Increased growth - roots, leaves
  - Shortened Susceptible stage
  - Compensation for disease damage

- Modifying the environment
  - pH, other nutrients
  - Rhizosphere interactions, nitrification, biological balance

- Inhibited Pathogen Activity
  - Reduced virulence
  - Direct effect on survival and multiplication
  - Biological control
Strategies to Reduce Mn Immobilization

- **Amendment**
  - Micronutrient
    - Timing/formulation
  - Biological amendment: *Bacillus, Trichoderma*

- **Detoxification**
  - Calcium chelation - gypsum
  - Manganese

- **Cultural practices**
  - Increase Mn availability
    - Ammonium sources of N
    - Inhibit nitrification
    - Crop sequence - after corn
  - Alternative weed control
    - Mulch
    - Reduce usage - chemistry
    - Reduce rates

<table>
<thead>
<tr>
<th>Time Mn applied relative to glyphosate (UltraMax®)</th>
<th>PPM tissue Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 4 days</td>
<td>20</td>
</tr>
<tr>
<td>Same time</td>
<td>22</td>
</tr>
<tr>
<td>+ 4 days</td>
<td>24</td>
</tr>
<tr>
<td>+ 9 days</td>
<td>30</td>
</tr>
</tbody>
</table>
## Interaction of Micronutrients with Glyphosate*

<table>
<thead>
<tr>
<th>Micronutrient</th>
<th>Rate</th>
<th>Yield</th>
<th>% Weed control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated control</td>
<td>None</td>
<td>46 a</td>
<td>0 a</td>
</tr>
<tr>
<td>Glyphosate** control</td>
<td>24 oz/a</td>
<td>57 b</td>
<td>100 e</td>
</tr>
<tr>
<td>Gly+MnCO₃</td>
<td>0.5 #Mn/a</td>
<td>75 d</td>
<td>91 de</td>
</tr>
<tr>
<td>Gly+MnSO₄</td>
<td>0.5 #Mn/a</td>
<td>70 cd</td>
<td>93 e</td>
</tr>
<tr>
<td>Gly+MnEDTA</td>
<td>0.25 #Mn/a</td>
<td>72 cd</td>
<td>100 e</td>
</tr>
<tr>
<td>Gly+Mn-AA</td>
<td>0.25 #Mn/a</td>
<td>67 c</td>
<td>85 d</td>
</tr>
<tr>
<td>Gly+ZnO</td>
<td>0.5 #Zn/a</td>
<td>49 ab</td>
<td>33 c</td>
</tr>
<tr>
<td>Gly+ZnChelate</td>
<td>0.25 #Zn/a</td>
<td>40 a</td>
<td>40 c</td>
</tr>
<tr>
<td>Gly+Zn+P</td>
<td>0.5 #Zn/a</td>
<td>41 a</td>
<td>20 b</td>
</tr>
</tbody>
</table>

* Glyphosate WeatherMax® formulation at 24 oz/a + AMS
Biological Amendments to Increase Mn

Microbes: *Bacillus (cereus)*, *Trichoderma (konigii)*

Concerns (other than Mn activity):
- Tolerance of glyphosate
- Timing
- Method of application
- Formulation
- Safety

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Corn yield (bu/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rainfed</td>
</tr>
<tr>
<td>None</td>
<td>176a</td>
</tr>
<tr>
<td>Bio # 1</td>
<td>181ab</td>
</tr>
<tr>
<td>Bio # 2</td>
<td>185b</td>
</tr>
</tbody>
</table>
Detoxifying Glyphosate

- In meristematic/reproductive tissues
  - Mn, Si+Mn, Mn+Cu foliar fertilization

- In root exudates in soil

- Approach:
  - Broadcast:
    - Lime
    - Gypsum
    - Phosphorus
  - In furrow treatment:
    - Gypsum (CaSO4)
    - Lime
    - Manganese
    - Ca + Mn

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rainfed</th>
<th>Irrigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>32a</td>
<td>29a</td>
</tr>
<tr>
<td>Gypsum</td>
<td>38b</td>
<td>36b</td>
</tr>
</tbody>
</table>
Modify Cultural Practices to Affect Mn Availability

✓ Crop sequence
✓ Firm seedbed
✓ Grass mulch
✓ Lower pH
✓ Moisture management
✓ Ammonium N - inhibiting nitrification

Residual effect of NH₃ for corn on Mn availability for soybean*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Tissue Mn</th>
<th>Bean Yld (bu/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>12.1</td>
<td>22</td>
</tr>
<tr>
<td>NH₃ only</td>
<td>14.3</td>
<td>26</td>
</tr>
<tr>
<td>NH₃+Mn</td>
<td>---</td>
<td>39</td>
</tr>
<tr>
<td>NH₃+NI</td>
<td>30.1</td>
<td>44</td>
</tr>
<tr>
<td>NH₃+NI+Mn</td>
<td>---</td>
<td>44</td>
</tr>
</tbody>
</table>

*NH₃ on 15” centers

NH₃ + N-serve (30” centers) Control
GLYPHOSATE: A simple Compound with Profound Effects on Nutrients & Disease

Vigor, Stage of Growth, Root Exudates
Health
Resistance

Nutrient efficiency
Susceptibility

Pathogen
Quantity
Activity
Virulence

ABBIOTIC ENVIRONMENT
Moisture
Temperature
pH (redox potential)
Density, gases
Nutrients
Organic matter (sinks)

RHIZOSPHERE ENVIRONMENT
Oxidizers, Reducers, Antagonists
Competitors, Mineralizers, Synergists

Interacting Factors Influencing
Summary of Glyphosate Effects

• Physiology of the plant
  - Nutrient composition
    - Inorganic micronutrients
    - Organic - N compounds (amino acids, etc.)
  - Nutrient efficiency
  - Defense compounds

• Environment
  - Nutrient availability, form, uptake
  - Rhizosphere microbial activity and balance

• Pathogen
  - Virulence, biological synergy
Conclusions & Recommendations

1. The glyphosate-resistance gene selectively reduces Mn uptake. 
   Select cultivars with highest Mn efficiency.

2. Application of glyphosate reduces Mn translocation in tissues.
   Apply micronutrients 8+ days after glyphosate.

   Select formulations that are compatible for uptake.

4. Changes in rhizosphere biology are accumulative.
   Use cultural practices that minimize glyphosate impact.
   Use a non-systemic herbicide.

5. Glyphosate reduces root growth.
   Detoxify glyphosate in roots and rhizosphere.

6. Severity of some diseases increase with glyphosate.
   Use alternate weed control - Minimize glyphosate use.