Glyphosate Effects on Diseases of Plants

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

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   ||             ||
HO-C-CH2-NH-CH2-P-OH
                  |
                  OH
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N-(phosphonomethyl)glycine

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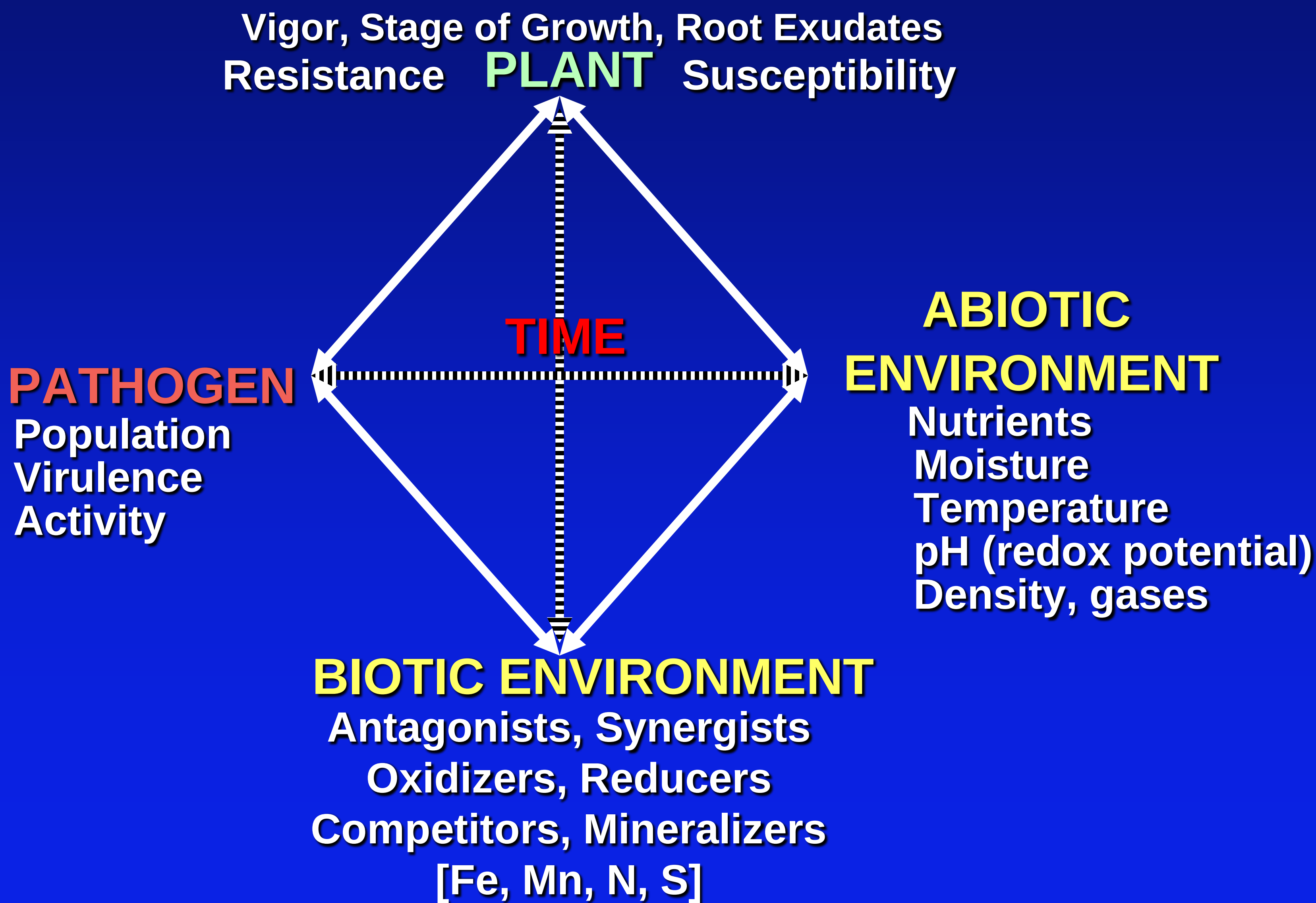
Glyphosate Effects on Diseases of Plants

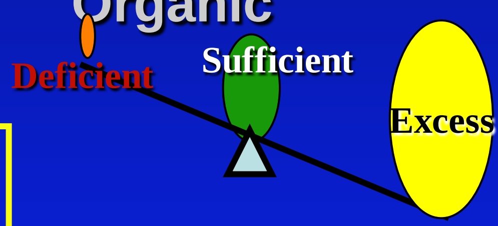
- Background - review
  - Interacting factors for disease
  - Some cultural factors affecting nutrition and disease
- Glyphosate
  - Characteristics
  - Glyphosate resistance
  - Reported effects of glyphosate
- Effect of glyphosate on disease
  - Take-all root and crown rot of cereals
  - Corynespora 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

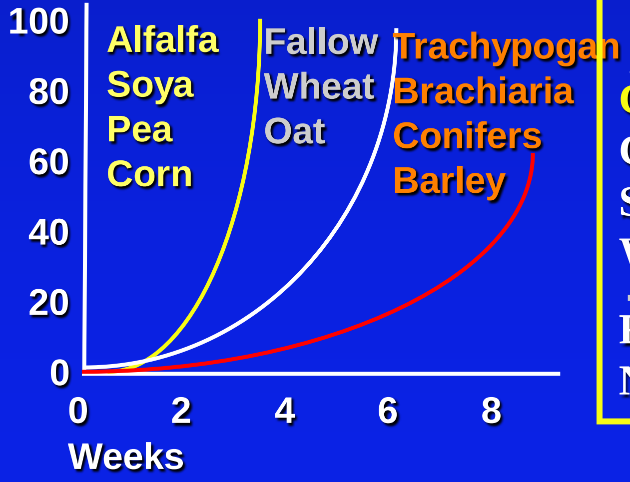


Changes in Agricultural Practices Change the Interactions

Crop Sequence	Tillage/No-till	Fertilization
Biotic environment	Residue break down	Rate/form
Nutrition	Soil density/aeration	Time applied
Nitrification	Pathogen survival	Source/assoc. ions
Organic matter	Nutrient distribution	Inorganic
	Denitrification	Organic



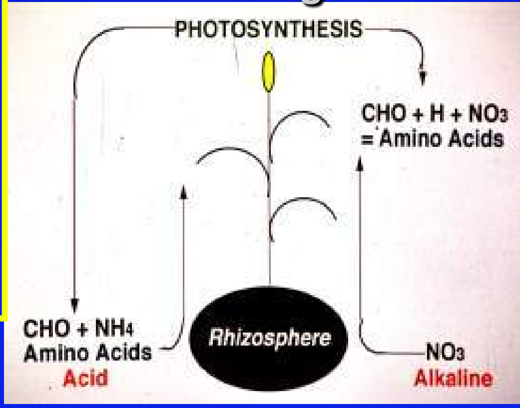
Effect of crop residue on nitrification



Crop sequence effect on Mn^{+2}

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

Metabolism of different forms of nitrogen



Factors Affecting N Form, Mn Availability and Severity of Some Diseases*

Soil Factor or Cultural Practice	Effect on: Nitrification	Mn Availability	Disease Severity
Low Soil pH	Decrease	Increase	Decrease
Green Manures(some)	Decrease	Increase	Decrease
Ammonium Fertilizers	Decrease	Increase	Decrease
Irrigation (some)	Decrease	Increase	Decrease
Firm Seed bed	Decrease	Increase	Decrease
Nitrification Inhibitors	Decrease	Increase	Decrease
Soil Fumigation	Decrease	Increase	Decrease
Metal Sulfides	Decrease	Increase	Decrease
High Soil pH	Increase	Decrease	Increase
Lime	Increase	Decrease	Increase
Nitrate Fertilizers	----	Decrease	Increase
Manure	Increase	Decrease	Increase
Low Soil Moisture	Increase	Decrease	Increase
Loose Seed bed	Increase	Decrease	Increase

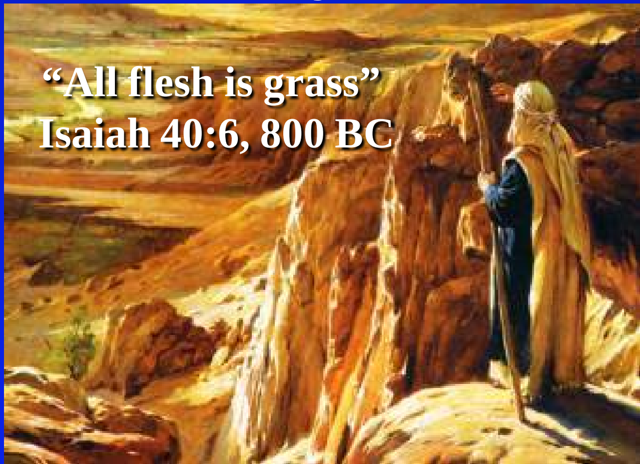
*Potato scab, Rice blast, Take-all, Phymatotrichum root rot, Corn stalk rot

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



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

Metal ion	$\frac{[ML]}{[M][L]}$	$\frac{[MHL]}{[M][H][L]}$	$\frac{[ML_2]}{[M][L_2]}$
Mg^{2+}	3.31	12.12	5.47
Ca^{2+}	3.25	11.48	5.87
Mn^{2+}	5.47	12.30	7.80
Fe^{2+}	6.87	12.79	11.18
Cu^{2+}	11.93	15.85	16.02
Fe^{3+}	16.09	17.63	23.00

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

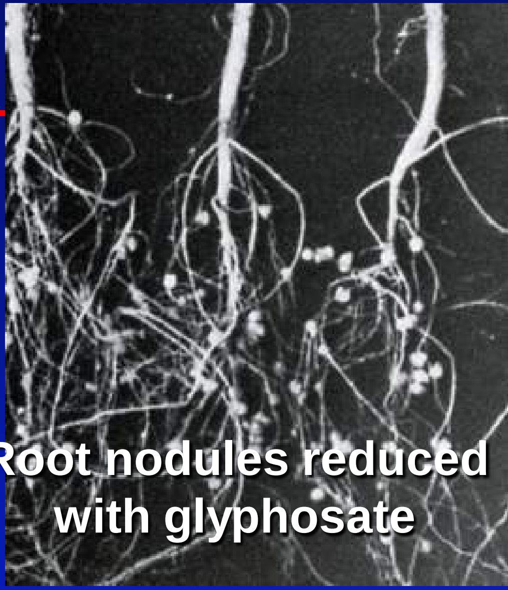
- Important because micronutrients are the:
  - Activators
  - Inhibitors
  - Regulators of plant physiological functions

Characteristic Effects of Glyphosate

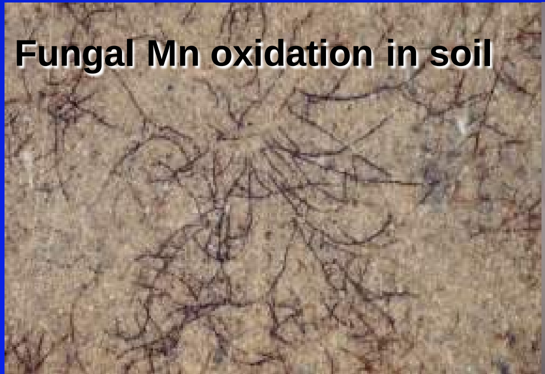
- Systemic in plants
  - A modified essential amino acid
  - Concentrates in meristematic tissues
    - Shoot and root tips
    - Reproductive structures
- Distributed throughout the rhizosphere in root exudates
- Non-specific herbicidal effect
- Toxic to some soil microbes; stimulates others
  - Changes nutrient availability
  - Changes virulence of some pathogens

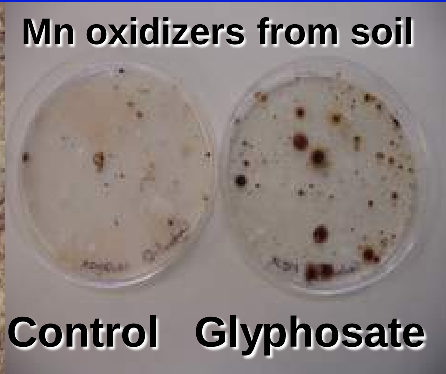
Some Microbial Interactions with Glyphosate

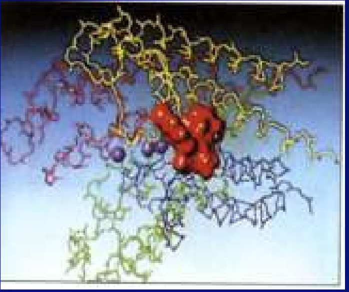
- Changes the soil microbial "balance"
- Toxic to beneficial organisms:
  - Rhizobium, Bradyrhizobium
    - Inhibits N-fixation
  - Mn reducing organisms (Biocontrol)
    - *Trichoderma* spp, *Bacillus* spp
  - Mychorrhizae
    - *Glomus mossea* - Zn, P uptake
- Stimulates:
  - Mn oxidizing organisms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



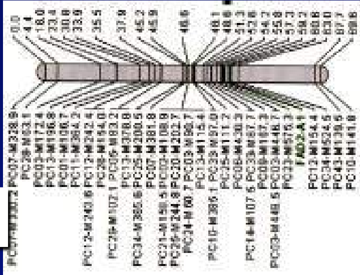
Manganese Availability
pH 5.2 to pH 7.8
Rhizosphere biology







Roundup Ready® Gene



[Greatly expanded usage of glyphosate]

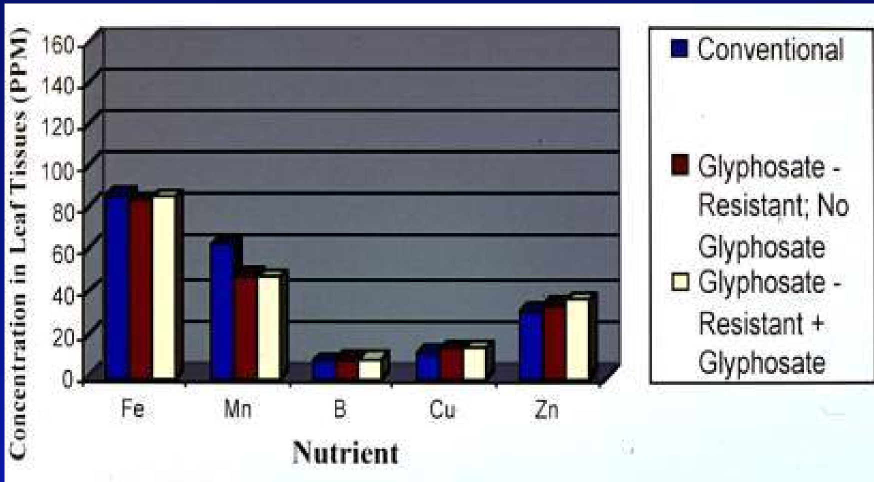
- **Confers "tolerance" to glyphosate**
  - Alternate metabolic pathway introduced
  - Slows down some physiologic processes
  - Provided selective herbicidal activity
  - There are several "modifiers" possible
- **Changes physiology of the plant (N metabolism)**
- **Incomplete "protection" of meristematic and reproductive tissues - depends on:**
  - Time of application
  - Method of application
  - Crop species
- **Often causes a "Yield Drag"**

Mis-shaped cotton boll from glyphosate

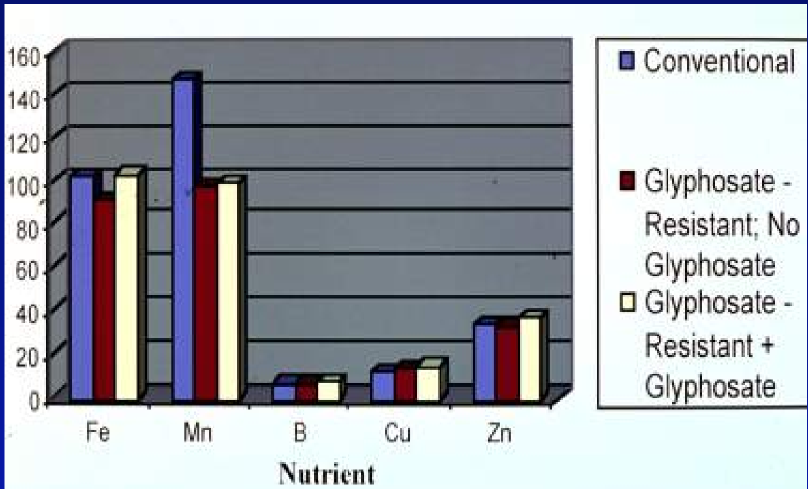
Normal

Glyphosate

"Glyphosate" Gene Effect on Mn Uptake



Soybean micronutrient concentrations



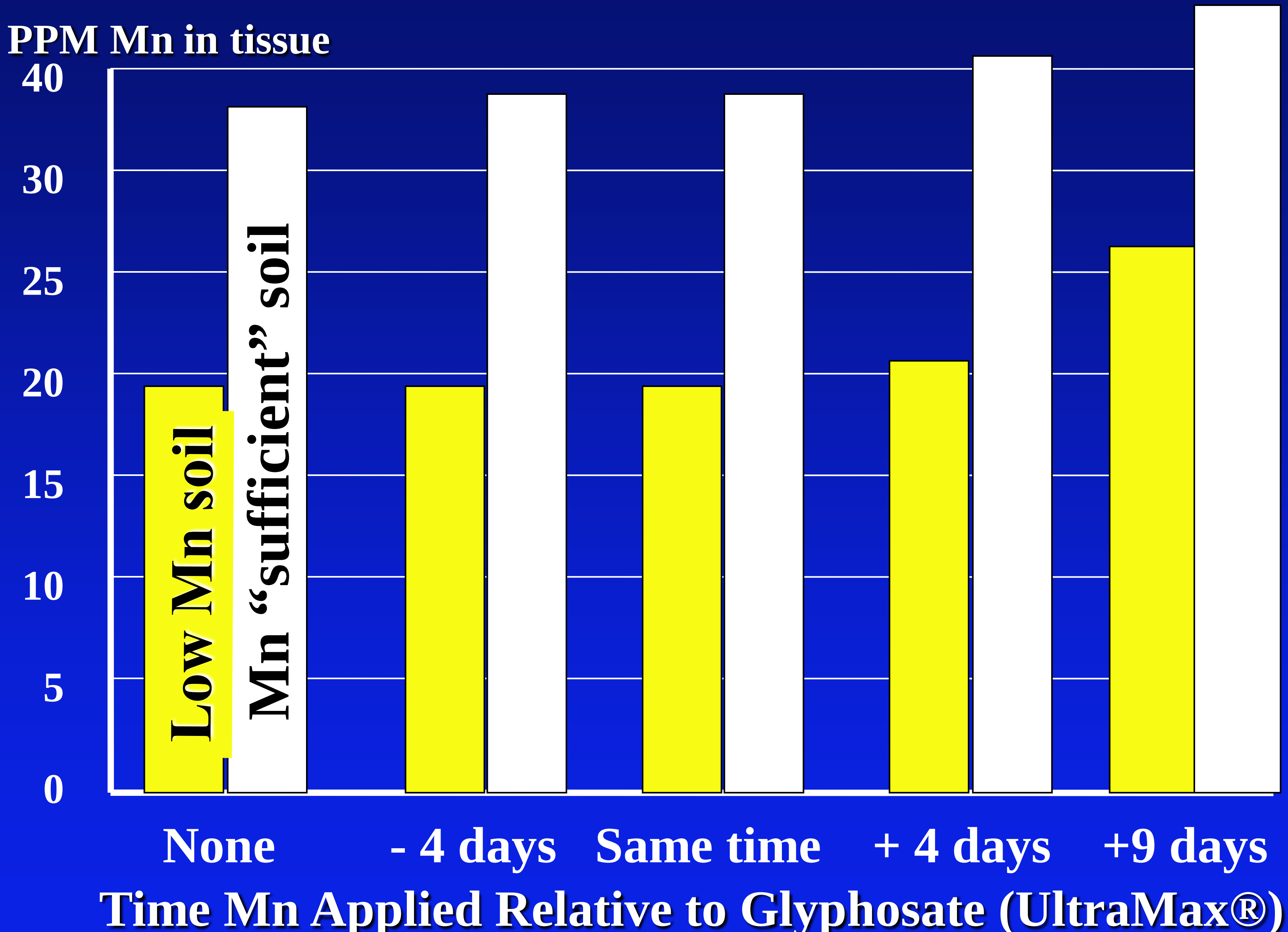
Corn micronutrient concentrations

Mn Efficiency of Isogenic soybeans - after Gordon, 2007

Isoline:	KS4202		KS4202 RR		Difference*	
Mn applied (lb./a)	Yield (bu/a)	Tissue Mn (ppm)	Yield (bu/a)	Tissue Mn (ppm)	Yield (bu/a)	Tissue Mn (ppm)
0	76.9	75	64.9	32	-12.0	- 43
2.5	76.1	80	72.8	72	- 4.1	- 3
5.0	74.9	92	77.6	87	+ 0.7	+ 12
7.5	72.6	105	77.6	95	+ 0.7	+ 10

* Difference compared with 0 Mn of normal

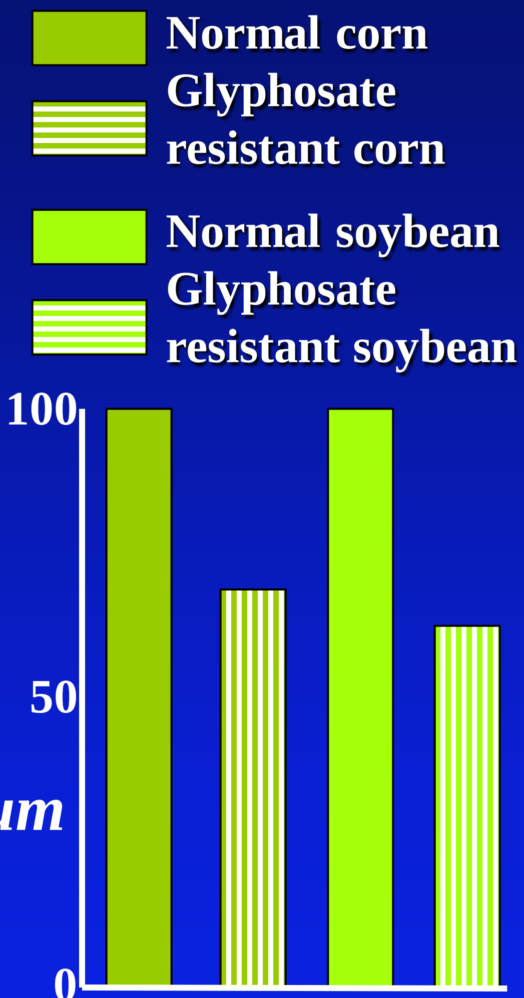
Residual Chelation Effect of Glyphosate on Mn



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*



Effect of the glyphosate resistance gene on Mn uptake efficiency

Some Diseases Increased by Glyphosate

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

Some Diseases Reduced by Glyphosate

Host plant	Disease	Pathogen
Soybean	Rust	*Phycopsora pakyrhiza*
Wheat	Rust	*Puccinia graminis*

Plant Pathogens Affected by Glyphosate

Pathogen	Pathogen
Increase:	
Botryospheara dothidea	***Monosporascus cannonbalus***
Corynespora cassicola	***Myrothecium verucaria***
Fusarium avenaceum	***Phaeomoniella chlamydospora***
F. graminearum	***Phytophthora spp.***
F. oxysporum f. sp cubense	***Pythium spp.***
F. oxysporum f.sp (canola)	***Rhizoctonia solani***
F. oxysporum f.sp. glycines	***Septoria nodorum***
F. oxysporum f.sp. vasinfectum	***Thielaviopsis bassicola***
F. solani f.sp. glycines	***Xylella fastidiosa***
F. solani f.sp. phaseoli	
F. solani f.sp. Pisi	**Decrease (obligate pathogens):**
Gaeumannomyces graminis	***Phykopsora pakyrhiza***
Magnaporthe grisea	***Puccinia graminis***
Marasmius spp.	

Abiotic increase: Mn deficiency diseases

Physiologic Roles of Manganese

Mn → CHO

Photosynthesis

Glycolysis (energy reactions)

Mn ↓

Shikimic Acid

Mn ↓

Amino Acids

Carbohydrate, hormone &

Amino Acid Synthesis

Root Growth

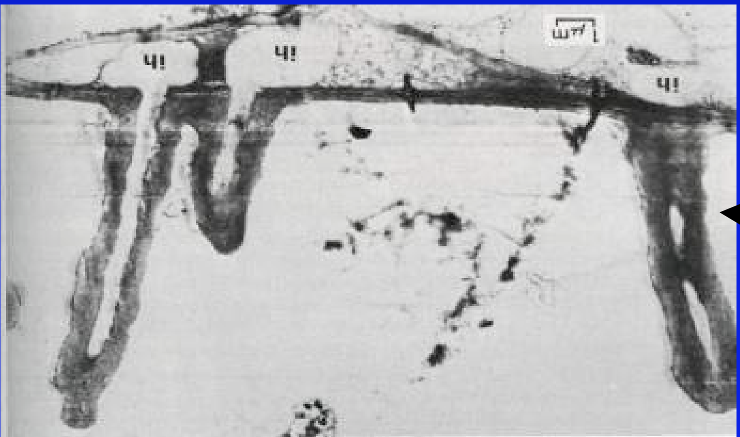
Cyanoglycosides

Phenylalanine

ammonia-lyase

Mn

COUMARINS LIGNINS FLAVANOIDS = Defense materials

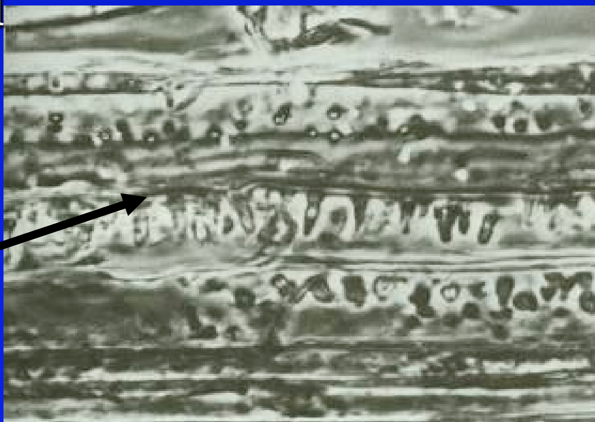


"Lignituber" formed in response to cell Penetration.

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 *Gaeumanomyces graminis* var *tritici* from *G. graminis* var *graminis*
- Virulence associated with manganese oxidation
- Very high tolerance for Mn

Mn oxidation
Virulent

No oxidation
Avirulent

15C to 25C

25C to 15C

Temperature	15 C				25 C			
Isolate	X	A	B	C	X	A	B	C
Mn Oxid.	0	0	+	+	0	+	+	0

VIRULENCE AND MANGNAESE OXIDATION

The Pathogen

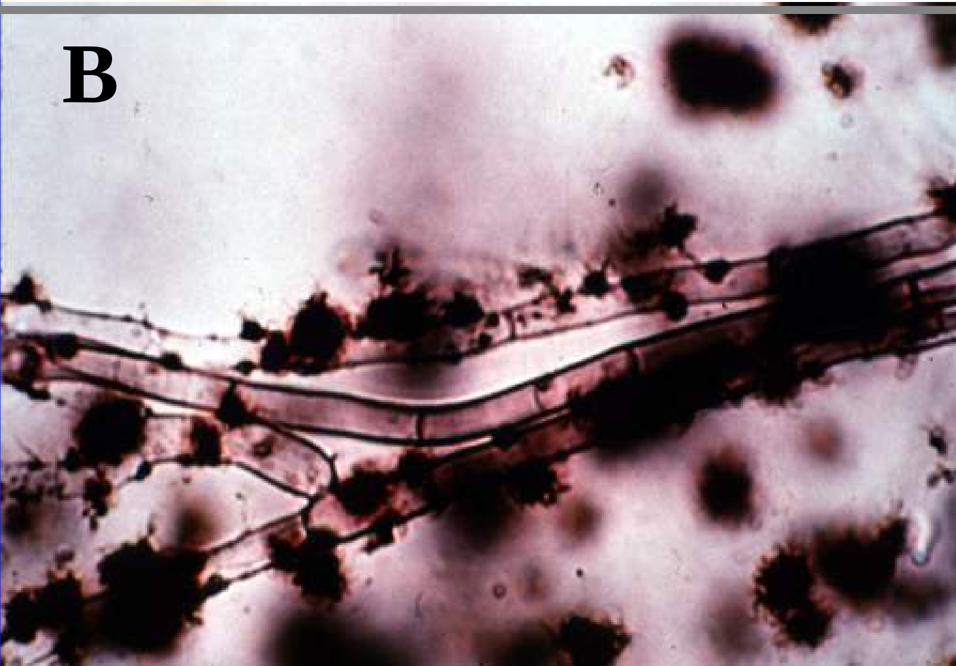
Gaeumannomyces graminis

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

B. Extracellular oxidation of Mn

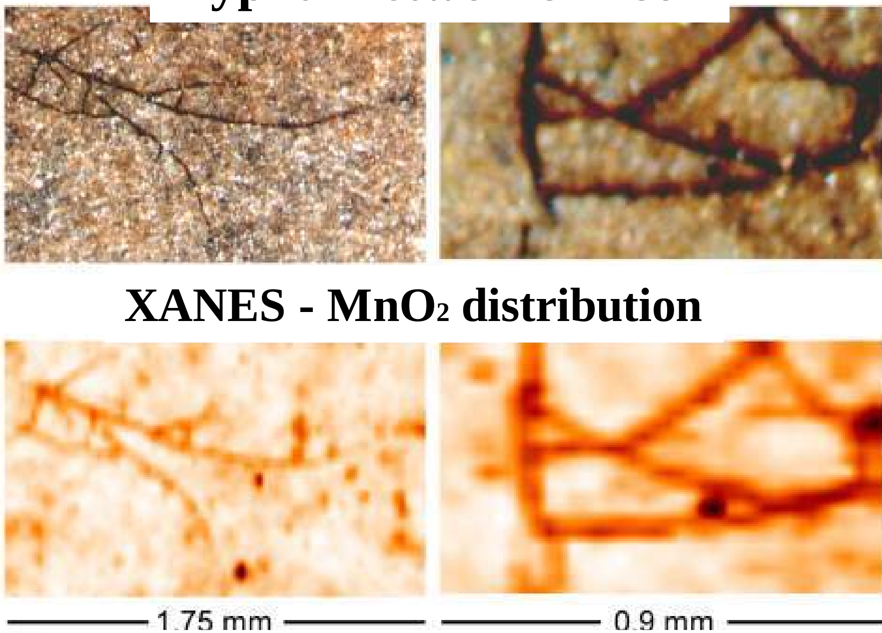
C. Dispersive X-ray microanalysis of ectotrophic mycelium on root

Ectotrophic growth of Ggt on wheat root



Gaeumannomyces oxidizes Mn in Soil, rhizosphere, and root tissue

Hyphal networks in soil



More intense with high soil moisture

Factors Affecting N Form, Mn Availability and Severity of Some Diseases*

Soil Factor or Cultural Practice	Effect on: Nitrification	Mn Availability	Disease Severity
Low Soil pH	Decrease	Increase	Decrease
Green Manures(some)	Decrease	Increase	Decrease
Ammonium Fertilizers	Decrease	Increase	Decrease
Irrigation (some)	Decrease	Increase	Decrease
Firm Seed bed	Decrease	Increase	Decrease
Nitrification Inhibitors	Decrease	Increase	Decrease
Soil Fumigation	Decrease	Increase	Decrease
Metal Sulfides	Decrease	Increase	Decrease
High Soil pH	Increase	Decrease	Increase
Lime	Increase	Decrease	Increase
Nitrate Fertilizers	----	Decrease	Increase
Manure	Increase	Decrease	Increase
Low Soil Moisture	Increase	Decrease	Increase
Loose Seed bed	Increase	Decrease	Increase

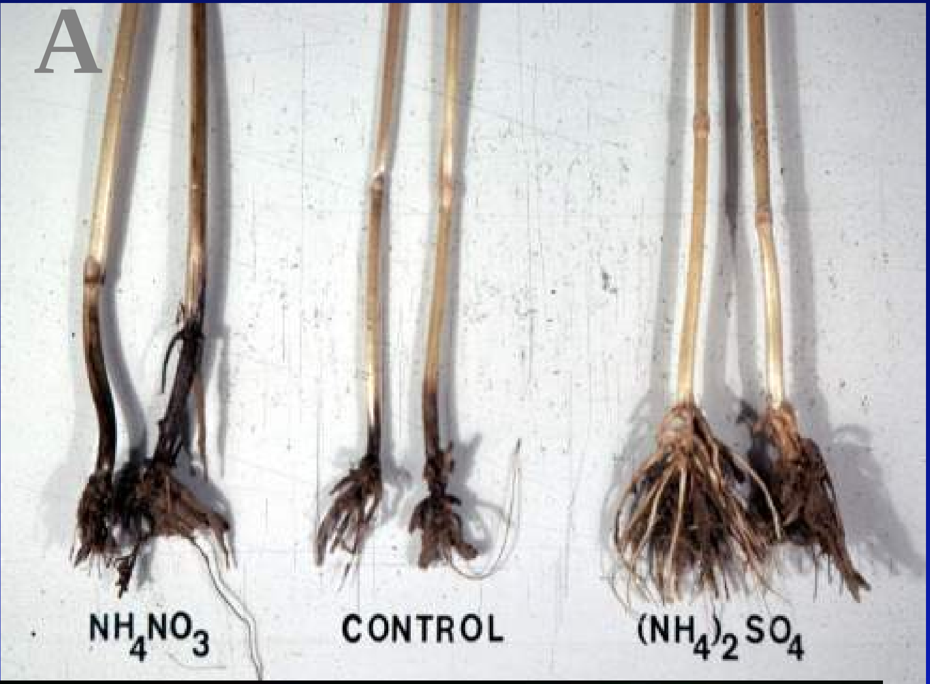
*Potato scab, Rice blast, Take-all, Phymatotrichum root rot, Corn stalk rot

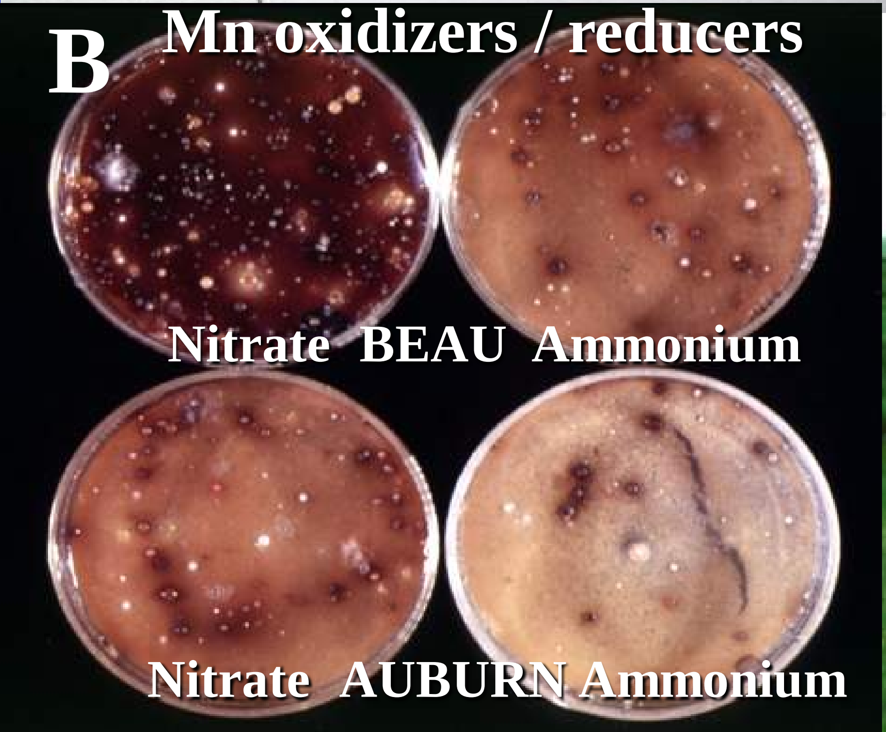
Effect of N form & inhibiting nitrification on take-all and rhizosphere Mn oxidizers

A. N form on Take-all

B. Manganese oxidizers

C. -/+ Nitrification inhibitor



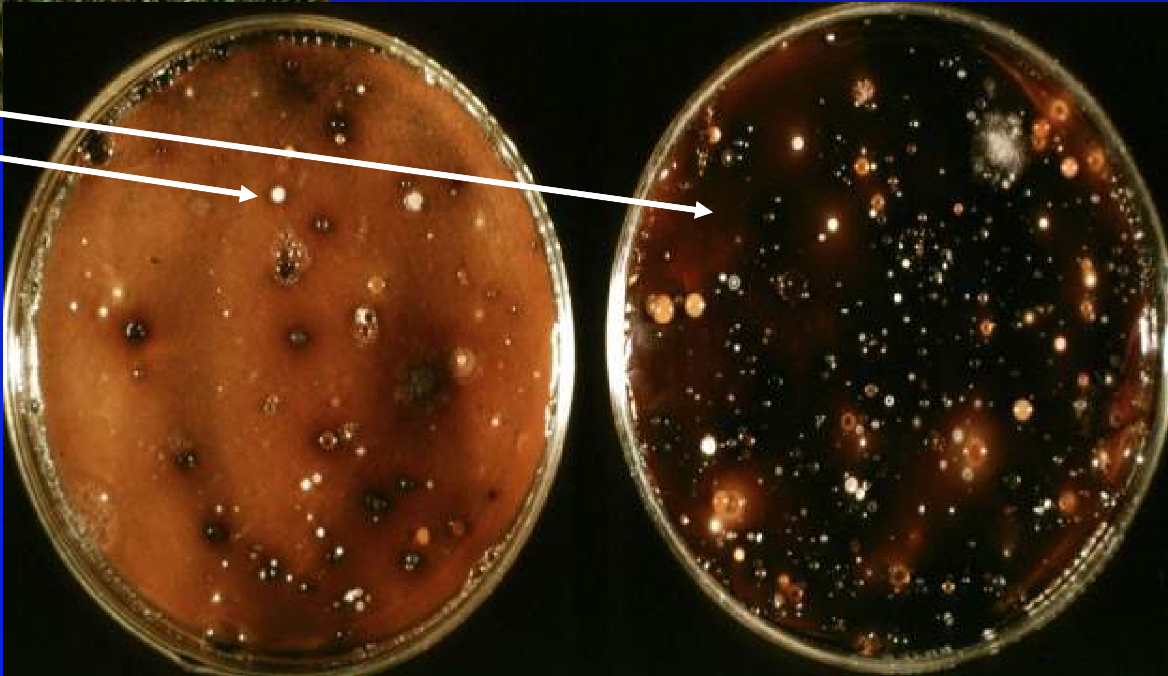


Effect of Cultural Practices on Tissue Mn and Take-all

Cultural Condition	Mn*	TA index
Loose Seedbed	11.2	3.0
Firm Seedbed	19.3	2.4
Nitrification (normal)	8.9	3.2
Inhibiting Nitrification	17.2	2.0
Wheat-wheat-wheat	20.0	4.8
Wheat-oats-wheat	55.0	1.4
Oats-oats-wheat	76.0	0.5

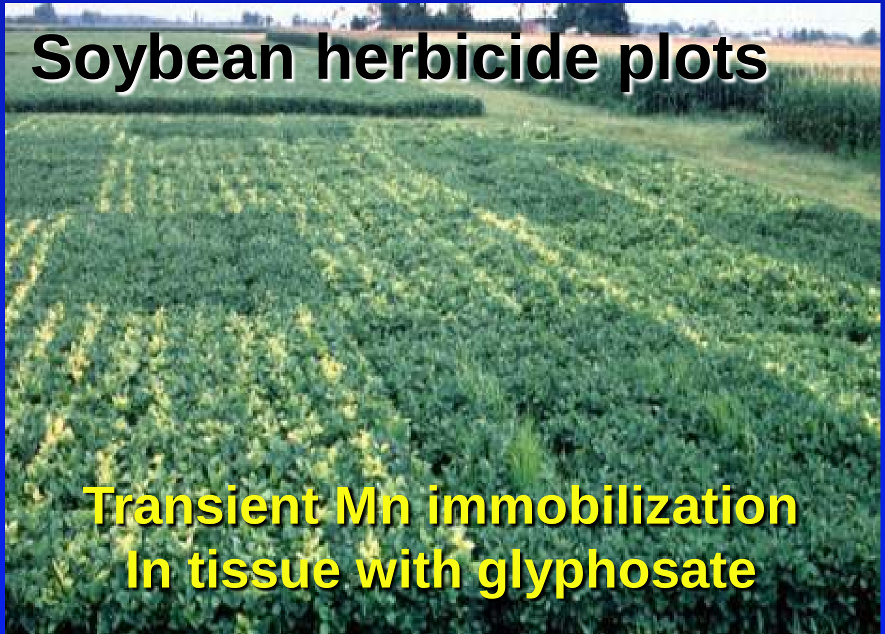
*Wheat tissue Mn, PPM; Take-all index = 1-5 (severe

Take-all and Populations of Mn-oxidizing Rhizosphere Bacteria



Cattle dung (manure)

Impact of Glyphosate on Take-all



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

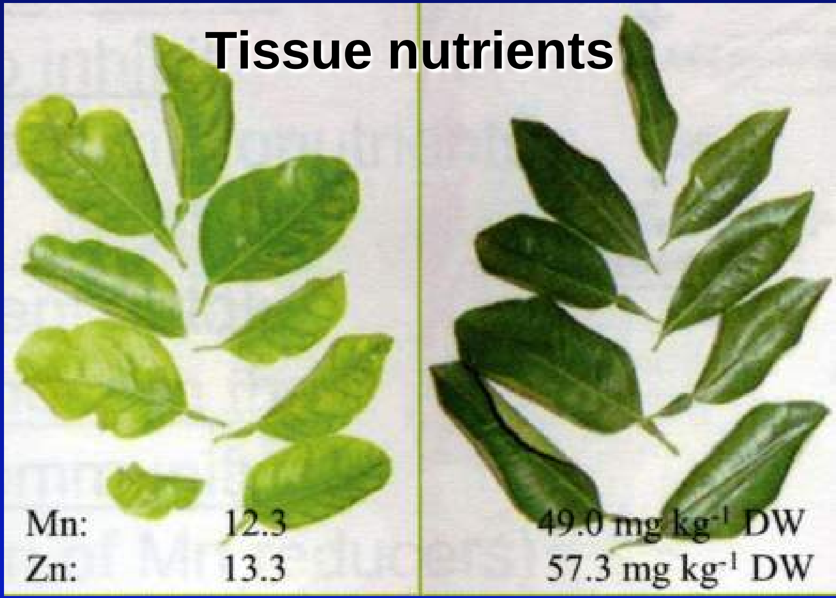
- Stunted soybean plants adjacent to glyphosate-killed giant ragweed plants
- Very severe Corynespora root rot
- Dead ragweed is not a host for Corynespora

Dead ragweed plant

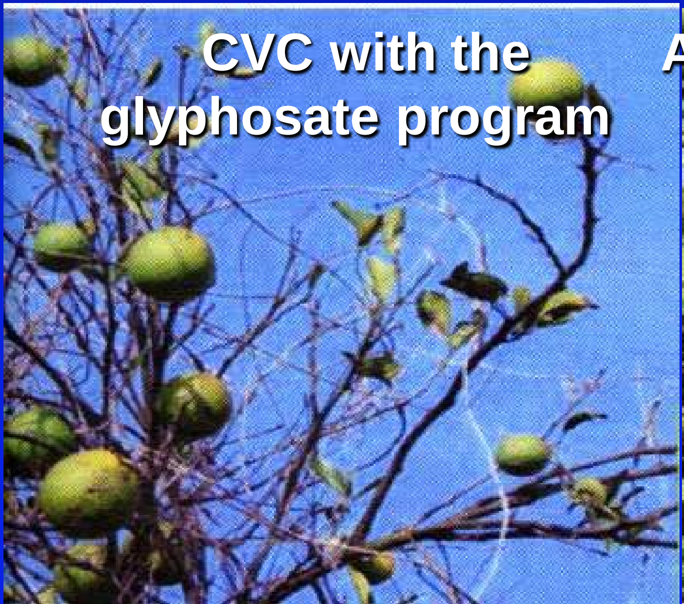
Surviving ragweed plant

Citrus Variegated Chlorosis

Predisposition to CVC (*Xylella fastidiosa*) by glyphosate



After T. Yamada



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 <u>increases</u> root rot
- Glyphosate increases manganese deficiency

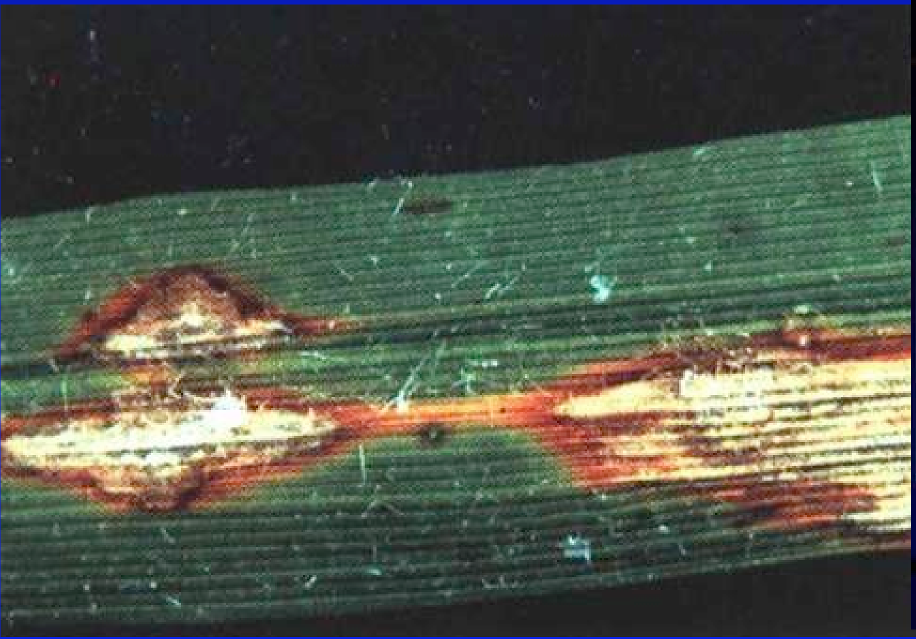
Manganese and N deficiency

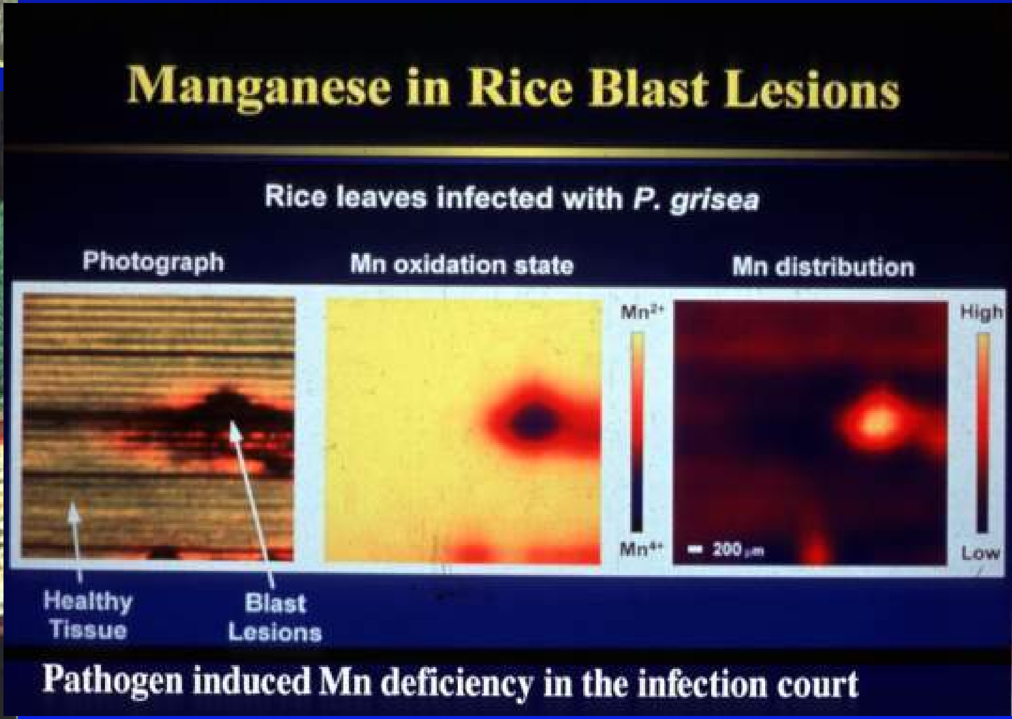
After
Burndown RR corn

Manganese "Forms" in Blast Infected Rice

Rice blast, caused by *Pyricularia grisea* (*Magnaporthe grisea*)

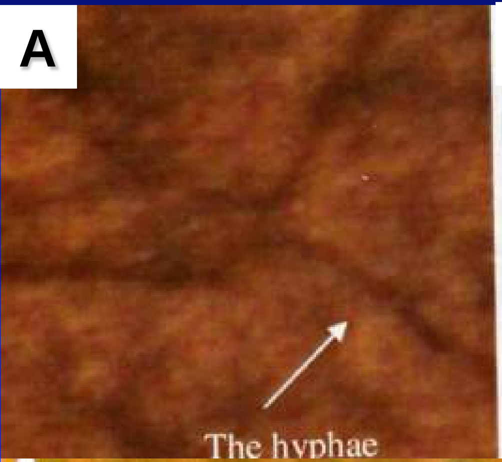
Only oxidized Mn in lesion area

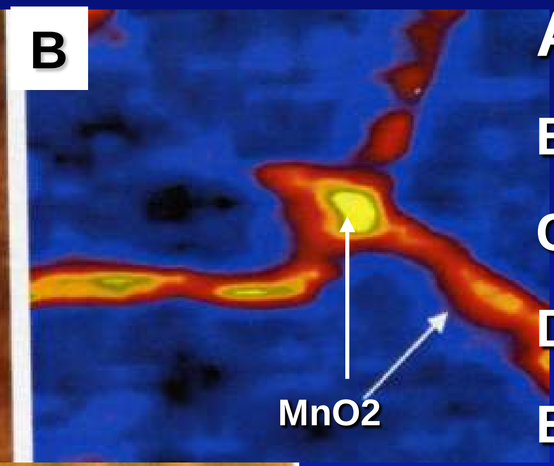


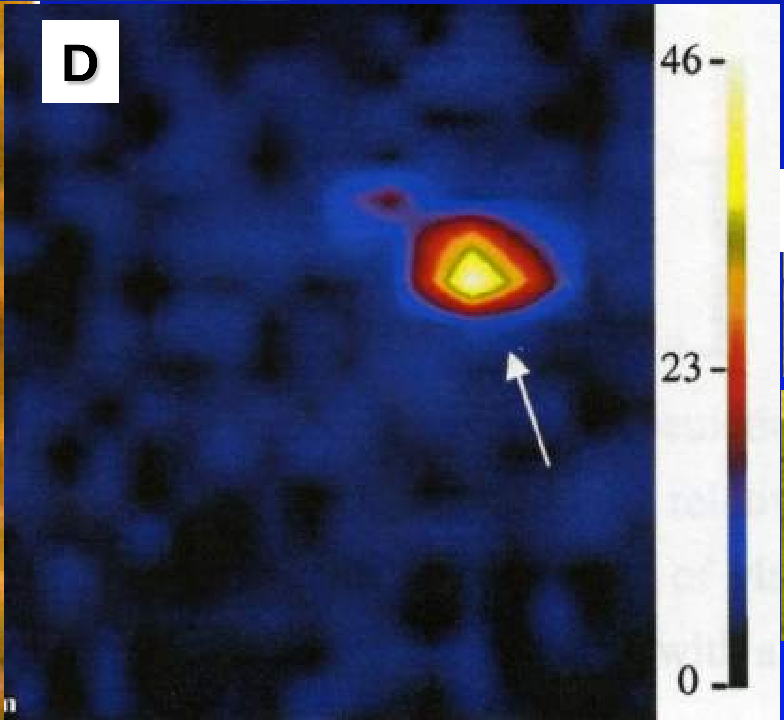


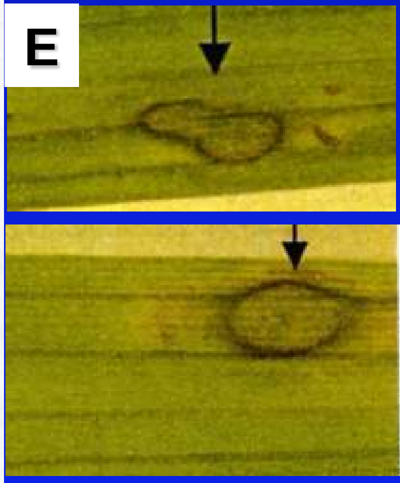
Magnaporthe grisea is a strong Mn oxidizer

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

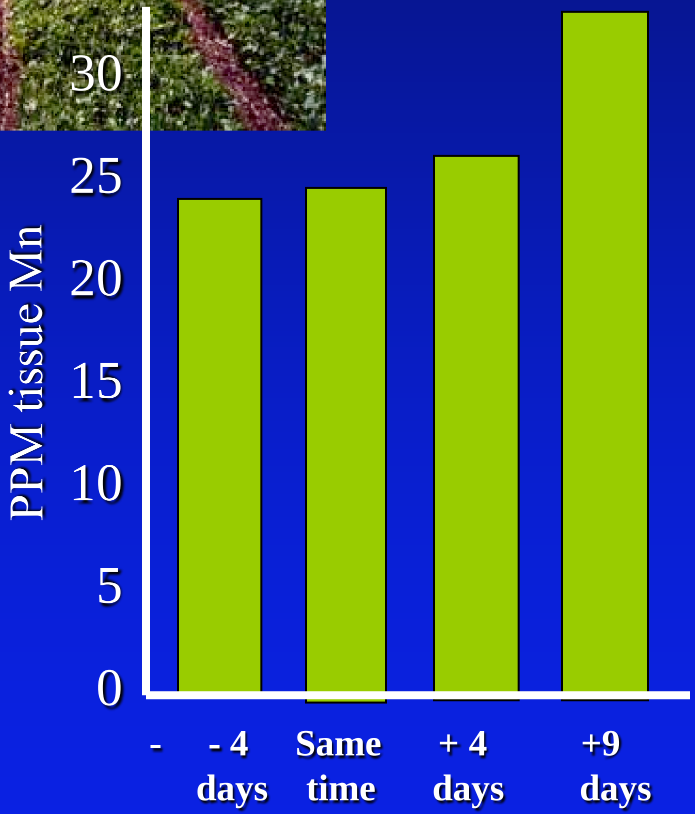
- May account for the more limited damage from soybean rust than anticipated in the U. S.

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



Time Mn applied relative to glyphosate (UltraMax®)

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)*

Concerns (other than Mn activity):

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

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

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

Effect of in-furrow treatments on Soybean tissue Mn

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

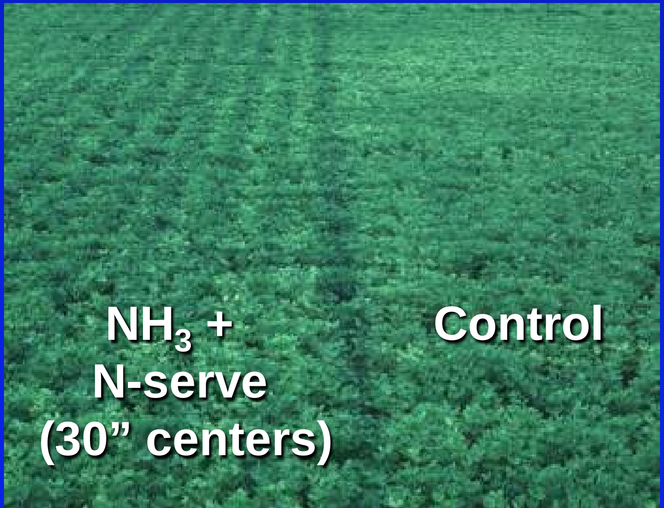
Modify Cultural Practices to Affect Mn Availability

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

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



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

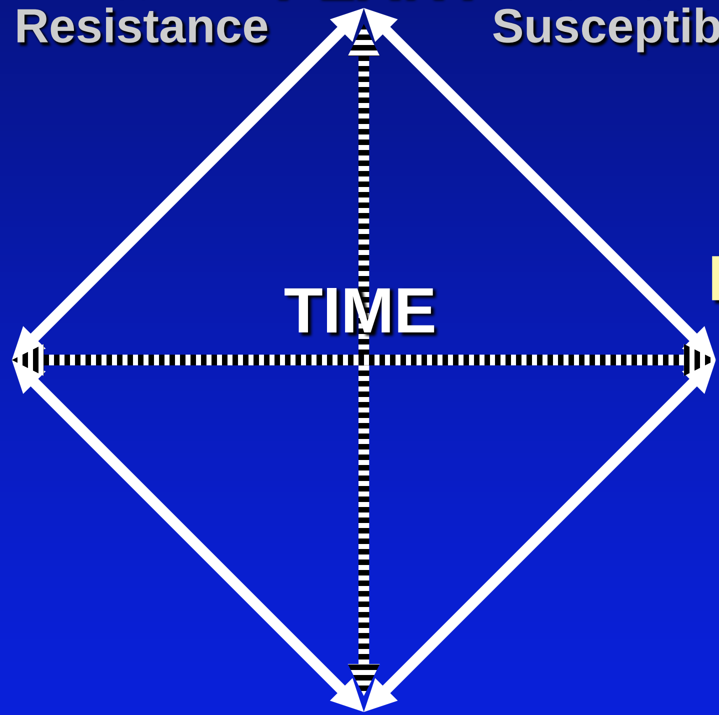
Vigor, Stage of Growth, Root Exudates

Health **PLANT** Nutrient efficiency

Resistance Susceptibility

Pathogen

Quantity
Activity
Virulence



ABIOTIC 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
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
   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