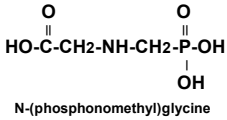
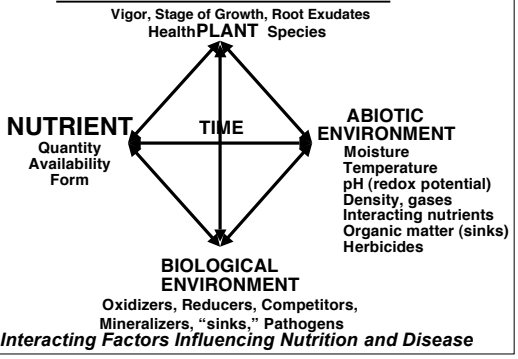
Glyphosate Resistance and Nutrient Management



N-(phosphonomethyl)glycine

D. M. Huber, Emeritus Professor
Botany & Plant Pathology Department
Purdue University, West Lafayette, IN 47907

GLYPHOSATE: A Simple Compound with Profound Effects on Nutrients & Disease



Interacting Factors Influencing Nutrition and Disease

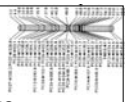
Some Characteristics of Glyphosate

- **A chemical chelator**
  - Small amount needed
  - Tightly bind mineral elements
    - Immobilize or increase solubility
    - Cu=inhibit nitrification, herbicides
    - Mn=herbicides, toxins, virulence
- **Systemic in plants**
  - A modified essential amino acid
  - Concentrates in meristematic tissues
    - Shoot and root tips
    - Reproductive structures
  - Released into rhizosphere in root exudates
- **Toxic to many soil microbes**
  - Reducing organisms (N-fixing, Mn-reducing, others)
  - [Stimulates Mn-oxidizers, Fusaria, Rhizoctonia, others]
- **Non-specific herbicidal effect**

Chelating stability constants of glyphosate

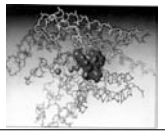
	[ML]	[MHL]	[ML2]
Metal ion	[M][L]	[M][H][L]	[M][L2]
Mg2+	3.31	12.12	5.47
Ca2+	3.25	11.48	5.87
Mn2+	5.47	12.30	7.80
Fe2+	6.87	12.79	11.18
Cu2+	11.93	15.85	16.02
Fe3+	16.09	17.63	23.00

Roundup Ready® Gene



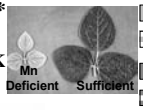
- **Confers "tolerance" to glyphosate**
  - Alternate metabolic pathway introduced
  - Slows down some physiologic processes
- **There are several "modifiers" possible**
- **Incomplete "protection" of meristematic and reproductive tissues - depends on:**
  - Time of application
  - Method of application
  - Crop species

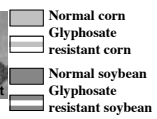
"Yield Drag"

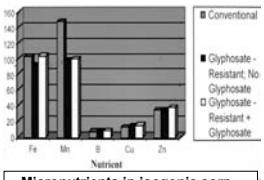


REPORTED EFFECTS OF GLYPHOSATE

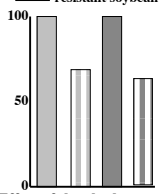
- **Reduced Mn & Fe uptake***
  - Root & foliage
  - [Reduced uptake also of K







Micronutrients in isogenic corn on a manganese sufficient soil

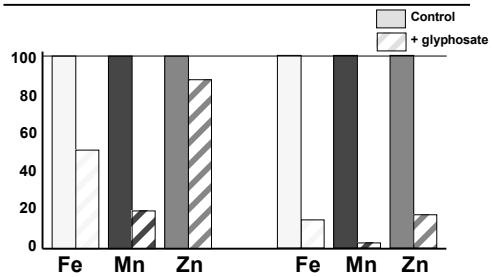


Effect of the glyphosate resistance gene on Mn uptake efficiency

**Can be modified by Mn or other micronutrient application*

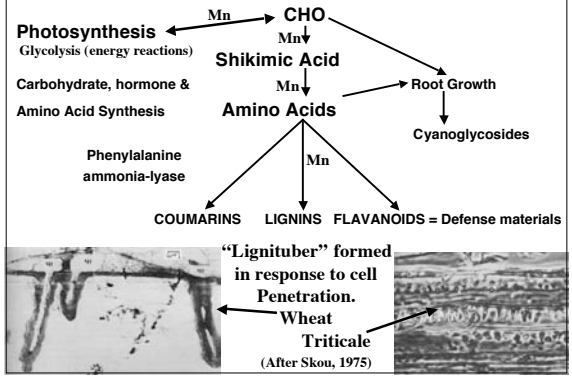
Effect of Residual Glyphosate* on Percent Nutrient Uptake and Translocation by Plants

(After Eker et al, 2006)



**2.5 % of the recommended herbicidal rate*

Physiologic Roles of Manganese



"Lignituber" formed in response to cell Penetration.
Wheat
Triticale
(After Skou, 1975)

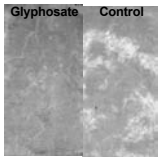
REPORTED EFFECTS OF GLYPHOSATE

- Immobilization of Mn*
  - Translocation
  - Reduced physiological efficiency
- Increased drought stress*
- Earlier maturity*
- Interaction with some diseases*
- Reduced nodulation and N-fixation
- Changes in soil microbes
  - Major genetic groups changed - Swanson, et al.
  - *Fusarium, Rhizoctonia*, "fungi" increase - Johal, Fernandez
  - Toxic to *Rhizobium* and Mn reducing organisms - Yamada, et al

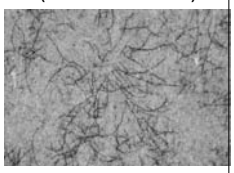
**Can be modified by Mn or other micronutrient application*

Reported Microbial Effects of Glyphosate

Mn reduction in Rhizosphere soil



Fungal Mn oxidation in soil (increased virulence)



Manganese Oxidation

- In soybean rhizosphere soil (3 wks after glyphosate applied):

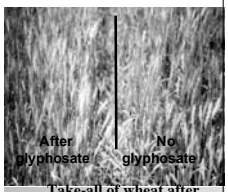
	Mn Reducing Organisms	Oxidizing Organisms
Control (no glyphosate)	7,250*	750
+ Glyphosate	740	13,250

*Colonies per gram of soil

Predisposing Effect of Glyphosate on Disease

- *Take-all of wheat*
- *Crown rot of canola*
- *Citrus variegated chlorosis*
- *Fusarium head blight of cereals*
- *Fusarium root rot of cereals*
- *Goss's wilt of corn*
- *Magnaporthe root rot*
- *Monosporascus root rot of melon*
- *Sugarcane decline*
- *Corynespora root rot of soybean*
- *Target spot of soybean*
- *Glume blotch of wheat*

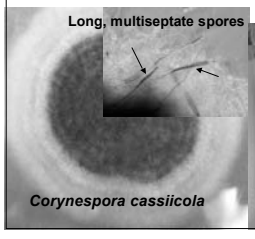
[Glyphosate is reported to control rusts]

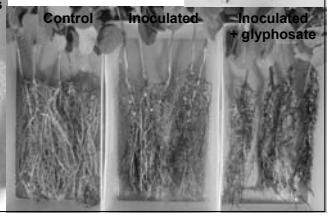


Take-all of wheat after glyphosate to RR beans

Corynespora Root Rot

- *An* extensive dark brown to black rotting of small lateral roots
- Generally considered a root "nibbler"
- Severe with glyphosate and near weeds killed by glyphosate

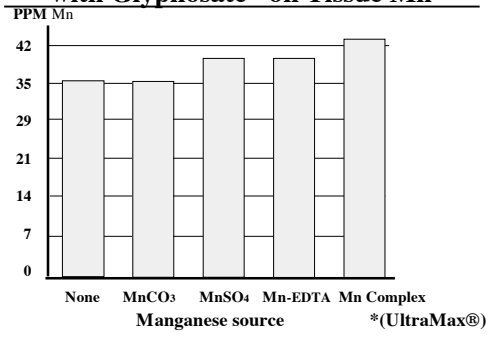




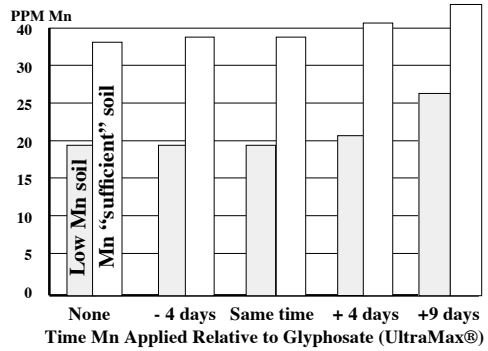
Strategies to Ameliorate Mn Immobilization

- Enrichment
  - Micronutrient
    - Timing/formulation
  - Biological amendment
    - *Bacillus, Trichoderma*
- Detoxification
  - Calcium chelation
  - Manganese
- Cultural practices
  - Increase Mn availability
    - Ammonium sources of N
    - Inhibit nitrification
    - Crop sequence - after corn
- Alternative weed control
  - Reduce usage - change chemistry
  - Mulch

Effect of Manganese Source Tank-Mixed with Glyphosate* on Tissue Mn



Effect of Time of Mn Application on Tissue Mn

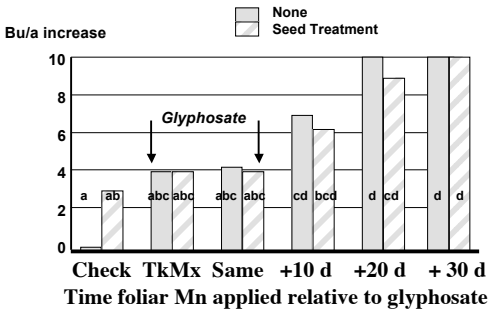


Effect of Foliar Mn on Soybean Yield*
Pinney Purdue Agricultural Center, 2003

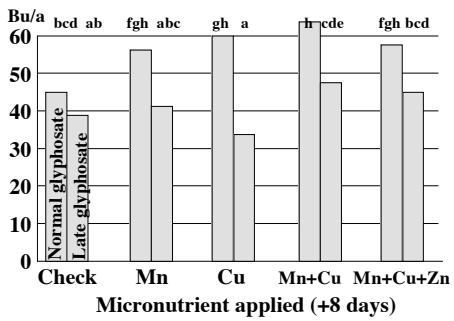
Treatment	Silt loam	Sandy loam
	---bushels per acre---	
Untreated	36 a	40.9 a
Mn (inorganic)	46 b	49.4 b
Mn (EDTA)	44 b	49.0 b
Mn (complex)	44 b	46.0 b

* Mn was applied 13 days after glyphosate (UltraMax®)

Effect of Seed+Foliar Mn on Soybean Yield



Effect of Glyphosate & Mineral Treatment on Soybean Yield, Organic Soil



Interaction of Micronutrients with Glyphosate*

Micronutrient	Rate	Yield	% Weed control
Untreated control	None	46 a	0 a
Glyphosate** control	24 oz/a	57 b	100 e
Gly+$MnCO_3$	0.5 #Mn/a	75 d	91 de
Gly+$MnSO_4$	0.5 #Mn/a	70 cd	93 e
Gly+MnEDTA	0.25 #Mn/a	72 cd	100 e
Gly+Mn-AA	0.25 #Mn/a	67 c	85 d
Gly+ZnO	0.5 #Zn/a	49 ab	33 c
Gly+ZnChelate	0.25 #Zn/a	40 a	40 c
Gly+Zn+P	0.5 #Zn/a	41 a	20 b

* Glyphosate WeatherMax® formulation at 24 oz/a + AMS

Biological Amendments to Increase Mn

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

Issues (other than Mn activity):

- Tolerance of glyphosate
- Timing
- Method of application
- Formulation
- Safety

	Corn yield (bu/a)	
Treatment	Rainfed	Irrigated
None	176a	186a
Bio # 1	181ab	187a
Bio # 2	185b	186a

Detoxifying Glyphosate

- **In meristematic/reproductive tissues**
  - Mn, Si+Mn, Mn+Cu
- **In root exudates in soil**

Broadcast:

- Lime
- Gypsum
- Phosphorus

In furrow treatment:

- Gypsum (CaSO4)
- Lime
- Manganese
- Ca + Mn

Effect of in-furrow treatments on Soybean tissue Mn

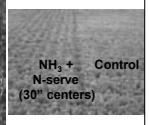
Treatment	Rainfed	Irrigated
Lime	32a	29a
Gypsum	38b	36b

Modify Cultural Practices to Affect Mn Availability

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

Crop sequence effect on Mn

Rotation	Extractable Mn
Continuous Corn	130 ppm
Continuous soybeans	64 pp,
Soybean, wheat, corn	91 ppm
Wheat, corn, soybean	79 ppm
Fall chissel	126 ppm
No-till	80 ppm



Residual effect of NH_3 for corn on Mn for soybean*

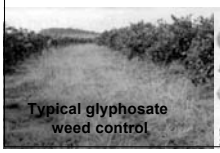
Treatment	Tissue Mn	Bean Yld (bu/a)
None	12.1	22
NH_3 only	14.3	26
NH_3+Mn	---	39
NH_3+NI	30.1	44
NH_3+NI+Mn	---	44

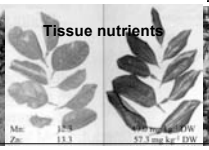
*NH_3 on 15" centers

Alternative weed control

- **Another herbicide**
  - Conventional (residual)
  - Non-systemic
- **Mulch system**

Predisposition of Citrus to CVC (*Xylella fastidiosa*) by Gyphosate





Conclusions & Recommendations

1. The glyphosate-resistance gene selectively reduced Mn uptake
   Select cultivars with highest Mn efficiency
2. Application of glyphosate reduced Mn translocation in tissues
   Apply micronutrients 8+ days after glyphosate
3. Glyphosate formulation and nutrient source influence uptake
   Select formulations that are compatible for uptake
4. Changes in rhizosphere biology are accumulative
   Use cultural practices that minimize glyphosate impact
5. Glyphosate reduces root growth
   Detoxify glyphosate in roots and rhizosphere
6. Disease severity increases
   Use alternate weed control -Minimize glyphosate use

Source of Chelators

- **Natural metabolites**
  - Plant root exudates - organic acids
  - Microbial metabolites - organic acids, toxins
  - Soil organic matter
- **Synthetic compounds**
  - Herbicides - glyphosate
  - Nitrification inhibitors - nitrapyrin
  - EDTA, DTPA, citric acid, amino acids

- **Micronutrients are the:**
  - Activators
  - Inhibitors
  - Regulators of plant physiological functions

Some Characteristics of Glyphosate

- **A chemical chelator**
  - Small amount needed
  - Tightly bind mineral elements
    - Immobilize or increase solubility
    - Impairs herbicidal activity

Chelating stability constants of glyphosate

Metal ion	[ML] [M][L]	[MHL] [M][H][L]	[ML$_2$] [M][L$_2$]
Mg2+	3.31	12.12	5.47
Ca2+	3.25	11.48	5.87
Mn2+	5.47	12.30	7.80
Fe2+	6.87	12.79	11.18
Cu2+	11.93	15.85	16.02
Fe3+	16.09	17.63	23.00

- **Systemic in plants**
  - A modified essential amino acid
  - Concentrates in meristematic tissues
    - Shoot and root tips
    - Reproductive structures
  - Released into rhizosphere in root exudates
- **Non-specific herbicidal effect**
- **Toxic to many soil microbes**

Chelators:

- **Form a chemical bond that increases or decreases an elements solubility or membrane permeability**
- **Active in very small amounts**
  - 6% residual glyphosate severely reduced Fe & Mn uptake
- **Effect of chelation**
  - General, non-specific = immobilization, solubility
  - Specific = chelate only specific elements

Mn, Fe =	piricularin		rice blast
	alfa-picolinic acid		rice blast
	glyphosate		take-all
Cu =	nitrapyrin		inhibit nitrification
	etradiazol		*Nitrosomonas spp.*
	3-methyl pyrazole		

Effect of Glyphosate on Rhizosphere Biology

- **Changes in microbes**
  - Genetic groups - Swanson, Canada
  - *Fusarium, Rhizoctonia, etc. - (increase)*
    - *Fernandez, Kremer, Johal*
  - Oxidizers-Reducers - Roemheld, Huber
  - *Rhizobium* - Yamada, Hoagland
- **Changes microbial activity**
  - Oxidation - reduction - Huber, Roemheld

Predisposing Effect of Glyphosate on Disease

- *Take-all of wheat*
- *Crown rot of canola*
- *Citrus variegated chlorosis*
- *Fusarium head blight of cereals*
- *Fusarium root rot of cereals*
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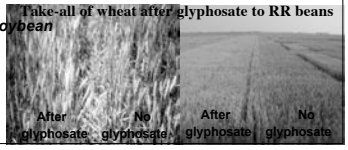
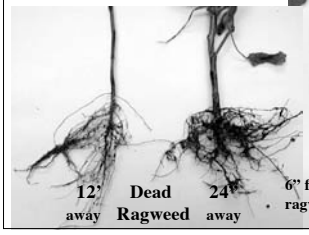
[Glyphosate is reported to control rusts]

Corynespora root rot of soybean



CAUSE

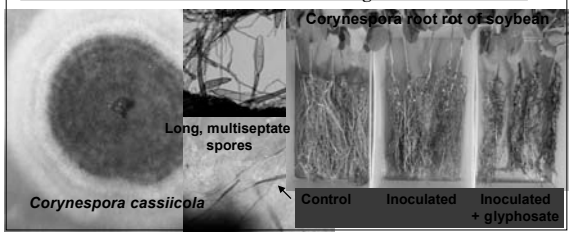
Very Severe Dark Brown to Black Root Rot



Koch's Postulates

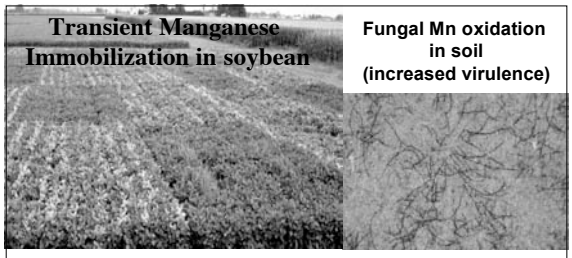
- Isolated *Corynespora cassiicola* from diseased roots (extensive dark brown to black rotted small lateral roots)
- Infested soil and reproduced symptoms on soybean roots
- Reisolated *Corynespora cassiicola* from infected roots and hypocotyls

ONLY *Rhizoctonia solani* isolated from Ragweed roots & stems

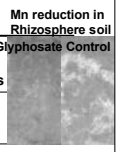


Recommendations

1. Select Mn efficient varieties with high Mn content
2. Plant soybeans after corn (preferably that had been fertilized with NH_3 + a nitrification inhibitor)
3. Plant in a firm seed bed
4. Make sure Mn formulation is compatible with glyphosate if tank mixing - or -
5. Apply foliar Mn 8 plus days after glyphosate
6. Rotate herbicides/weed control strategies



Manganese Oxidation

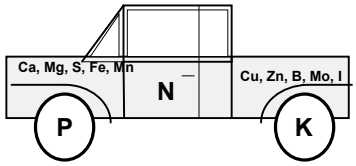


- In soybean rhizosphere soil (3 wks after glyphosate applied):

	Mn Reducing Organisms	Oxidizing Organisms
Control (no glyphosate)	7,250*	750
+ Glyphosate	740	13,250

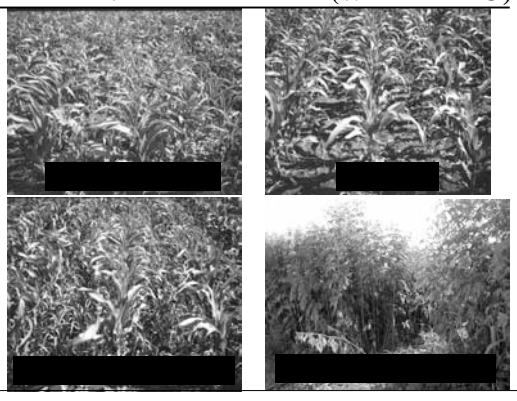
*Colonies per gram of soil

EACH ELEMENT FUNCTIONS AS PART OF A DELICATELY BALANCED INTERDEPENDENT SYSTEM WITH THE PLANT'S GENETICS AND THE ENVIRONMENT



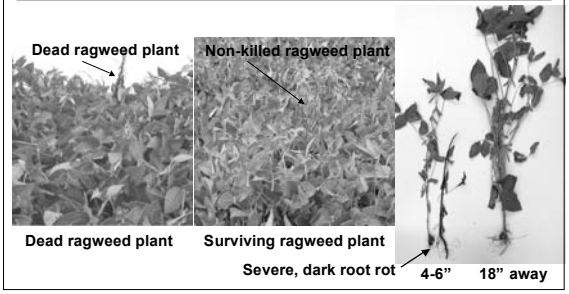
Nutrient Balance is Important

Herbicide-Nutrient Tank Mixes (WeatherMax®)

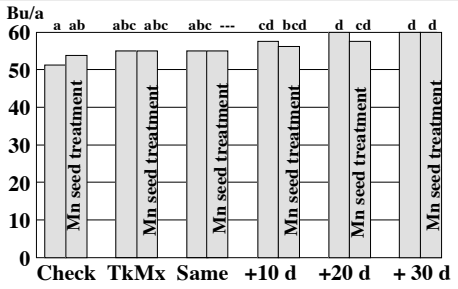


OBSERVATION

Stunted Soybean Plants Adjacent to Glyphosate-Killed Giant Ragweed Plants



Effect of Mn Seed/Foliar Treatment on Soybean Yield, silt loam, 2004



Effect of Glyphosate & Mn Tank Mixes on Chlorophyll & Soybean Grain Yield*

Manganese Formulation	Rate	SPAD-502 reading	Yield
	(kg/ha)	(11 DAT)	(bu/a)
Untreated	None	23.9 a	24 a
Glyphosate only	None	25.9 a	33 a
Mn-EAA	0.5	35.6 b	48 b
Mn-EDTA	0.7	36.8 b	50 b
Mn-LS	0.6	36.4 b	58 b
MnSO4	2.5	37.1 b	56 b

*From Bernards, Thelen, and Penner, 2004

Modify Cultural Practices to Affect Mn Availability

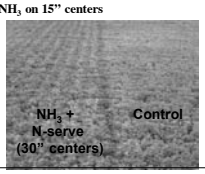
- ✓ Crop sequence
- ✓ Firm seedbed
- ✓ Grass mulch
- ✓ Lower pH
- ✓ Moisture management
- ✓ Ammonium N
  - inhibiting nitrification

Manganese Availability
pH 5.2 to pH 7.8
Rhizosphere biology

Residual effect of NH_3 for corn on Mn availability for soybean*

Treatment	Tissue Mn	Bean Yld (bu/a)
None	12.1	22
NH_3 only	14.3	26
NH_3+Mn	---	39
NH_3+NI	30.1	44
NH_3+NI+Mn	---	44

*NH_3 on 15" centers



Effect of Cultural Practices on Tissue Mn

Cultural Condition	Tissue Mn*
Loose Seedbed	11.2
Firm Seedbed	19.3
Nitrification	8.9
Inhibiting Nitrification	17.2
Wheat-wheat-wheat	20.0
Wheat-oats-wheat	55.0
Oats-oats-wheat	76.0

*Wheat

Crop sequence effect on Mn

Rotation	Extractable Mn
Continuous Corn	130 ppm
Continuous soybeans	64 pp,
Soybean, wheat, corn	91 ppm
Wheat, corn, soybean	79 ppm
Fall chissel	126 ppm
No-till	80 ppm

Interacting Factors Influencing Disease Severity that are Affected by Glyphosate