Nutrient - Disease - Herbicide Interactions

Brown Seed Field Day
September 9, 2011

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In Agriculture We Are Asked to Do Impossible Things

Parenting skills

Look back and take inventory once in a while!

Anticipate!

Hesitate!

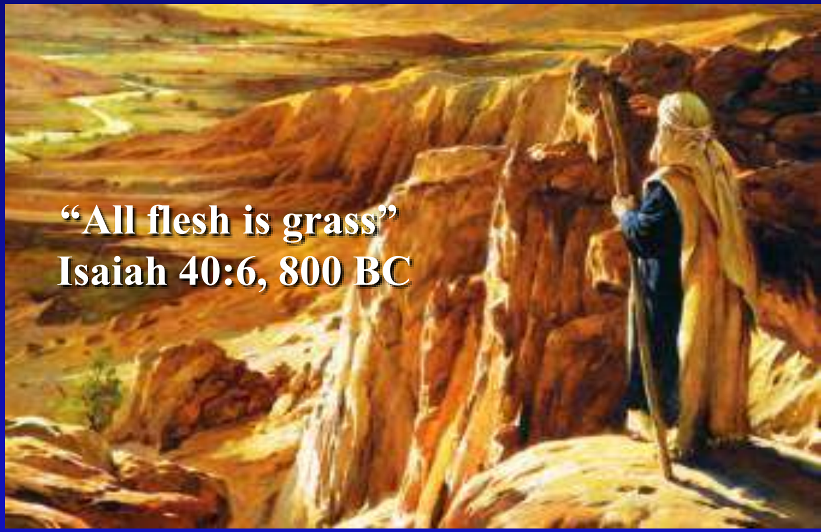
AVOID HAZARDS

← Bad Parenting!

Look back and take inventory once in a while!

Understanding Glyphosate and Glyphosate-resistant Crops Impact on Nutrition, Disease & Sustainability

- Background
- Understanding glyphosate
  What it is and how it works
- Understanding glyphosate-resistance
  - What it is and what it doesn't do
- Recognizing the interactions
  - Symptoms - nutrition, disease
- Remediation
- The bigger picture - Food/Feed nutrition and safety

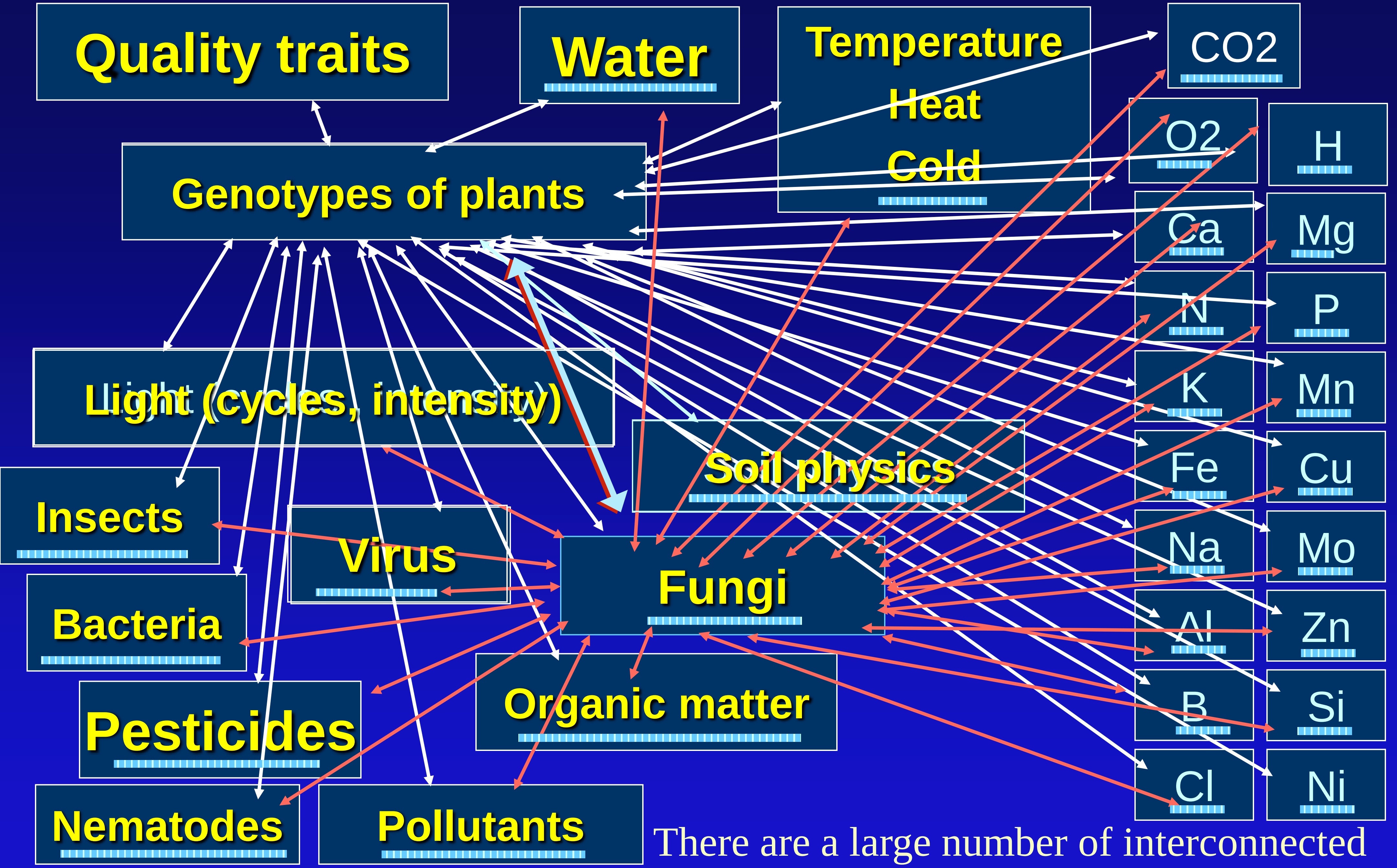


The Importance of Reducing Stresses

Genetic Potential - Nutrition Physiology Management Environment Diseases Pests = Harvest

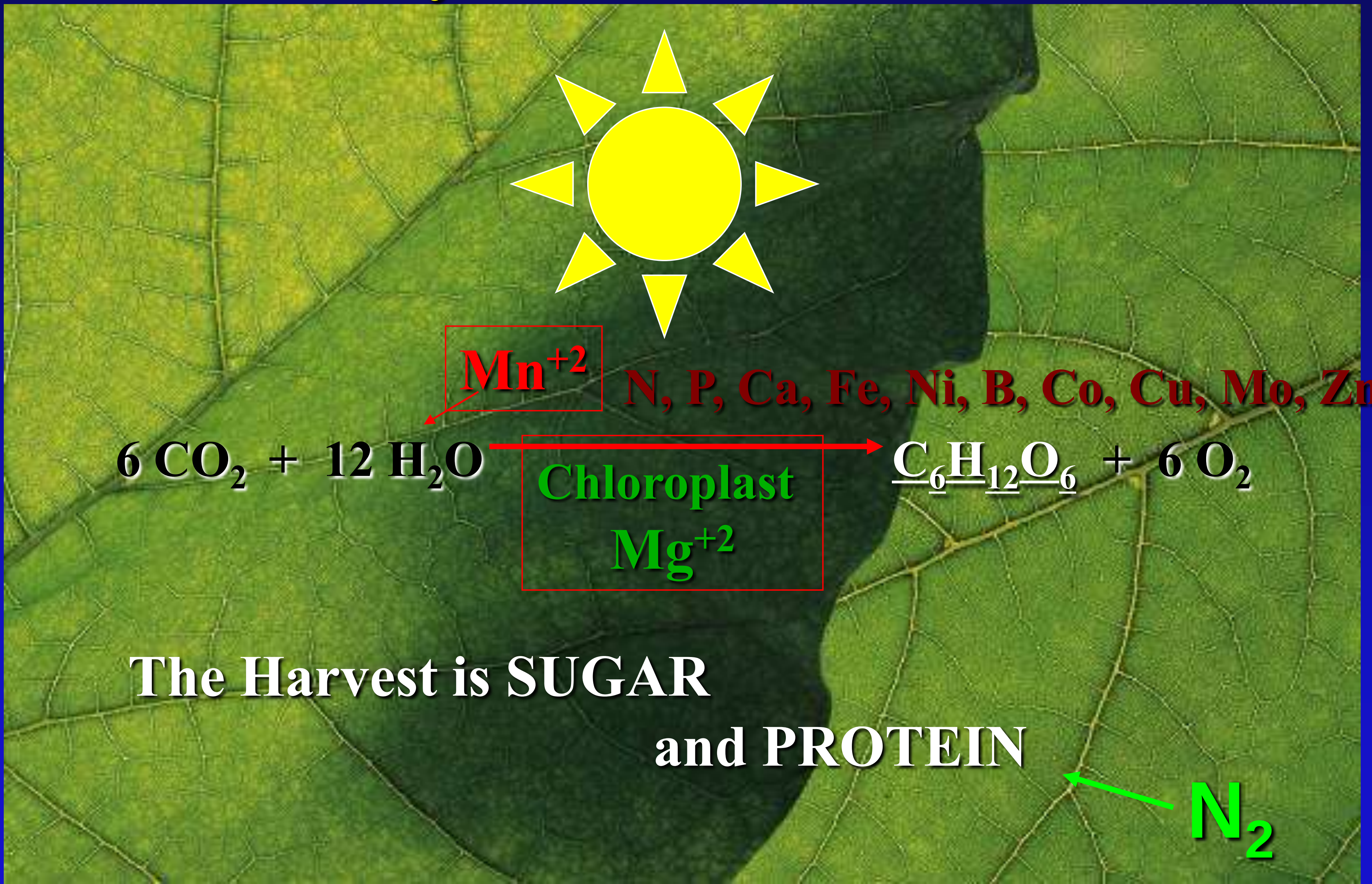
Potential - Stresses = Yield

There is no free lunch!

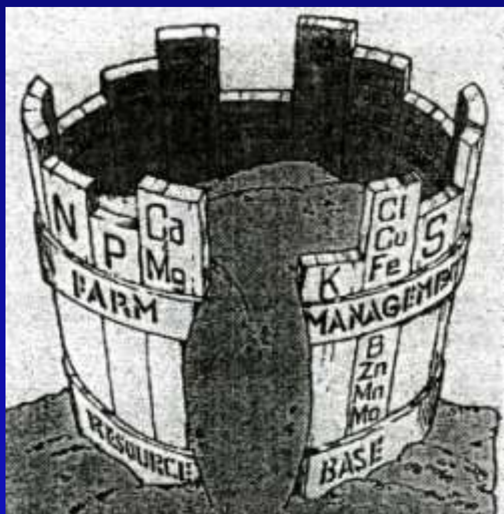


There are a large number of interconnected plant properties and responses to physical and biological environmental factors.

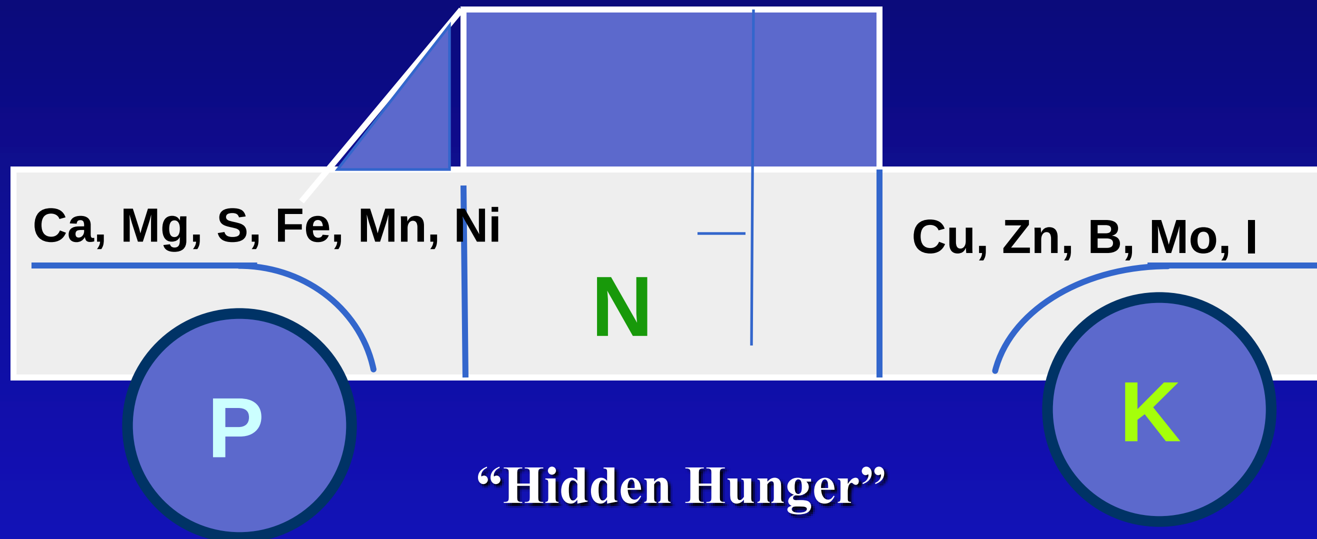
Photosynthesis and N-fixation



NUTRIENT BALANCE IS IMPORTANT BECAUSE EACH ELEMENT FUNCTIONS AS PART OF A DELICATELY BALANCED, INTERDEPENDENT SYSTEM WITH THE PLANT'S GENETICS AND THE ENVIRONMENT



"Law of the minimum"



"Hidden Hunger"

Nutrient *BALANCE* may be a matter of <u>root function!</u>

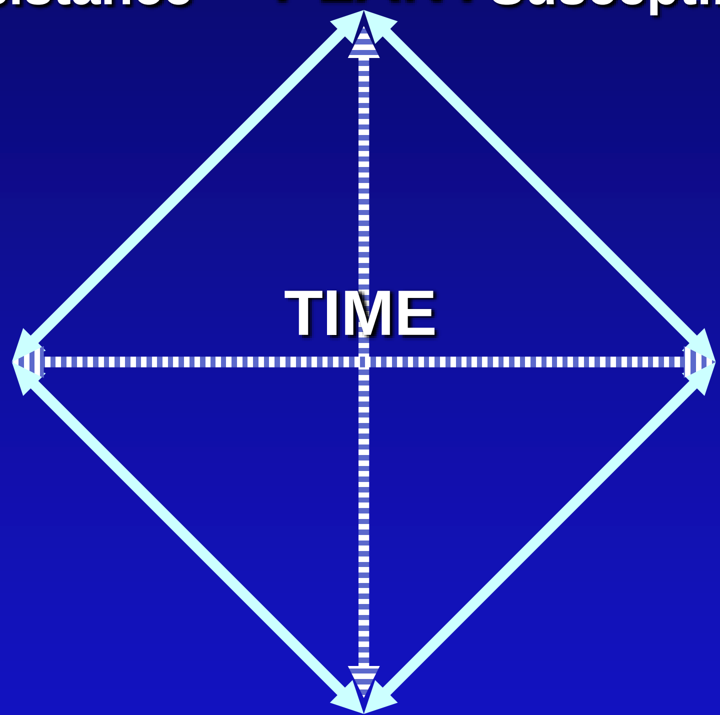
"The roots may be the root of the problem!"

"The weak link may be underground!"

Interacting Factors Determining Nutrient Availability and Disease Severity

Vigor, Stage of Growth, Root Exudates

Resistance **PLANT** Susceptibility



PATHOGEN
- Population
- Virulence
- Activity

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

BIOTIC ENVIRONMENT

Antagonists, Synergists

Oxidizers, Reducers

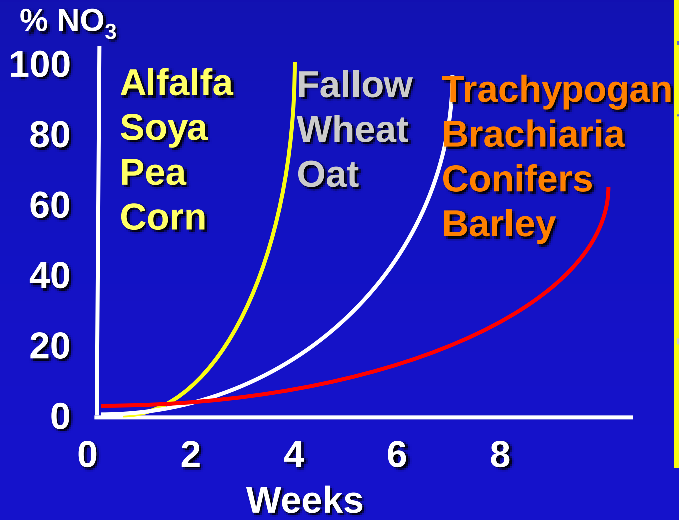
Competitors, Mineralizers

[Cu, Fe, K, Mn, N, S, Zn]

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
	Herbicide usage	

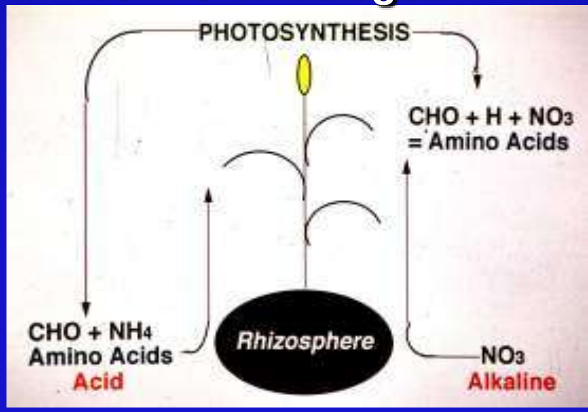
Effect of crop residue on nitrification



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
Glyphosate	----	Decrease	Increase
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

Mn Sufficiency* Range for Agronomic Crops

Crop	Range	Crop	Range
Barley	25-100	Sorghum	6-190
Bean	20-100	Soybean	20-100
Canola	25-250	Sugar beets	26-360
Corn	15-300	Sugar cane	25-400
Cotton	25-350	Sunflower	50-1000
Oats	25-100	Tobacco	26-400
Peanut	60-350	Tomato	25-35
Rice	150-800	Wheat, spring	25-100
Rye	14-45	Wheat, Winter	16-200

*Depends on: cultivar efficiency, growth stage, soil physical and biological environment

After Bennett, 1994; Mills and Jones, 1996

Understanding the Characteristics of Glyphosate

Glyphosate has Changed Agriculture for 30+Years

- **A strong chemical chelator**

  Chelates minerals in the **spray tank**

  Chelates minerals in the **plant**

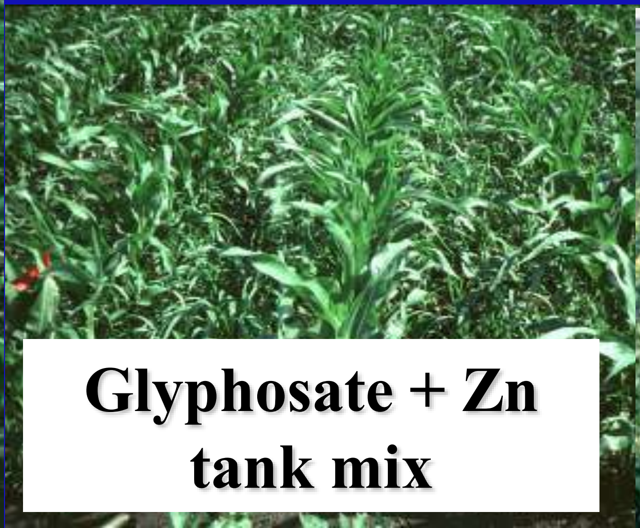
  Chelates minerals in the **soil**

  Reduces: B, Ca, Co, Cu, Fe, K, Mg, Mn, Ni, Zn

- **Non-specific herbicidal effect**

Chelating stability constants of glyphosate

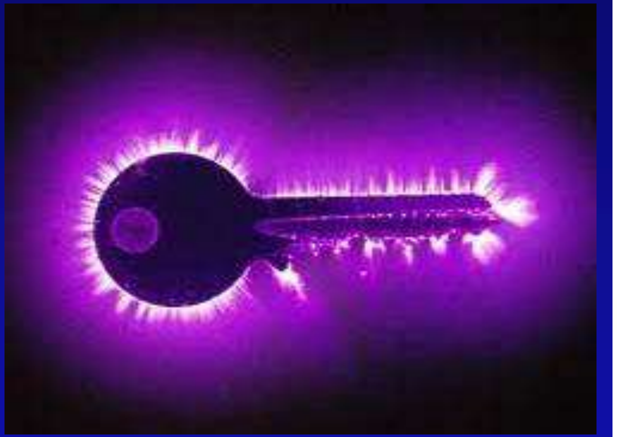
Metal ion	$\frac{[ML]}{[M][L]}$	$\frac{[MHL]}{[M][H][L]}$	$\frac{[ML_2]}{[M][L_2]}$
Mg^{2+}	3.31	12.12	5.47
Ca^{2+}	3.25	11.48	5.87
Mn^{2+}	5.47	12.30	7.80
Fe^{2+}	6.87	12.79	11.18
Cu^{2+}	11.93	15.85	16.02
Fe^{3+}	16.09	17.63	23.00



Nutrients are:

Components of plant parts as well as

Activators,



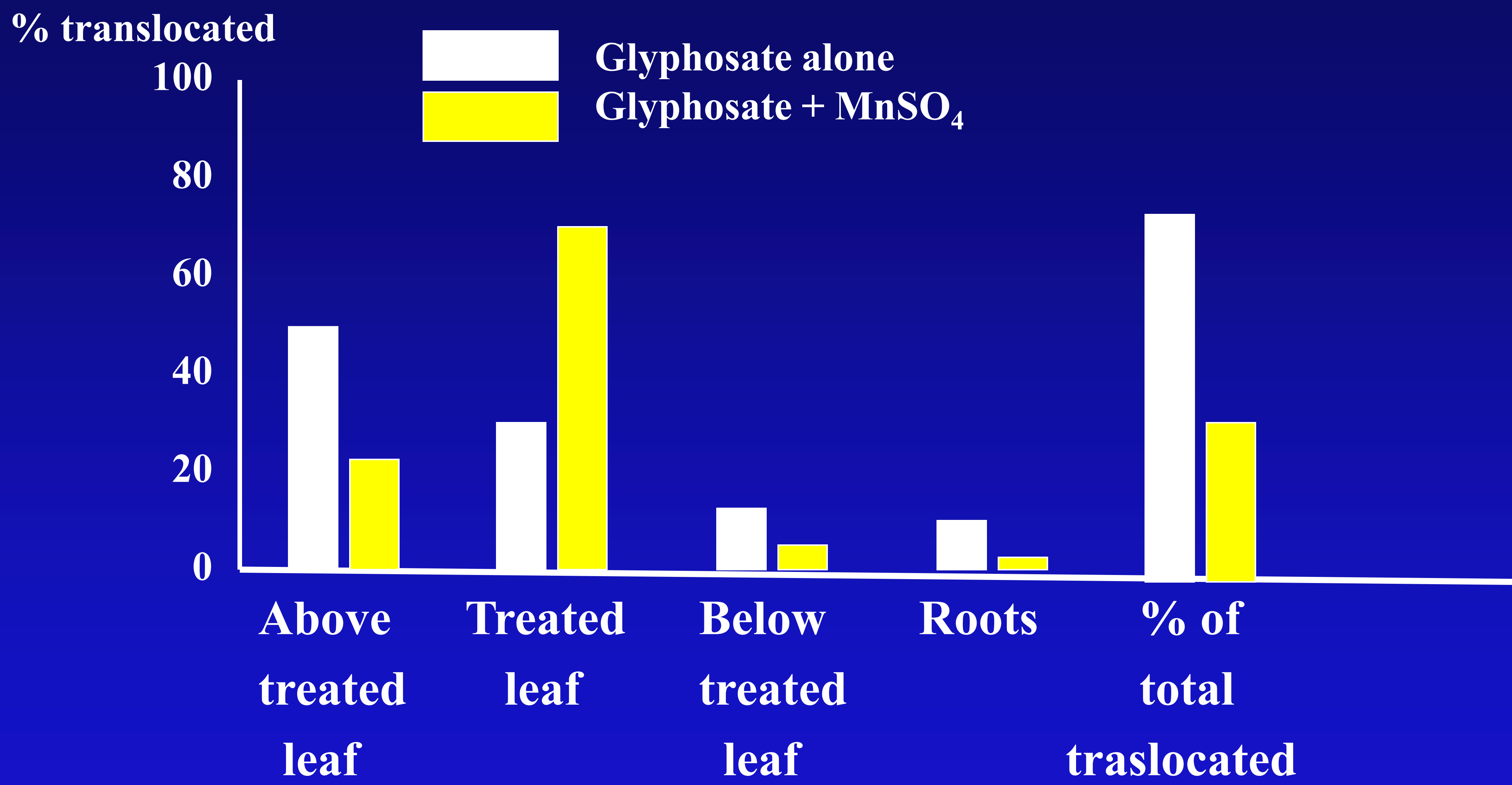
Inhibitors,

and Regulators

of Physiological Processes

Many herbicides and pesticides are chelators

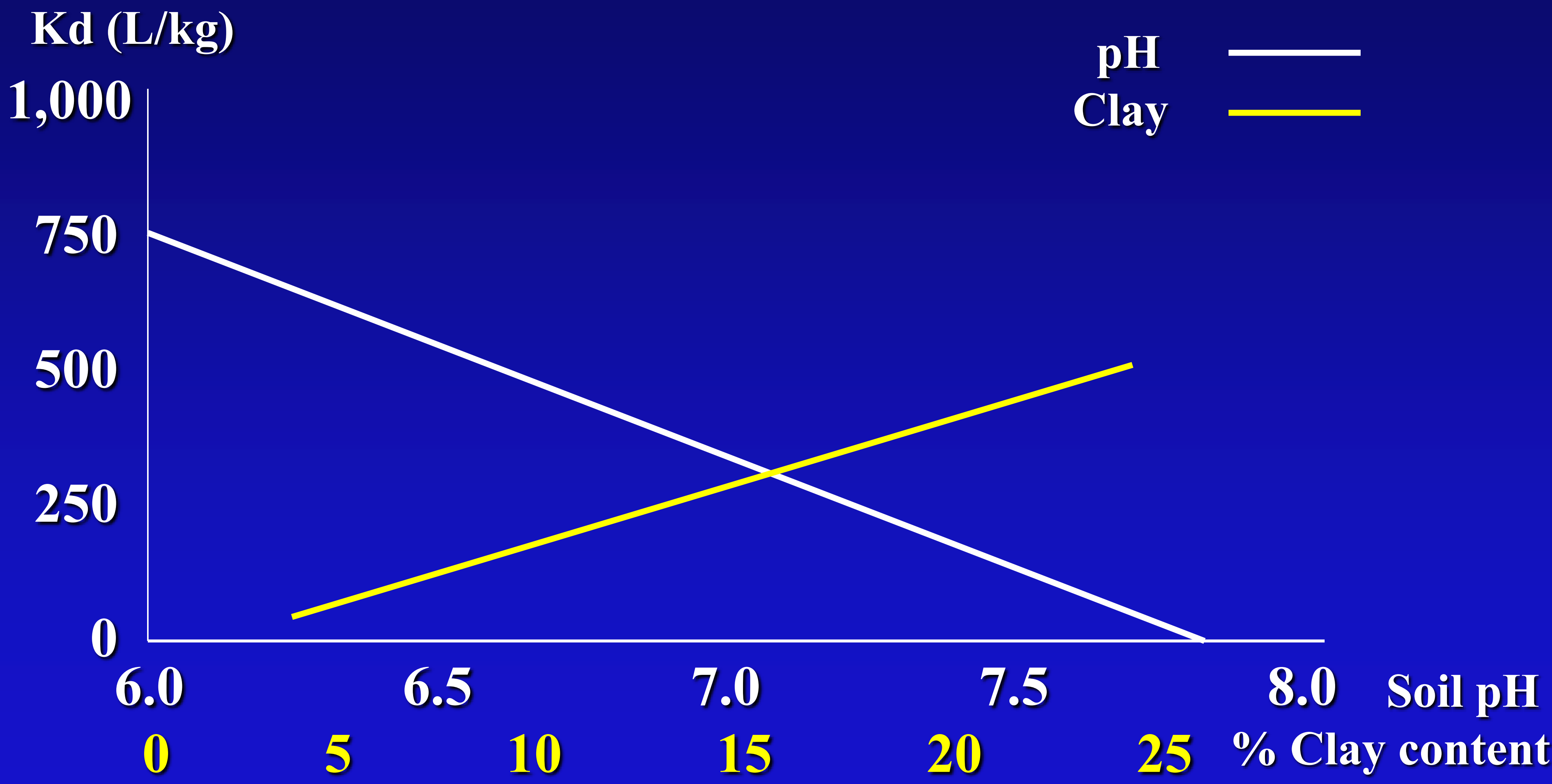
Effect of Mn* on translocation of Glyphosate



*Tank-mix with AMS - 48 hours after treatment - C^{14} glyphosate

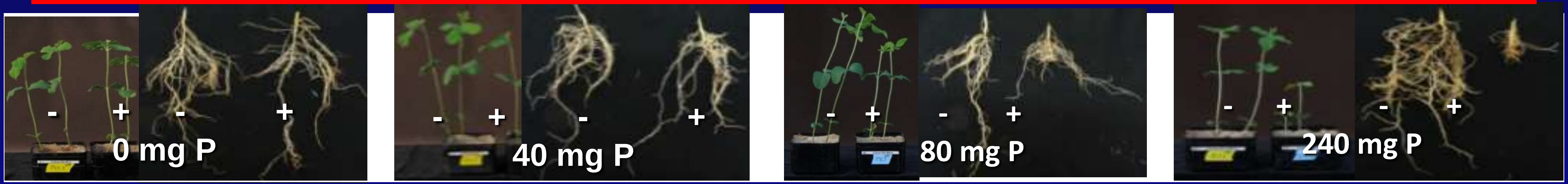
Effect of pH on Soil Sorption of Glyphosate

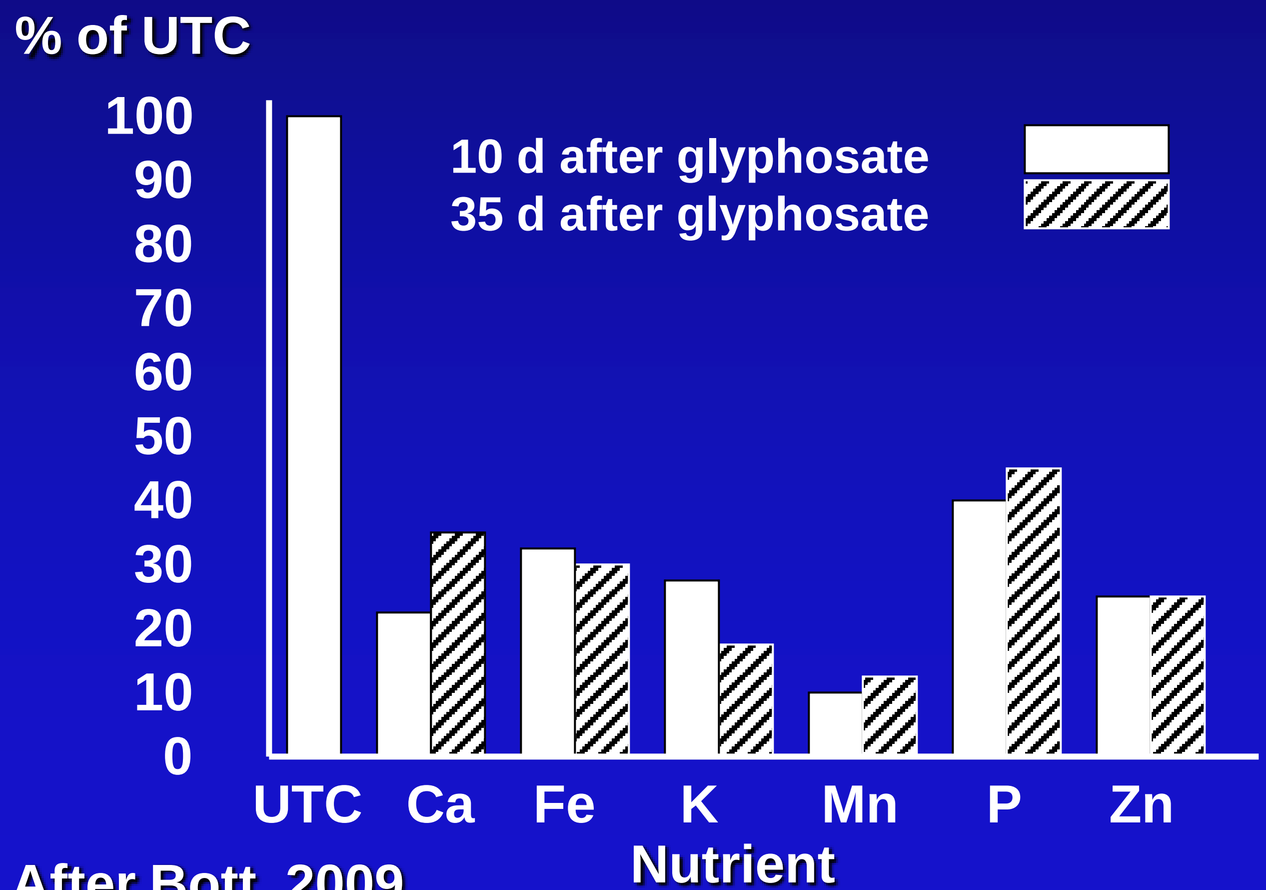
(After Farenhorst et al, 2009)

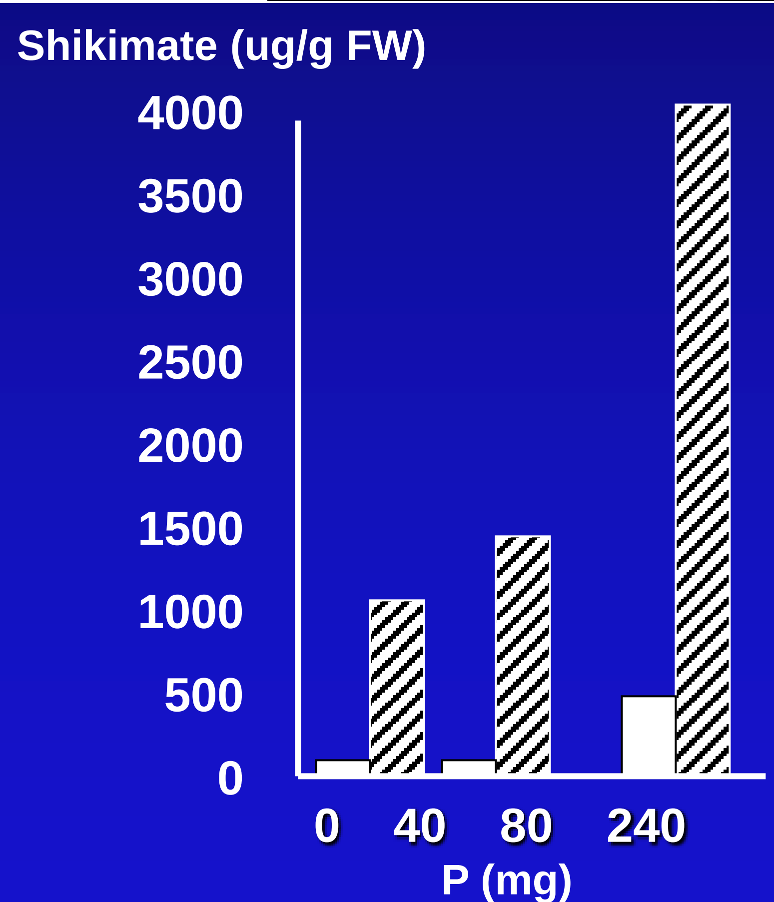


Glyphosate kd values = 19 - 547; 2,4-D kd values = 0.12 - 2.61

Effect of Phosphorus Desorption of Glyphosate in Soil on Soybean growth and Nutrient Content



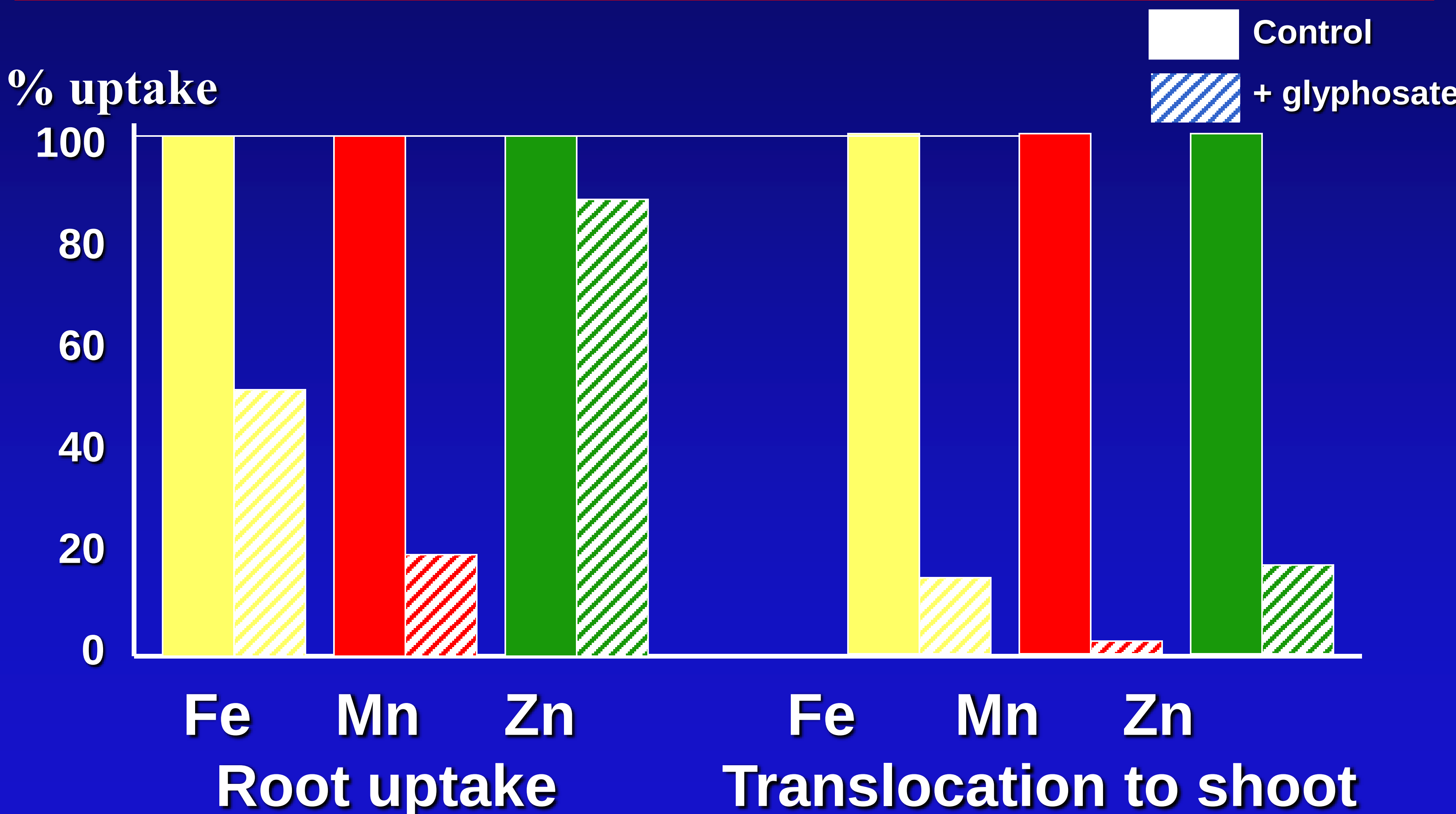




After Bott, 2009

Effect of Residual or ’drift’ Glyphosate on Percent Nutrient Uptake and Translocation by Plants

After Eker et al 2006*



* 1/40th of recommended herbicidal rate = 0.4 oz/a = 12 g/a

Foliar application of glyphosate

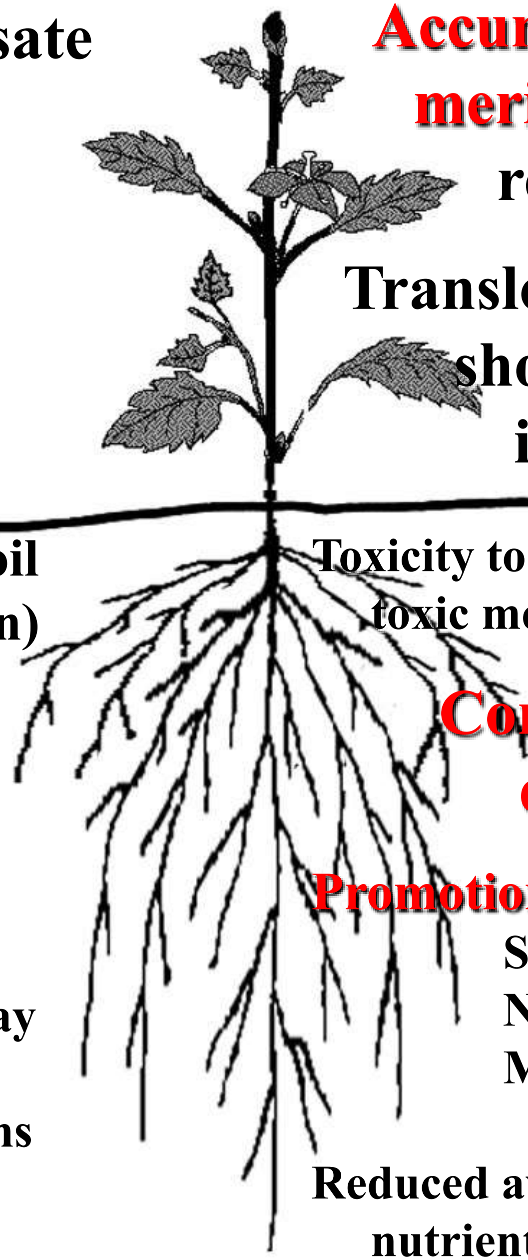
Systemic movement throughout the plant

Chelation of micronutrients

Intensifies stress

Accumulation of glyphosate in meristematic tissues (shoot, reproductive, and roots)

Translocation of glyphosate from shoot to root and release into the rhizosphere



Accumulation of glyphosate in soil (fast sorption; slow degradation)

Desorbed by phosphorus

Residual soil and residue effects

Glyphosate toxicity to:

- N-fixing microbes
- Bacterial shikimate pathway
- Mycorrhizae
- Biological control organisms
- Earthworms
- PGPR organisms

Toxicity to root tips by glyphosate or its toxic metabolites (e.g. AMPA)

Compromise of plant defense mechanisms

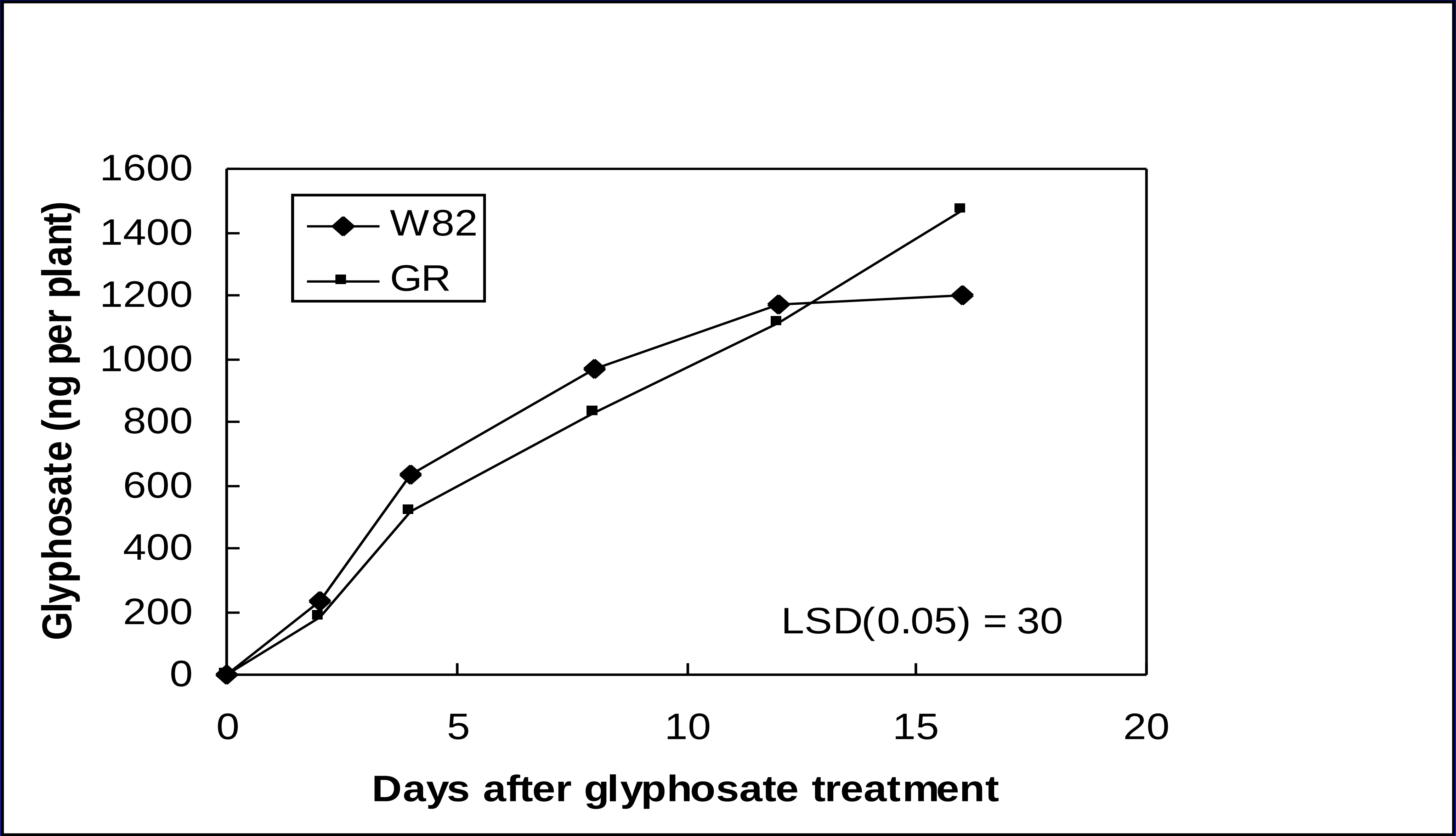
Promotion of soil-borne organisms:

- Soilborne pathogens - DISEASE
- Nutrient oxidizers (Fe, Mn, N)
- Microbial nutrient sinks (K, Mg)

Reduced availability or uptake of essential nutrients (Cu, Fe, K, Mg, Mn, N, Zn)

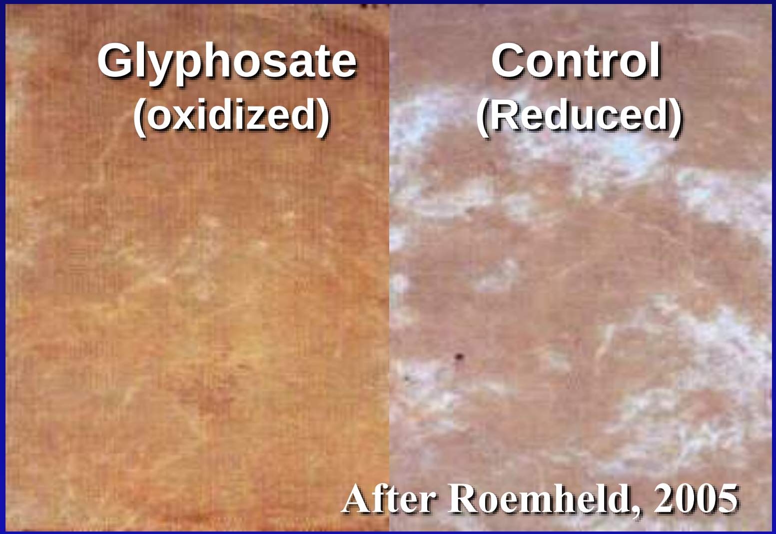
Schematic of glyphosate interactions in soil

Cumulative glyphosate release in root exudates of GR Soybean

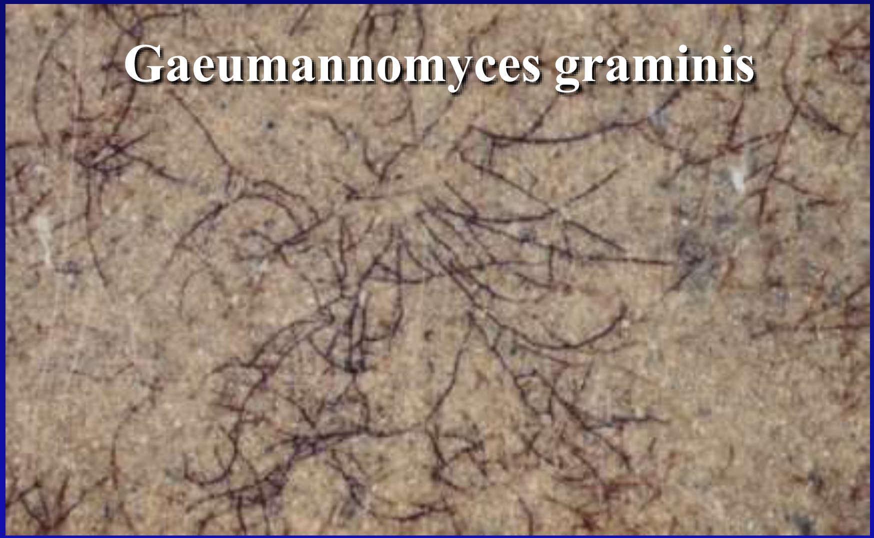


Kremer et al. Int. J. Environ. Anal. Chem. 85:1165, 2005

Mn Oxidation/Reduction in Soybean Rhizosphere Soil



Fungal Mn oxidation in soil (increased virulence)

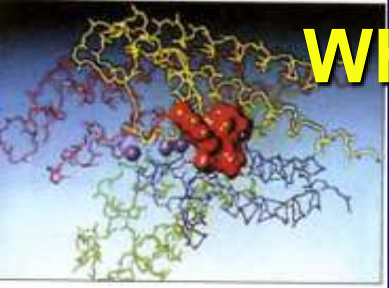


Manganese Oxidation in Soybean Rhizosphere

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

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

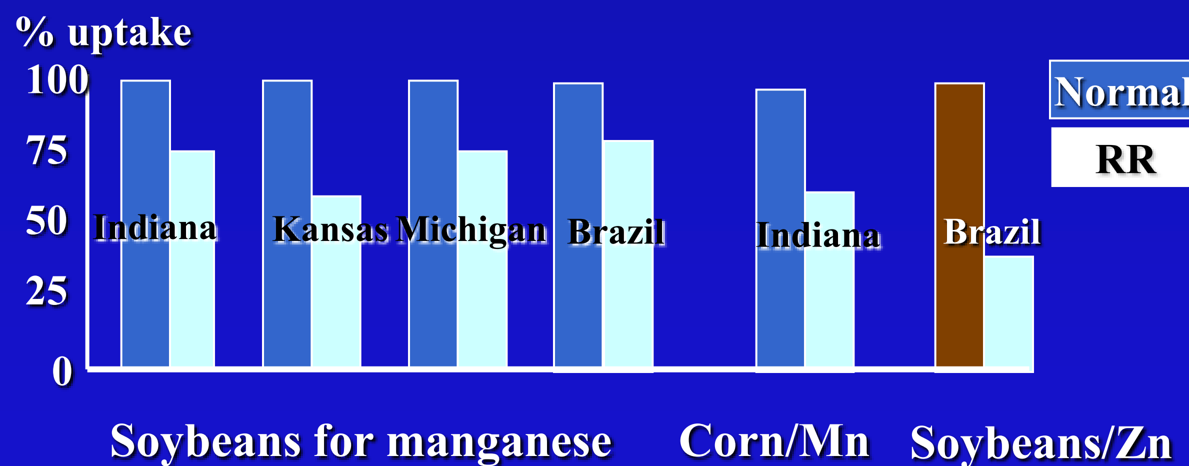
*Colonies per gram of soil



What's Special About Glyphosate Tolerance? (Roundup Ready® Genes)

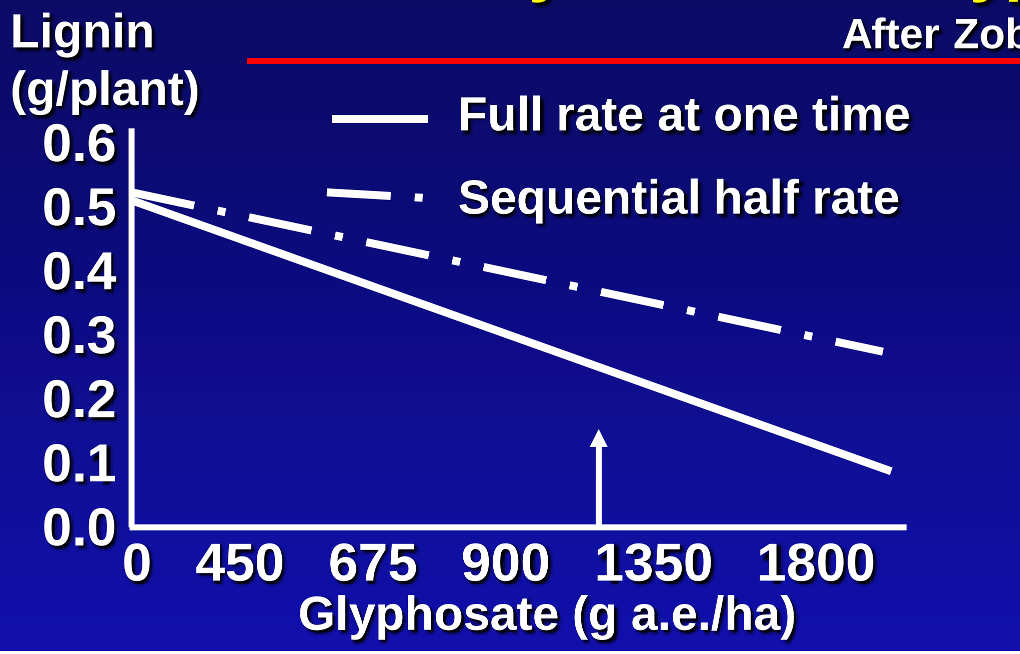
[Greatly expanded usage of glyphosate]

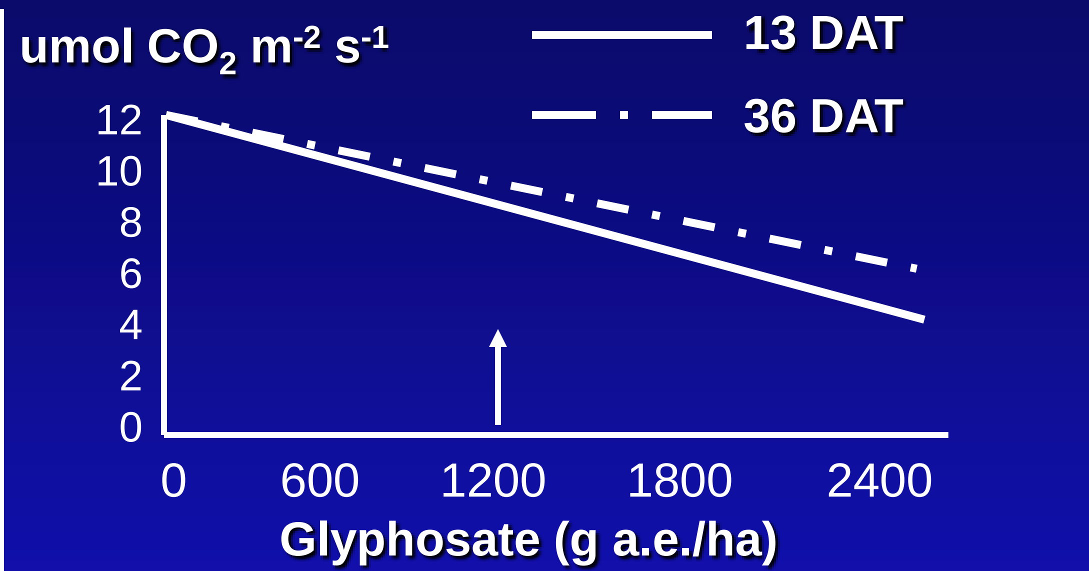
- **The technology inserts an alternative EPSPS enzyme that is not blocked by glyphosate in *mature* tissue**
- **There is nothing in the RR plant that operates on the glyphosate applied to the plant!**
  - **Glyphosate chelation is not selective it immobilizes nutrients Ca, Co, Cu, Fe, K, Mg, Mn, Ni, Zn**
  - **Reduces nutrient uptake**
- **Can cause a "Yield Drag"**
- **It is there for the life of the plant**

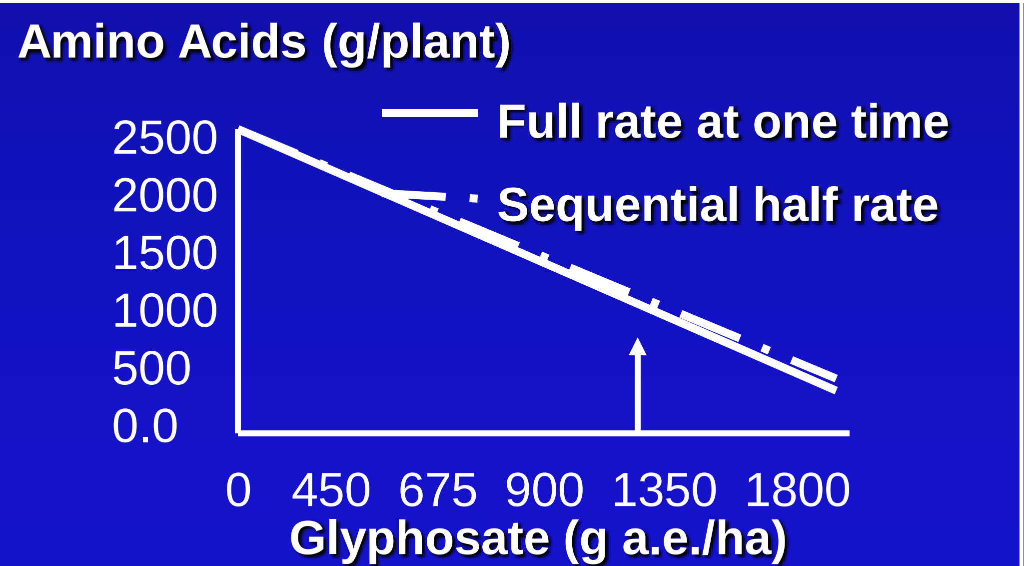


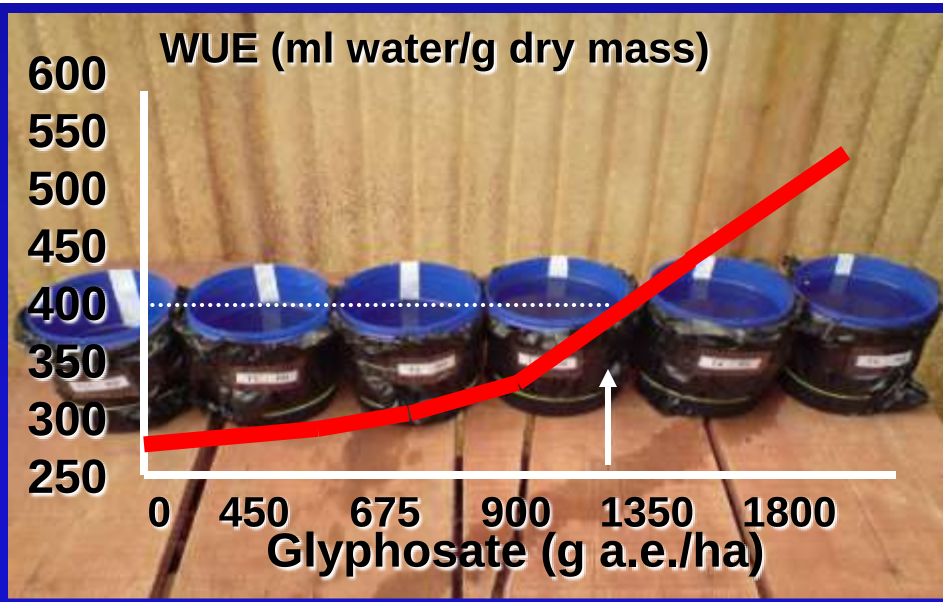
Effect of Glyphosate on Lignin, AA, Water Use Efficiency, and Photosynthesis of 'Glyphosate-Resistant' Soybeans

After Zobiole, 2009

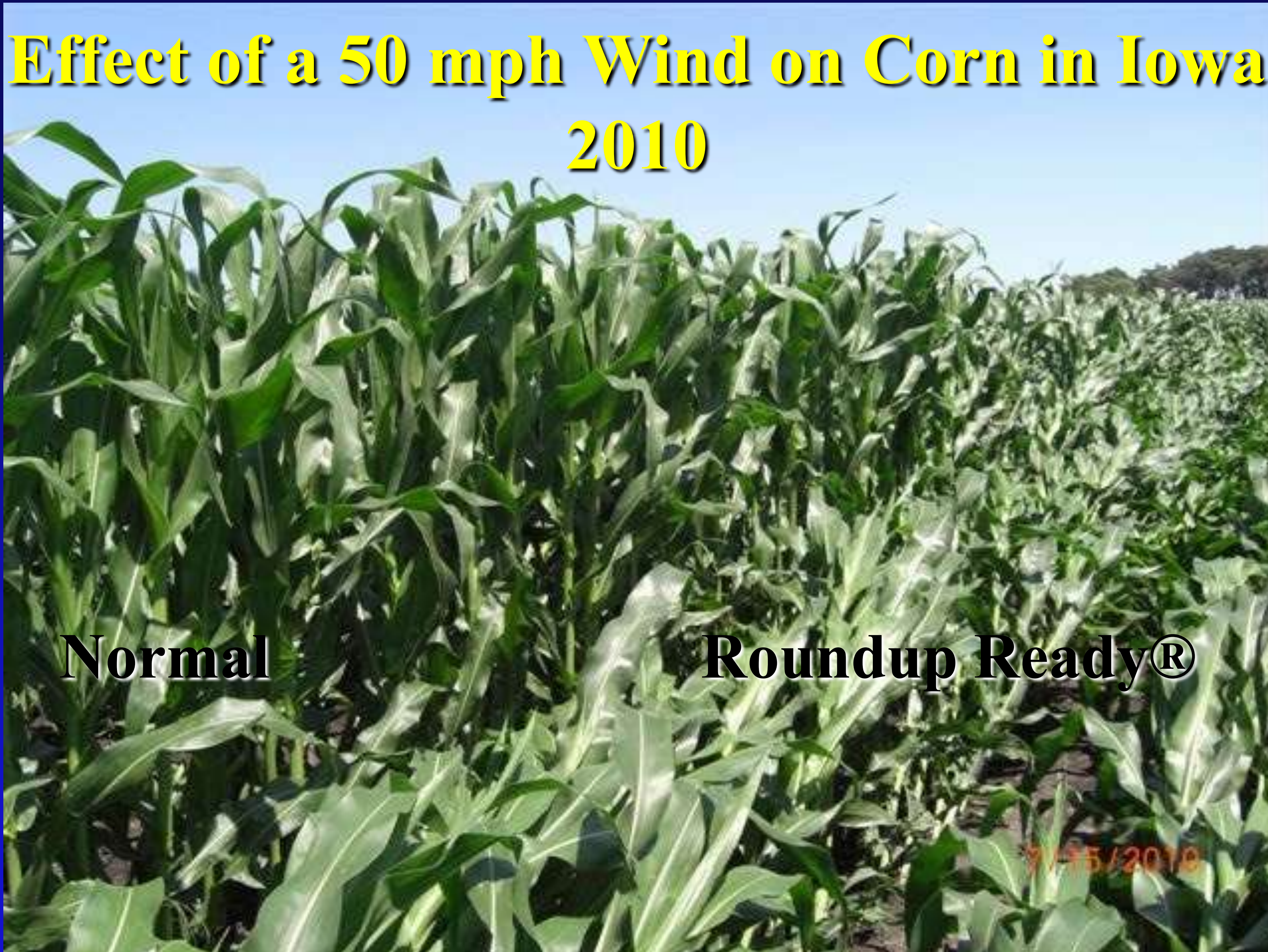




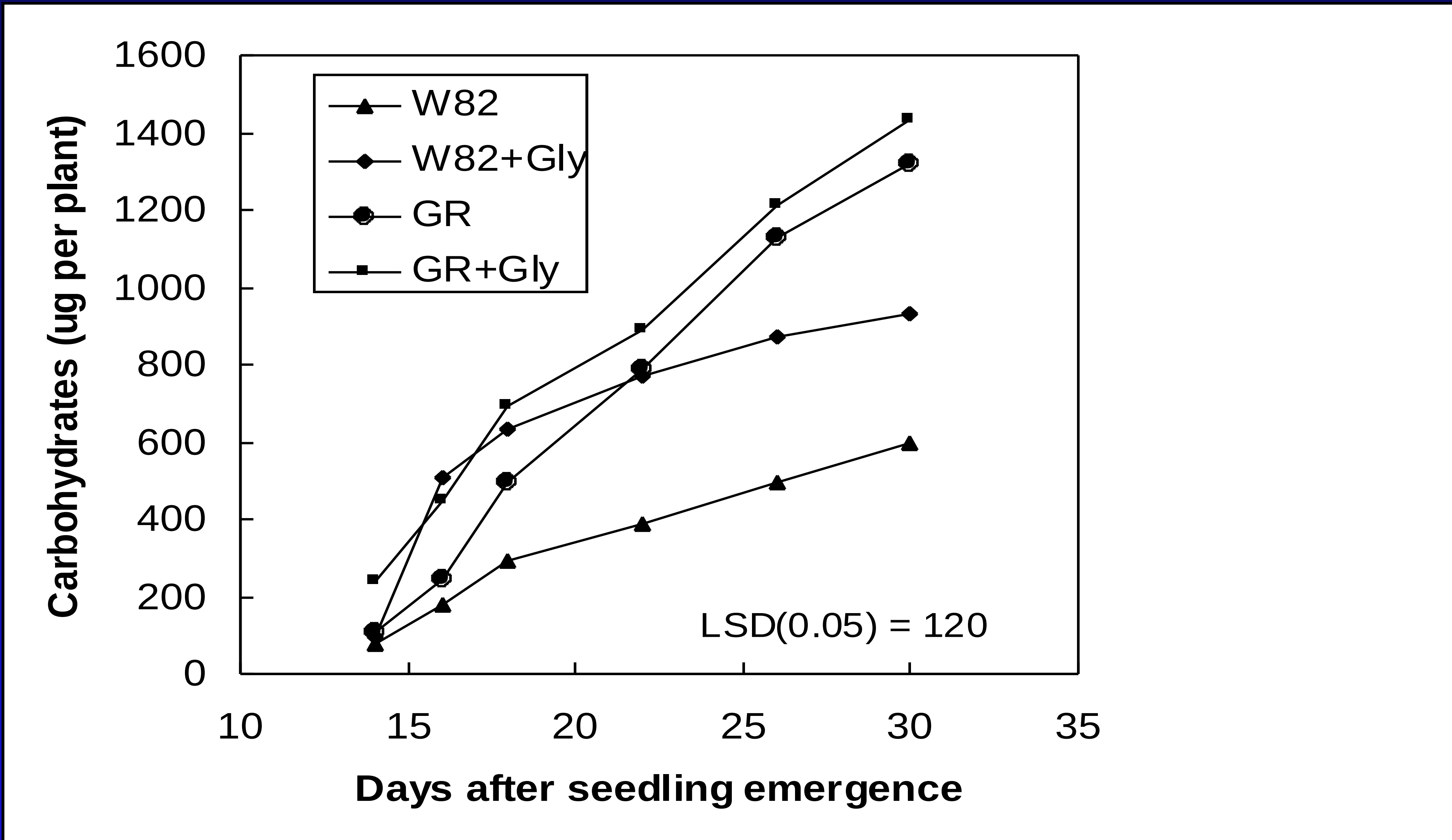




Effect of a 50 mph Wind on Corn in Iowa 2010

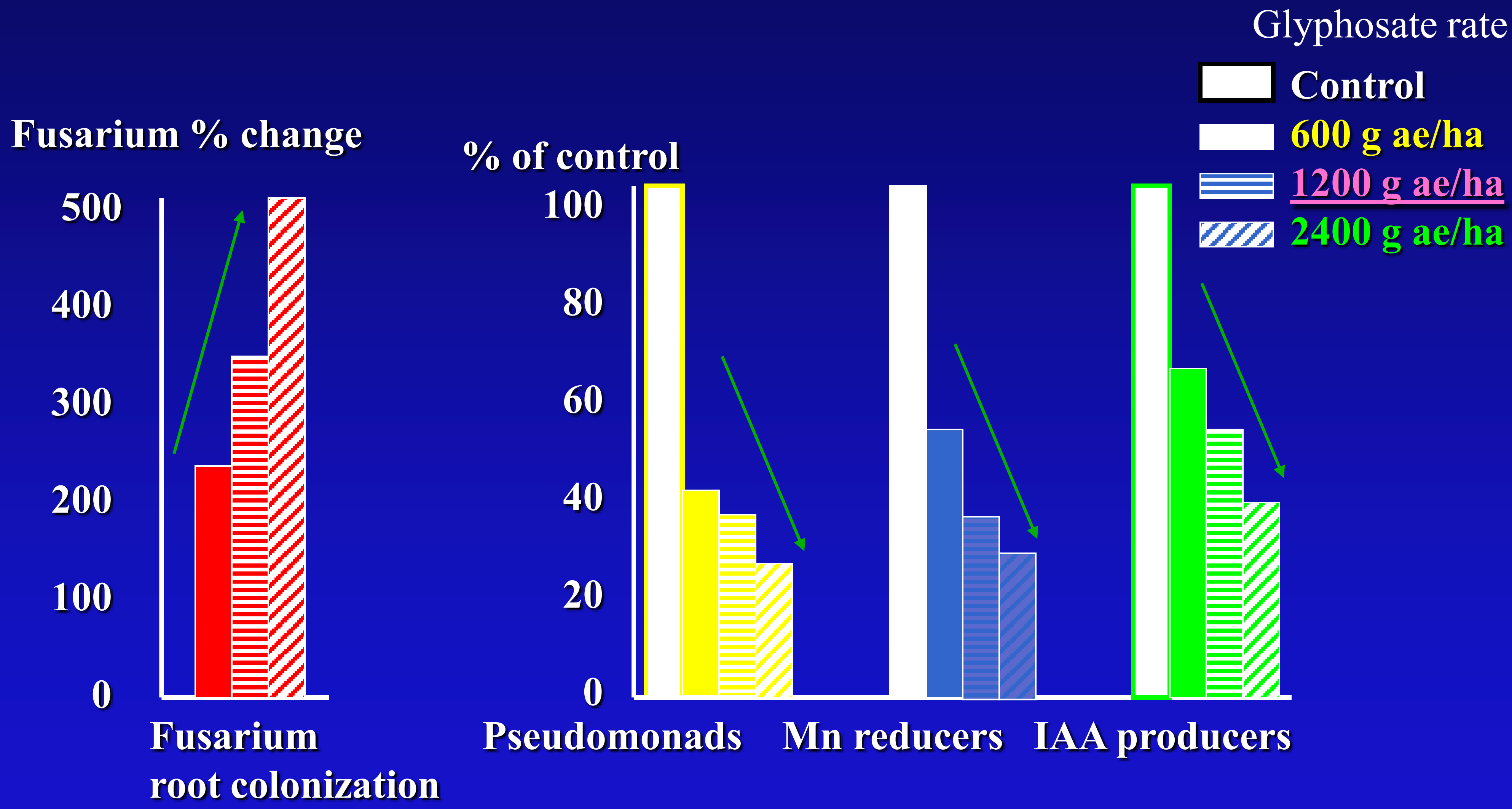


Cumulative carbohydrate released in exudates by GR soybean



(Kremer et al. Int. J. Environ. Anal. Chem. 85:1165, 2005)

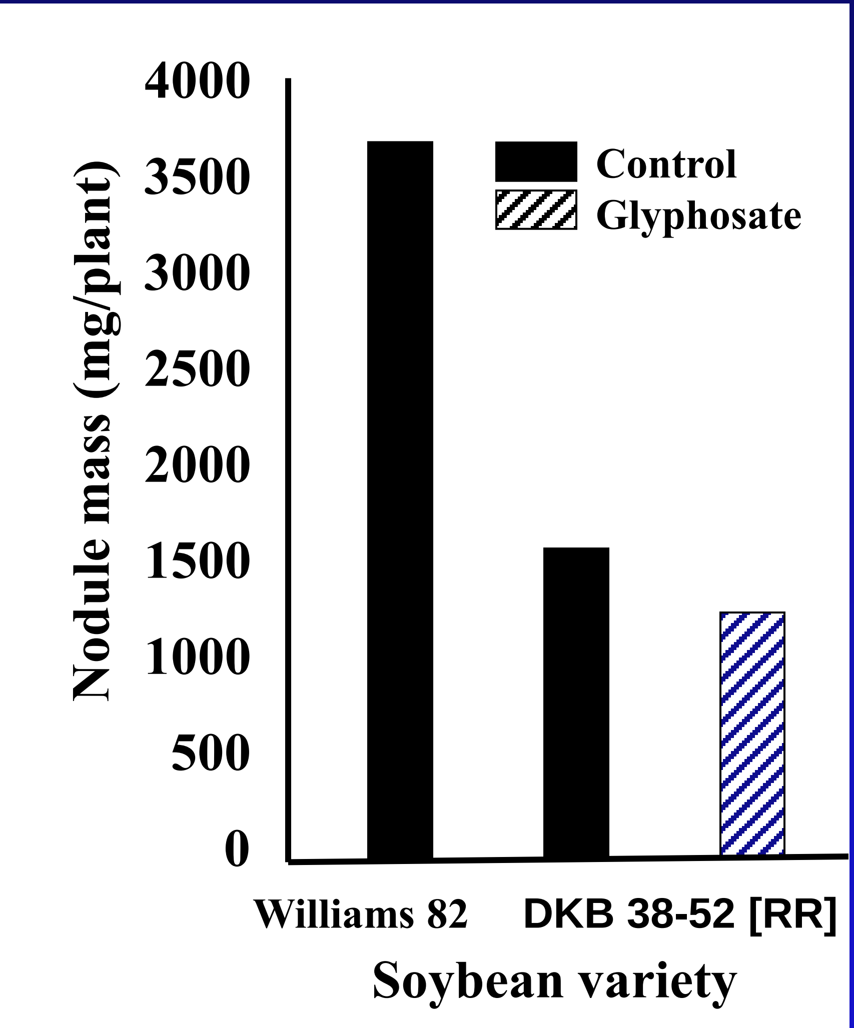
Microbiocidal Activity of Glyphosate



After Zobiole et al., 2010

Effect of the RR Gene & Herbicide on Root Nodule Mass

After Kremer & Means, 2009



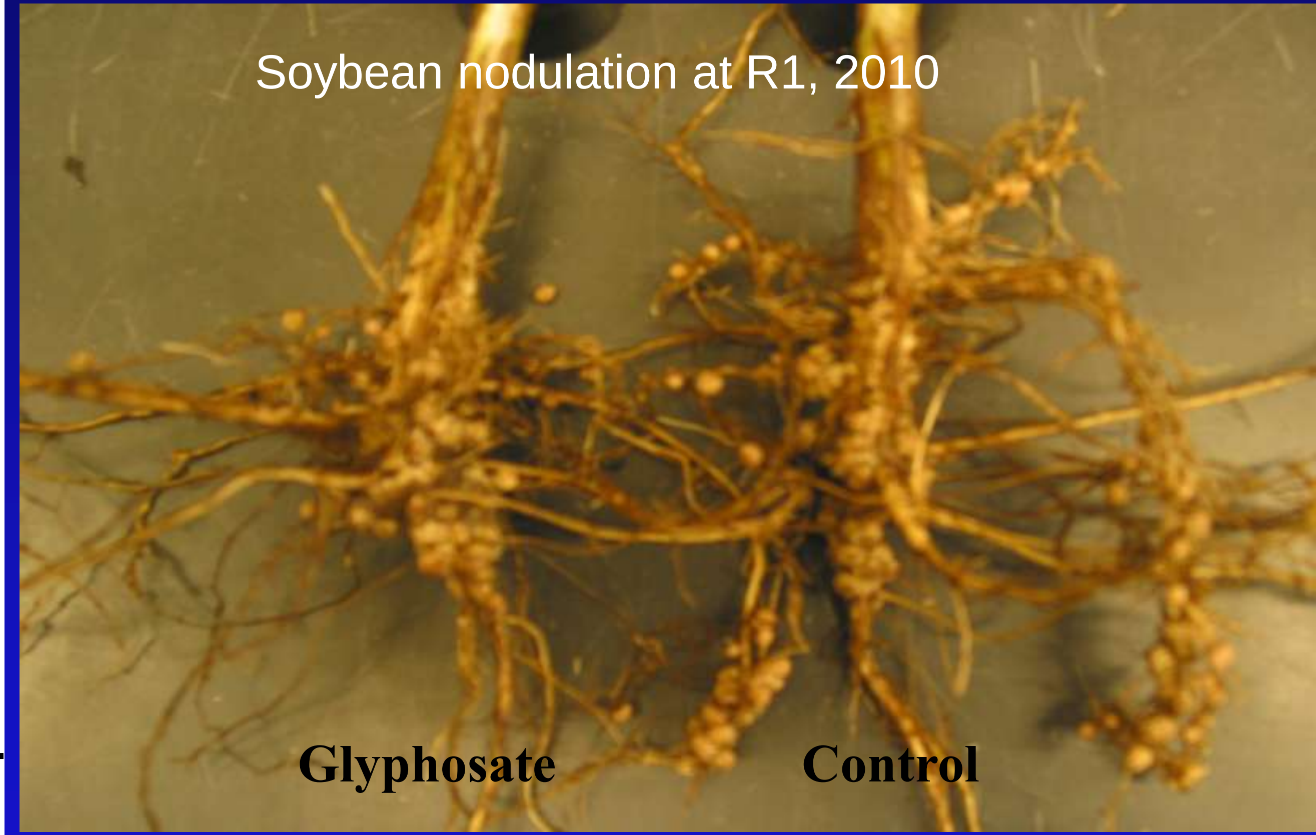
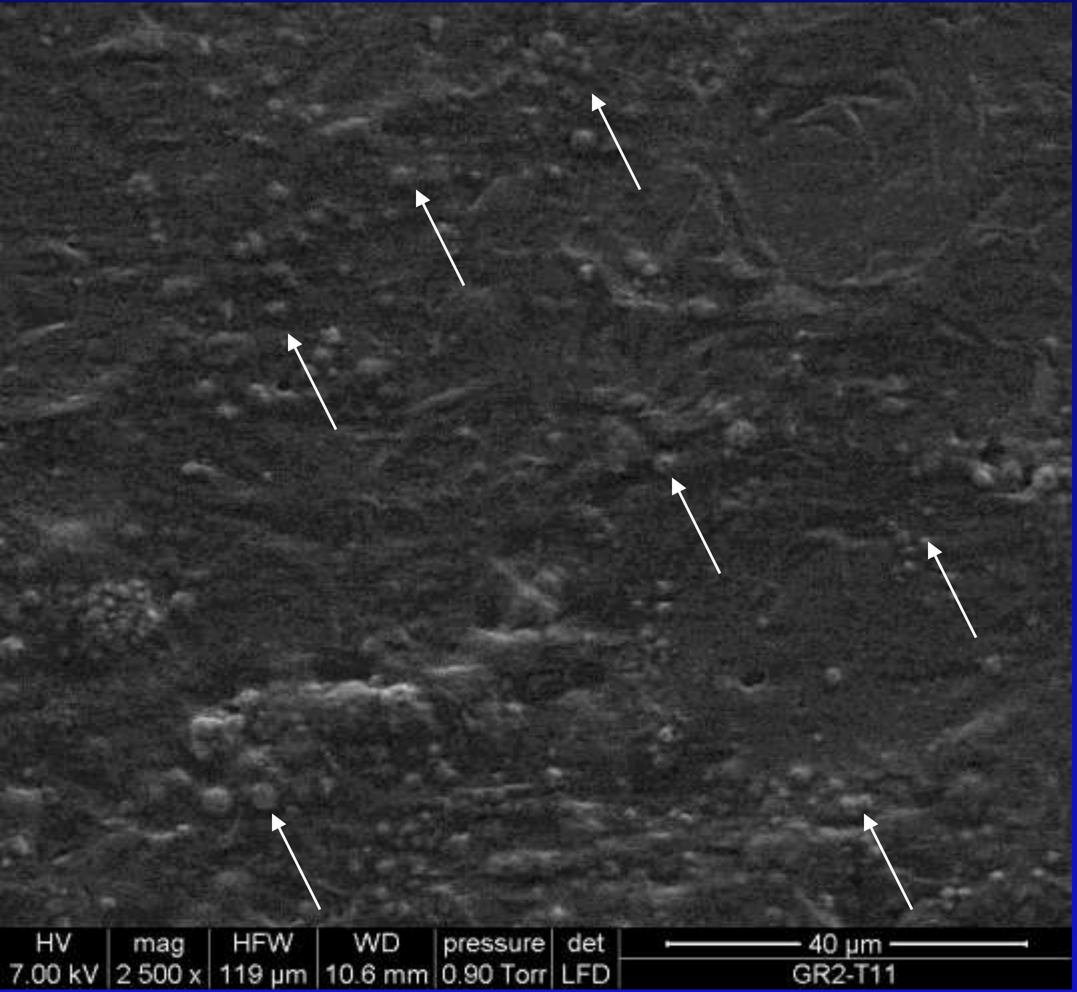
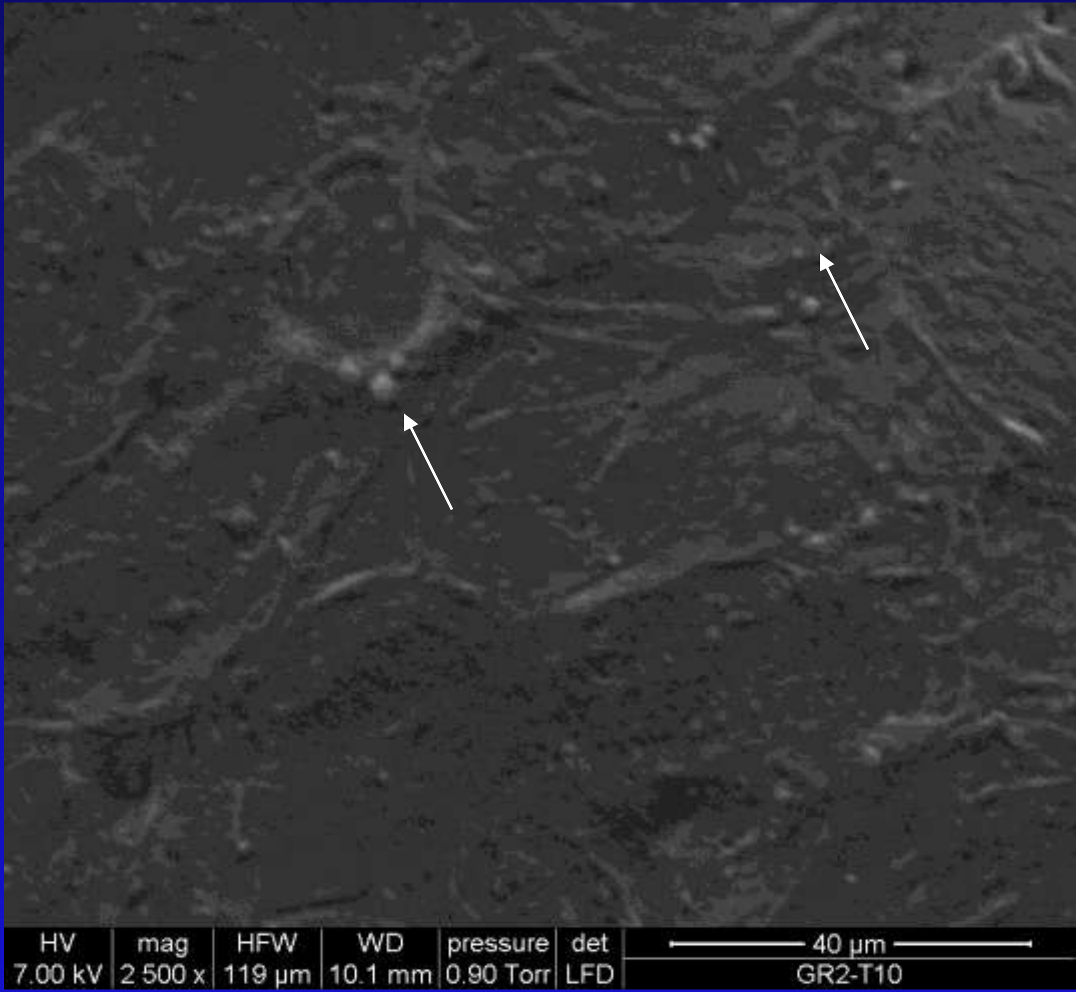


Photo by R. Kremer

Effect of Glyphosate on Nodule *Bradyrhizobium* on Roundup Ready® Soybeans



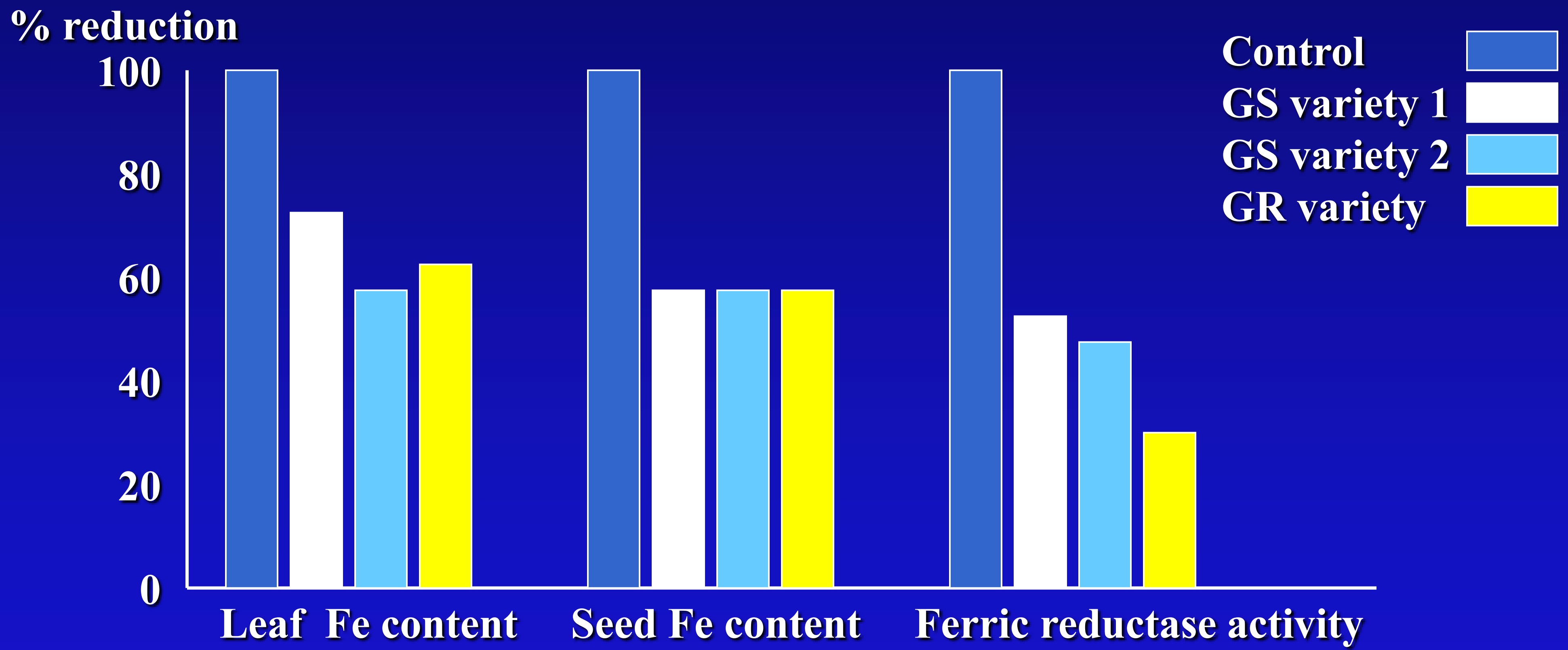
Normal nodule with many bacteria



Nodule after foliar glyphosate

After Zobiole et al., 2010

Effect of Glyphosate Drift* on Soybean Leaf and Seed Iron & Ferric Reductase Activity



***Drift rate = 12.5 % of herbicide rate = 56 g/a**

After Bellaloui et al, 2009

Reduced Nutrient Efficiency of Isogenic RR Soybeans (After Zobiole et al, 2008, 2009)

Isoline	Tissue: Mn %	Zn %
Normal	100	100
Roundup Ready©	83	53
RR + glyphosate	76	45

Copper, iron, and other essential nutrients Were also lower in the RR isoline and reduced further by glyphosate!

% Mineral Reduction in Tissue of Roundup Ready® Soybeans Treated with Glyphosate

Plant tissue	Ca	Mg	Fe	Mn	Zn	Cu
Young leaves	40	28	7	29	NS	NS
Mature leaves	30	34	18	48	30	27
Mature grain	26	13	49	45		

Reduced:

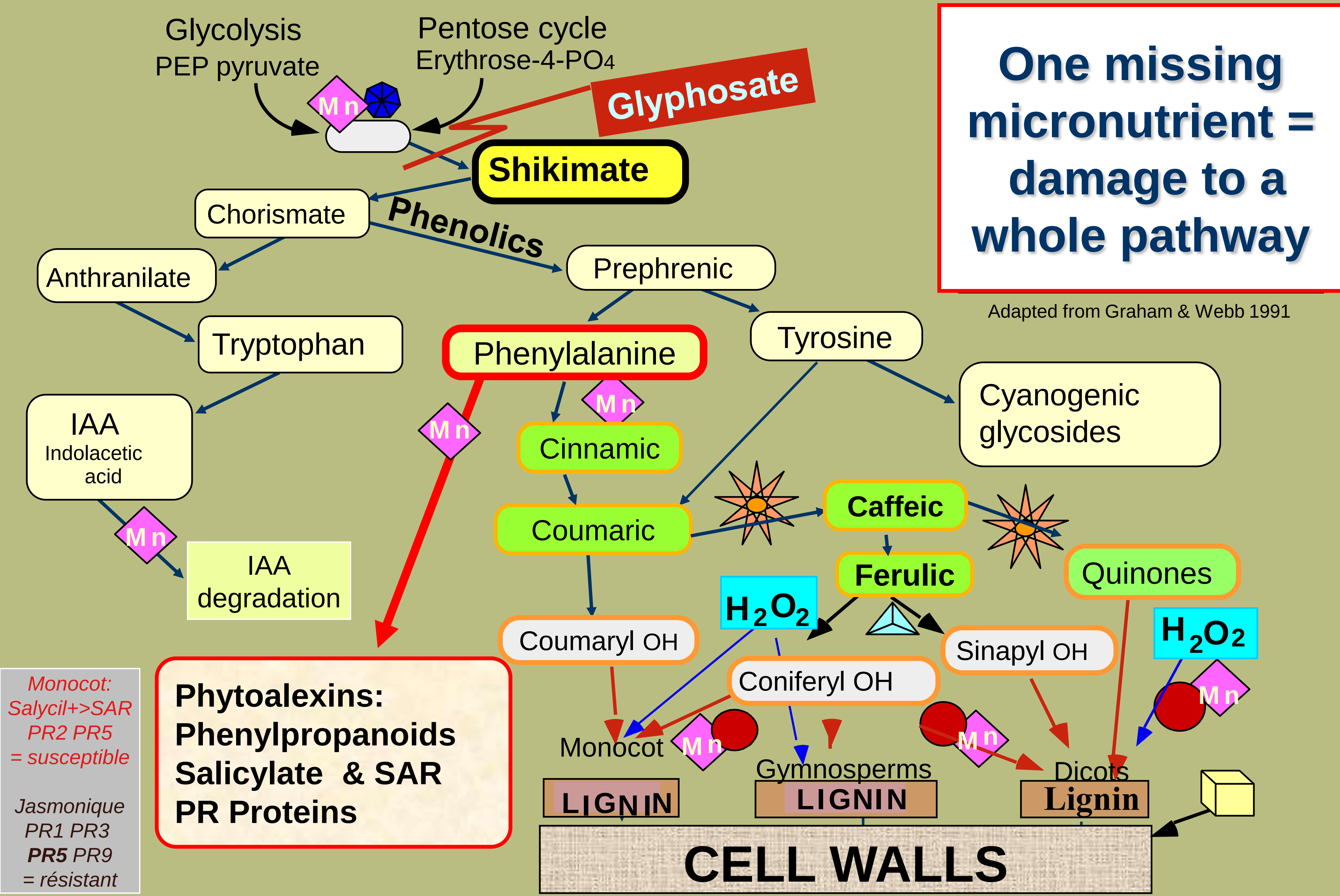
Yield 26%

Biomass 24%

After Cakmak et al, 2009

Importance of High Nutrient Seed

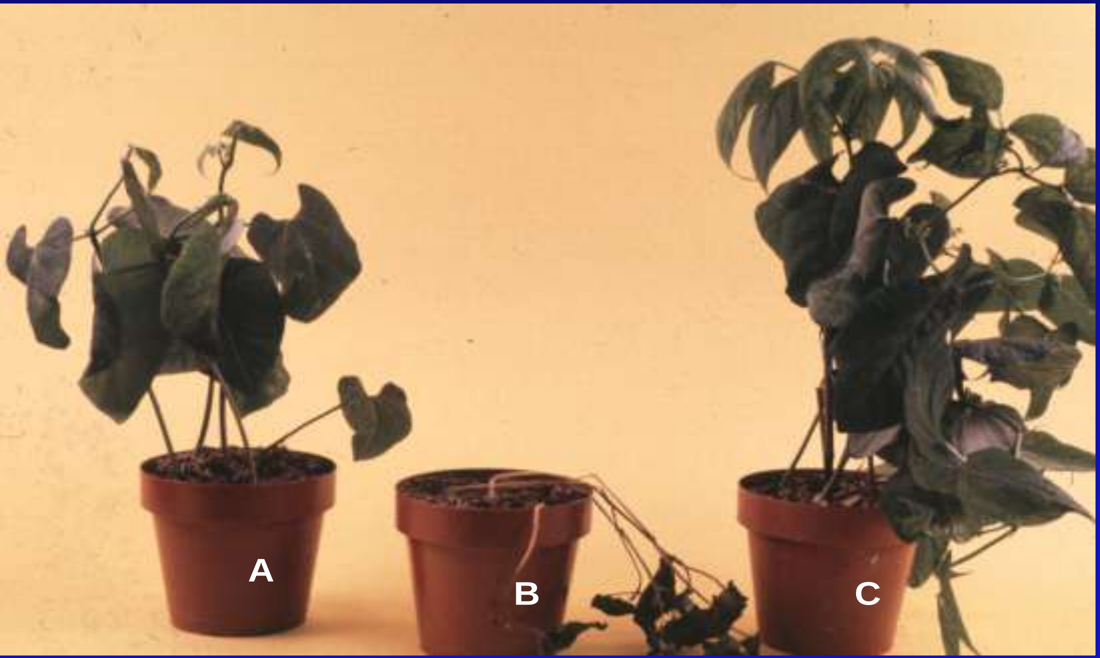
After Andre Comeau, 2008



One missing micronutrient = damage to a whole pathway
Adapted from Graham & Webb 1991
Glycolysis
PEP pyruvate
Pentose cycle
Erythrose-4-PO4
Glyphosate
Mn
Shikimate
Chorismate
Phenolics
Anthranilate
Prephrenic
Tryptophan
Phenylalanine
Tyrosine
IAA
Indolacetic acid
Mn
Mn
Mn
Cinnamic
Cyanogenic glycosides
IAA degradation
Coumaric
Caffeic
Ferulic
Quinones
H2O2
H2O2
Coumaryl OH
Sinapyl OH
Coniferyl OH
Monocot
Mn
Mn
Mn
Gymnosperms
Dicots
LIGNIN
LIGNIN
Lignin
CELL WALLS
Phytoalexins:
Phenylpropanoids
Salicylate & SAR
PR Proteins
Monocot:
Salycil+>SAR
PR2 PR5
= susceptible
Jasmonique
PR1 PR3
PR5 PR9
= résistant

Herbicide action is by soil-borne fungal pathogens

Glyphosate Increases Disease Susceptibility



Glyphosate Sterile soil | Glyphosate Field soil | No glyphosate Control

Effect of glyphosate on susceptibility to anthracnose. A) hypersensitive response; B) non-limited response after glyphosate is applied.

After Rahe and Johal, 1988; 1990; See also Johal and Huber, 1999; Schafer et al, 2009.

Role of Soil Pathogens in Response to Glyphosate

- *Fusarium* and *Pythium* readily colonized susceptible giant ragweed roots when treated with glyphosate
- Resistant Giant Ragweed in unsterile soil were killed by a 4x rate of glyphosate, yet susceptible biotypes were not killed with the same rate in sterile soil.
- Dry weight of susceptible biotypes treated with Ridomil Gold was not changed by glyphosate
- Resistant giant ragweed biotypes were resistant to *Pythium*
- Glyphosate increased susceptibility to *Pythium*

Glyphosate susceptible biotype 4 DAT

Pythium Control | Pythium + glyphoste | Glyphosate control

Glyphosate treated

Susceptible biotype | Resistant biotype

Ridomil | Ck | Ridomil | Ck

Fungicide

Schafer et al, 2009, 2010

Some Plant Pathogens Increased by Glyphosate

Pathogen	Pathogen
Increased:	*Cercospora* spp.
Botryospheara dothidea	*Marasmius spp.*
Corynespora cassicola	*Monosporascus cannonbalus*
Fusarium spp.	*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	*Clavibacter nebraskensis*
F. solani f.sp. Pisi	*Xanthomonas sterwartii*
Gaeumannomyces graminis	
Magnaporthe grisea	

(“Emerging” and “reemerging diseases”)

Abiotic: Nutrient deficiency diseases; bark cracking, mouse ear, ‘witches brooms’

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	*Fusarium oxysporum*
Citrus	CVC	*Xylella fastidiosa*
Corn	Root and Ear rots	*Fusarium* spp.
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, Target spot	*Corynespora cassicola*
Soybeans	White mold	*Sclerotina sclerotiorium*
Soybeans	SDS	*Fusarium solani* f.sp. *glycines*
Sugar beet	Rots, Damping off	*Rhizoctonia and* Fusarium
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*

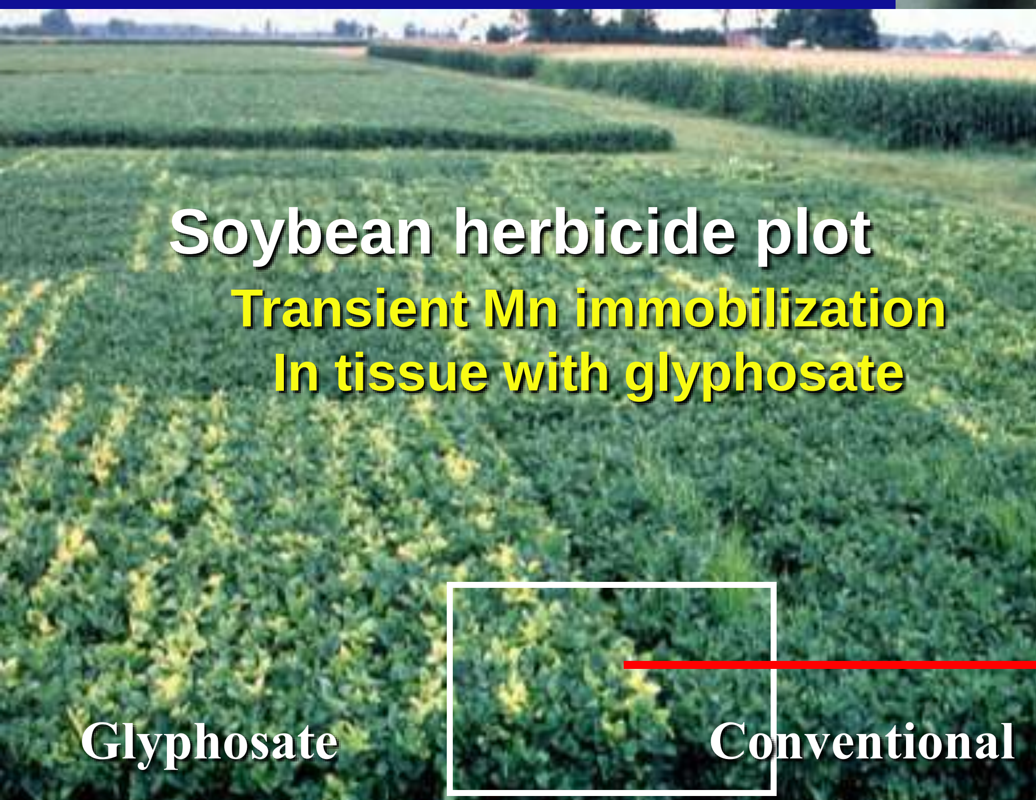

Fusarium scab


Take-all root rot

Effect of Glyphosate on Soybean Root Colonization by Fusarium (observed consistently, 1997-2007)

After Kremer, 2010

Impact of Glyphosate on Take-all



Impact of Glyphosate on Take-all

Factors Predisposing to Fusarium Head Scab

(*Fusarium* spp.; *Gibberella zeae*)

- ✓ ***Environment*** **was the most important factor in FHB development in eastern Saskatchewan, from 1999 to 2002**
- ✓ ***Application of glyphosate formulations*** **was the most important agronomic factor associated with higher FHB levels in spring wheat**
- ✓ **Positive association of glyphosate with FHB was *not affected by environmental conditions* as much as that of other agronomic factors…**

Number of glyphosate applications the previous three years	% Increase in head scab
None	00
1 to 2	152 ***
3 to 6	295 ***

(Fernandez et al. 2005, *Crop Sci. 45: 1908-1916*)

(Fernandez et al., 2007, Crop Sci. 47:1574-1584)

Glyphosate Predisposition to SDS, IA, 2010

Effect of Residual Glyphosate on RR2Y Soybeans, 2010*

2010 Soybean (– Osage County, MO

Scenarios - Substrates & glyphosate release from grass roots; soil fungi proliferate on grass AND soybean seedling roots; effects of soil residual glyphosate.

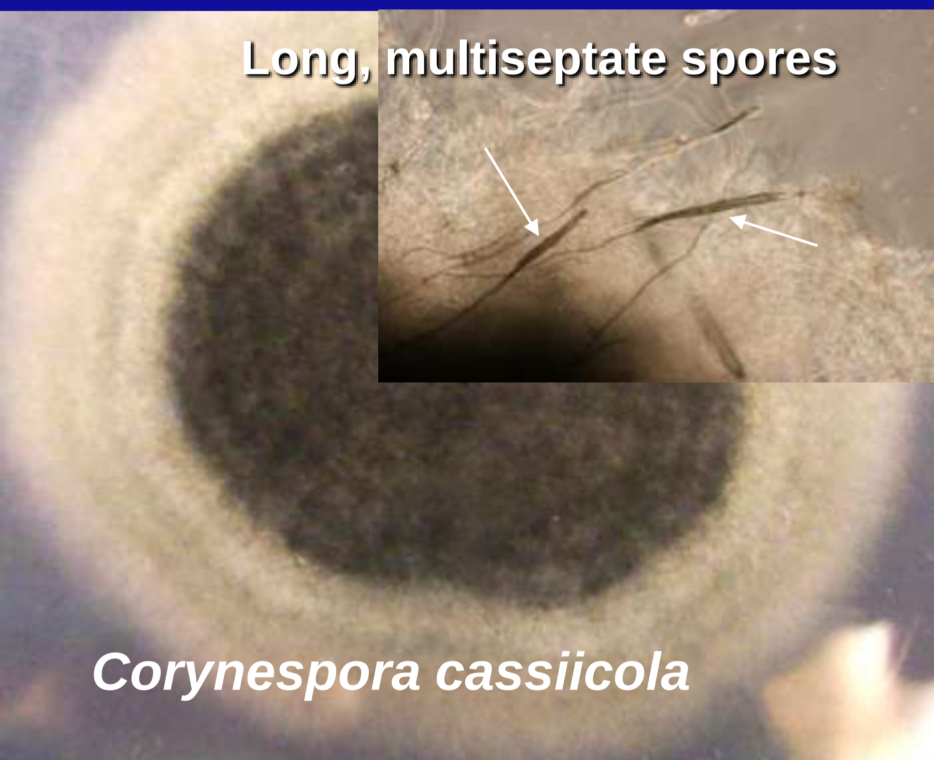
* Asgrow RR2Y

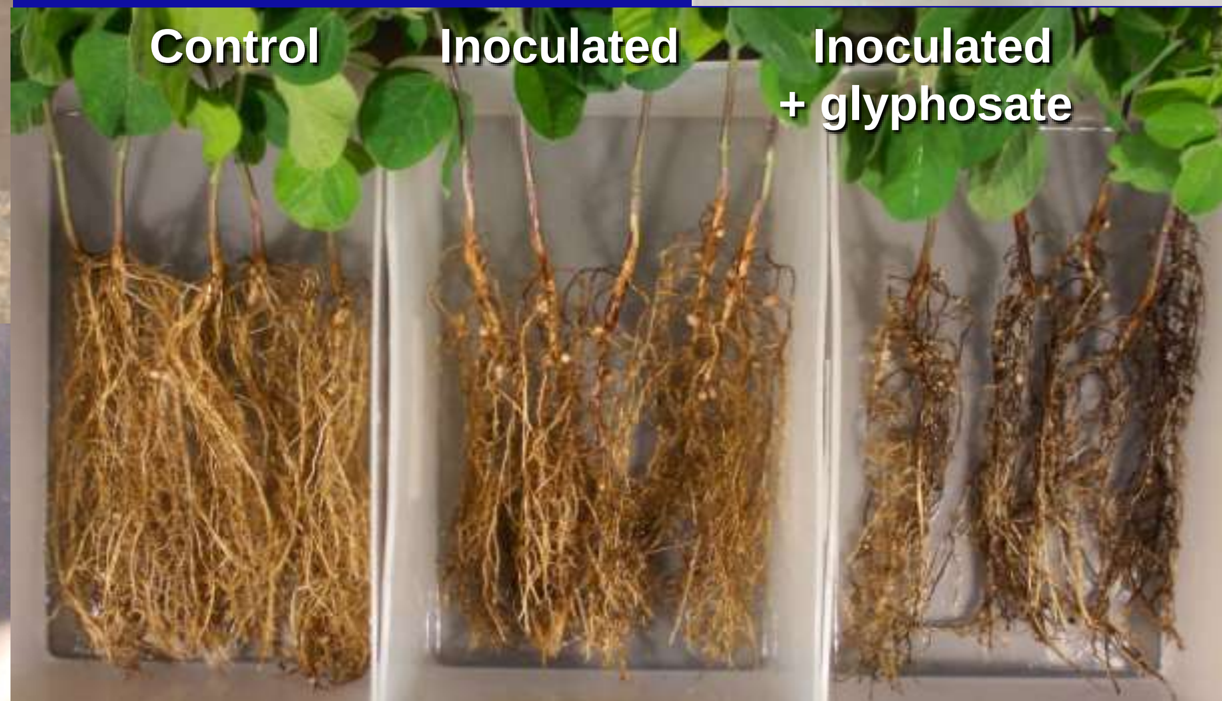
After Kremer, 2010

Corynespora Root Rot

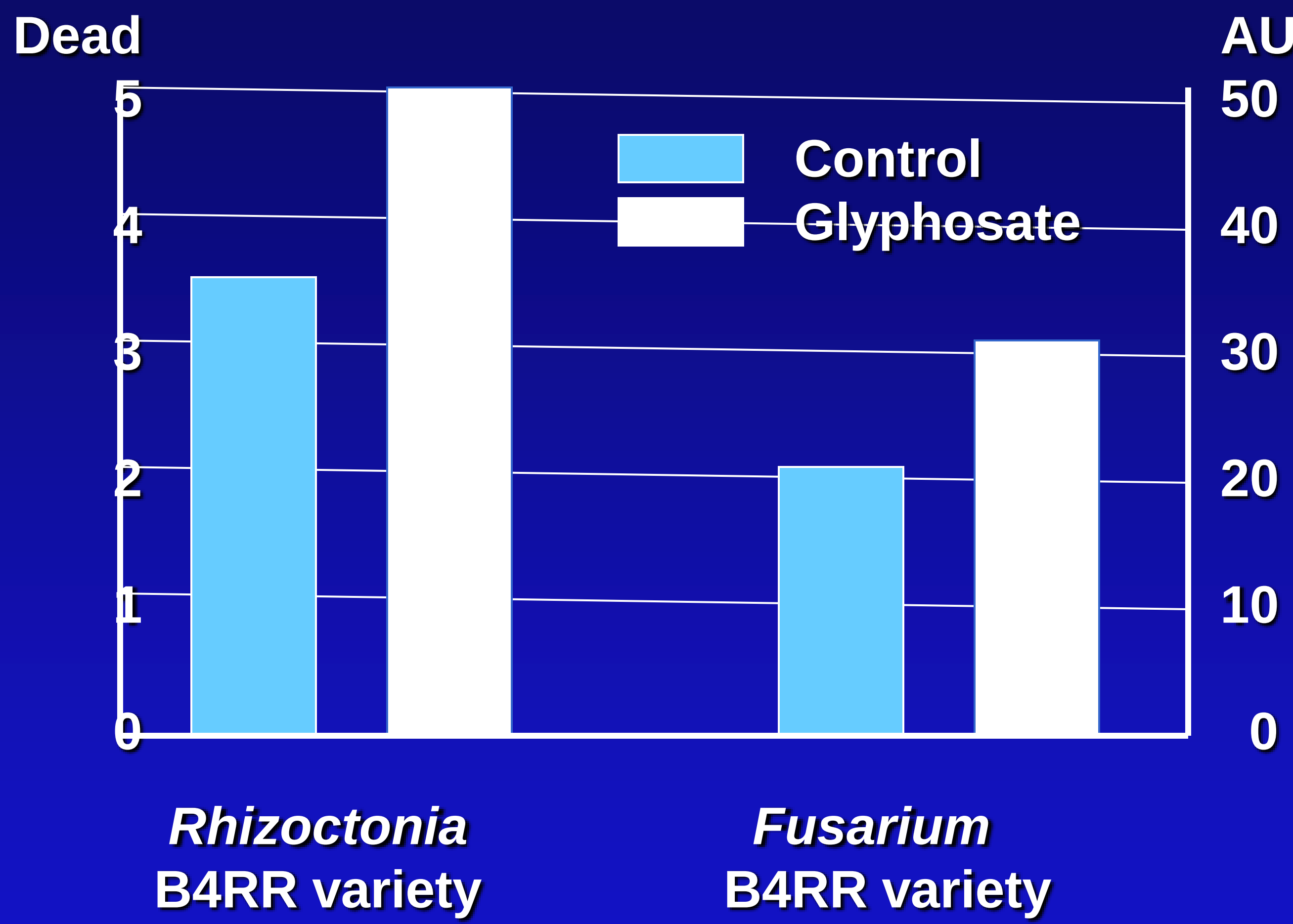
- An extensive dark brown to black rotting of small lateral roots
- Generally considered a root "nibbler"
- Severe with glyphosate and especially near weeds killed by glyphosate

Dead ragweed



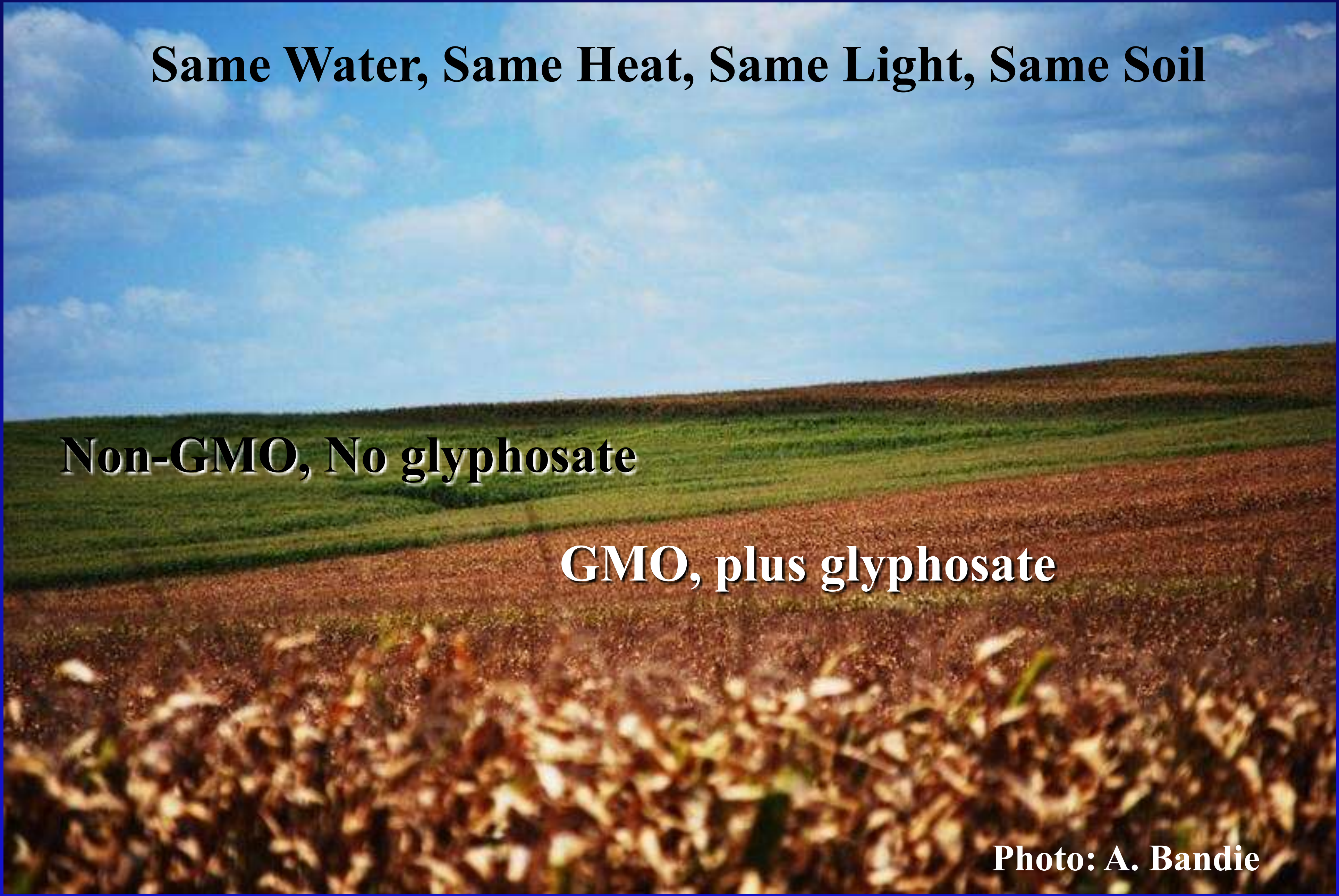


Impact of Glyphosate on Sugar Beet Resistance



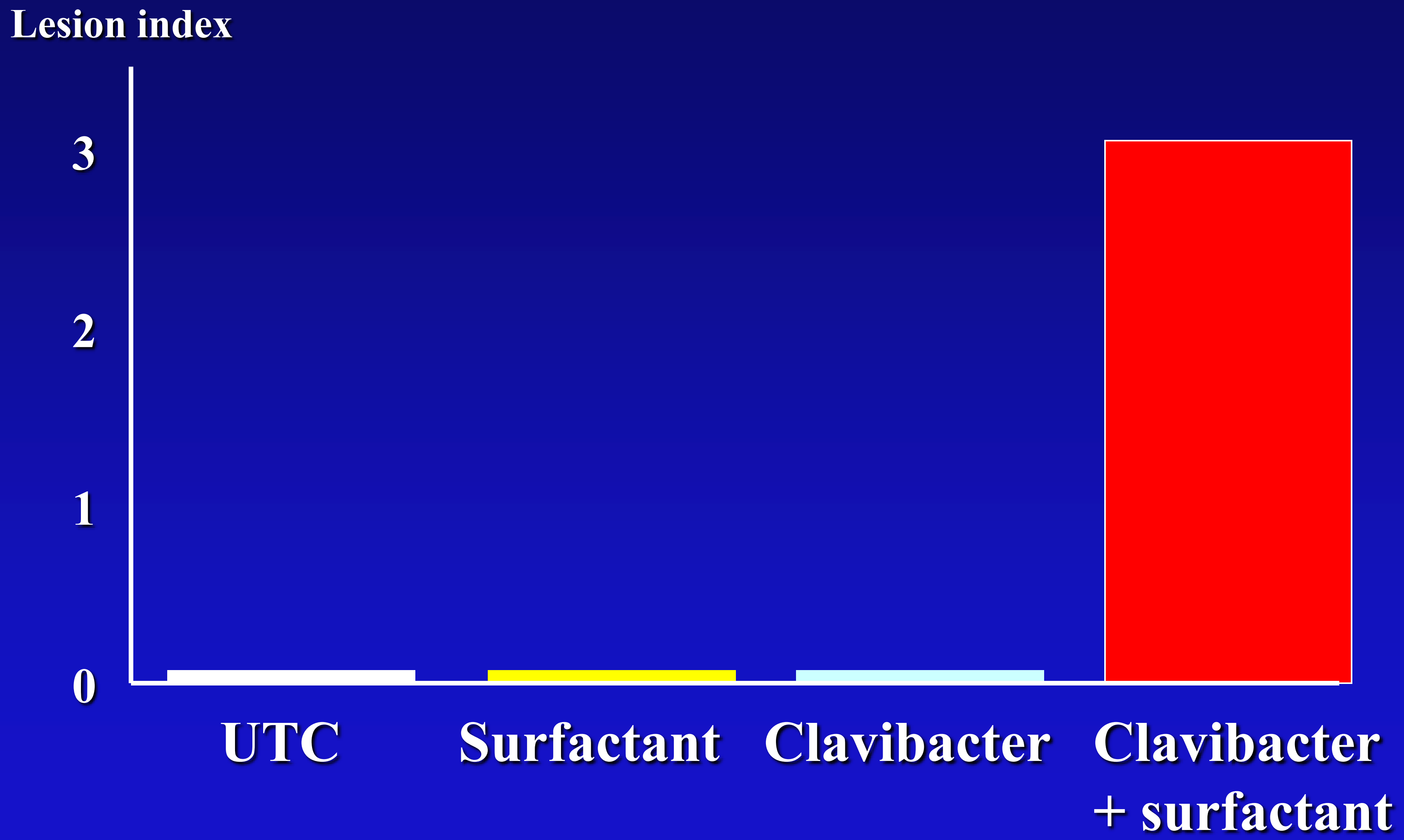
"Precautions need to be taken when certain soil-borne diseases are present if weed management for sugar beet is to include post-emergence glyphosate treatments." **Larson et al., 2006**

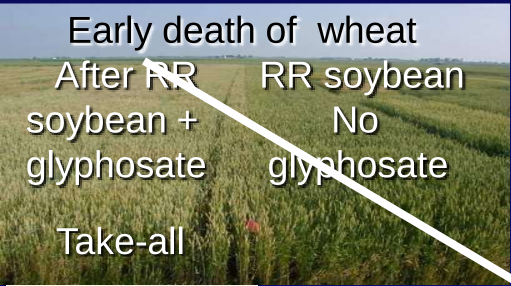
A Rose Amongst the Thorns" - SDS of Soybeans, 2010



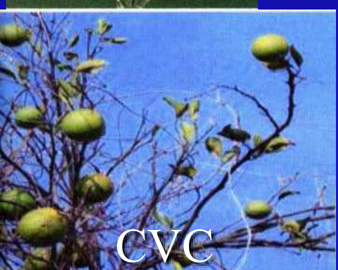
Effect of Surfactant on Goss' Wilt Infection

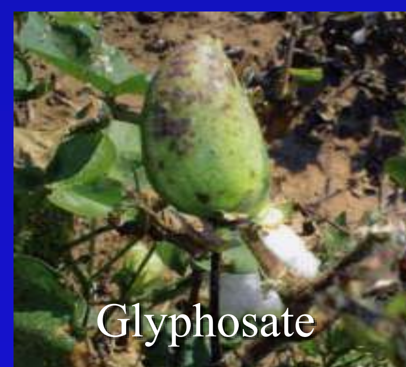
(Goss' wilt resistant corn hybrid)

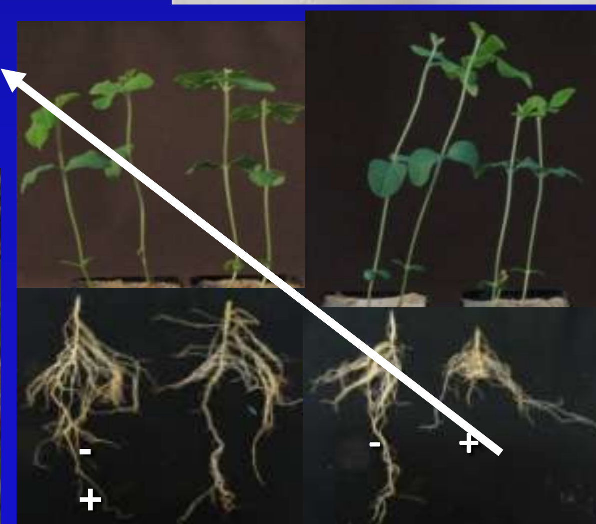




Recognizing the Interactions







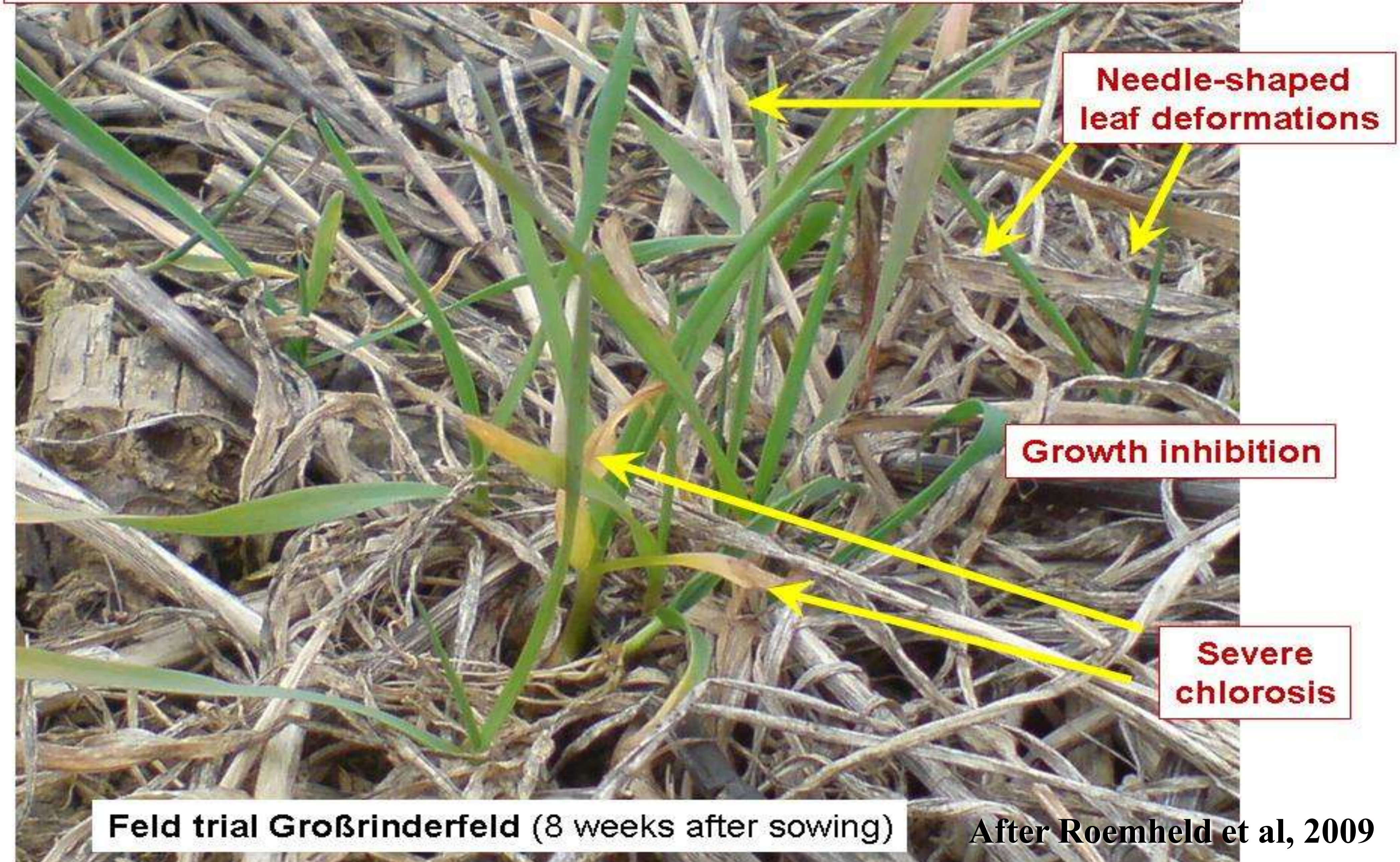
Some SYMPTOMS of Glyphosate Damage

(Sub-herbicidal depending on rate and length of exposure)

- ✓ Low vigor, stunting, slow growth
- ✓ Leaf chlorosis (yellowing) - complete or between the veins
- ✓ Leaf mottling - sometimes with necrotic flecks or spots
- ✓ Leaf distortion - small, curling, strap, wrinkling, 'mouse ear'
- ✓ Abnormal stem proliferation ('witches broom')
- ✓ Bud, fruit abortion
- ✓ Retarded regrowth after cutting (alfalfa, perennial plants)
- ✓ Lower yields, lower mineral value
- ✓ Predisposition to infectious diseases - NUMEROUS!
- ✓ Predisposition to insect damage
- ✓ Induced abiotic diseases - drought, winter kill, sun scald
- ✓ Root stunting, poor growth, inefficient N-fixation and uptake
- ✓ Bark cracking *after Univ. of Hawaii; Univ. of Connecticut, Ohio State University*

Effect of Late Application of Glyphosate

Close up of field symptoms of plant damage in treatments with short waiting times (1 d) after Glyphosate pre-crop application



After Roemheld et al, 2009

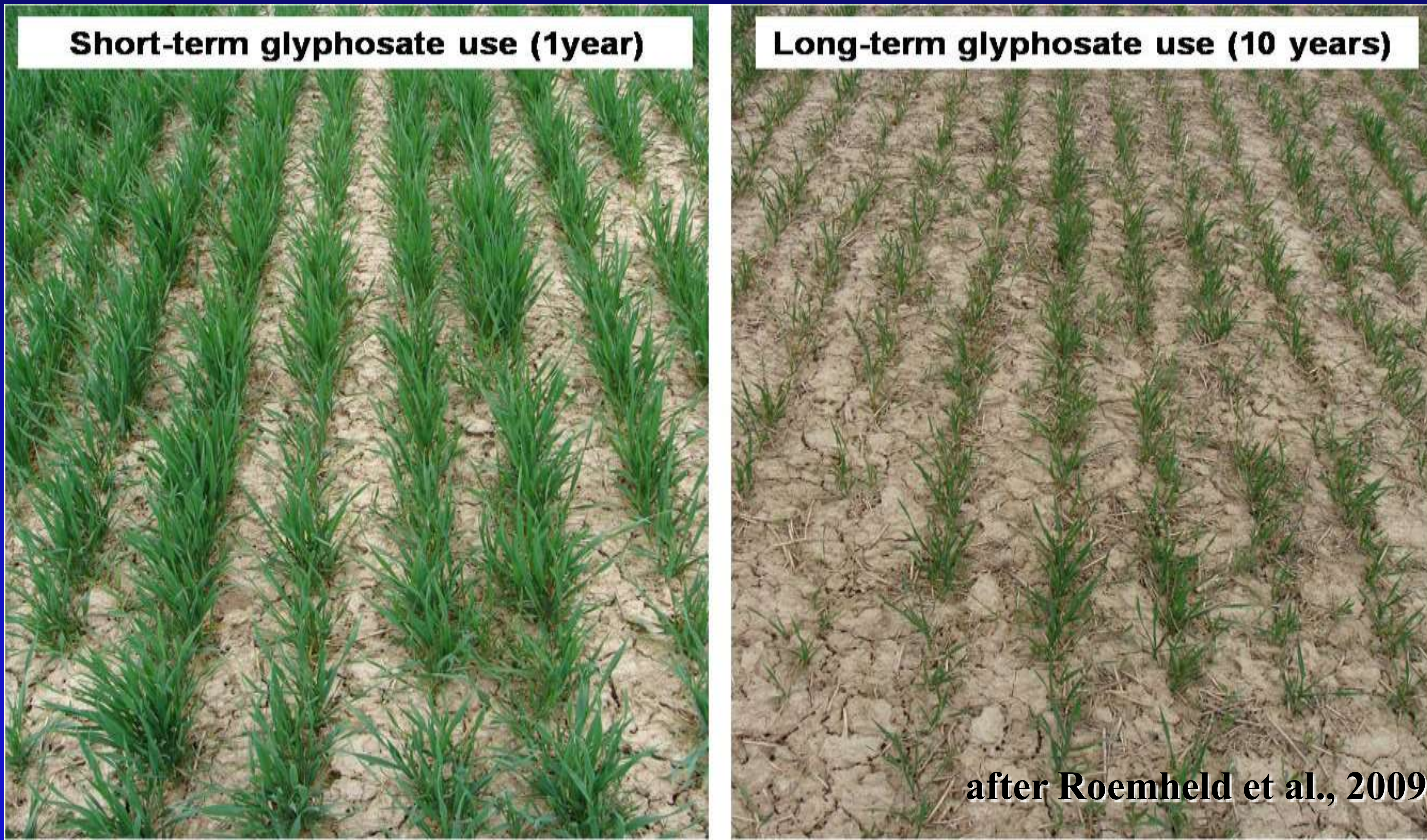
Effect of Planting Delay after Glyphosate (Residual Glyphosate in Soil)

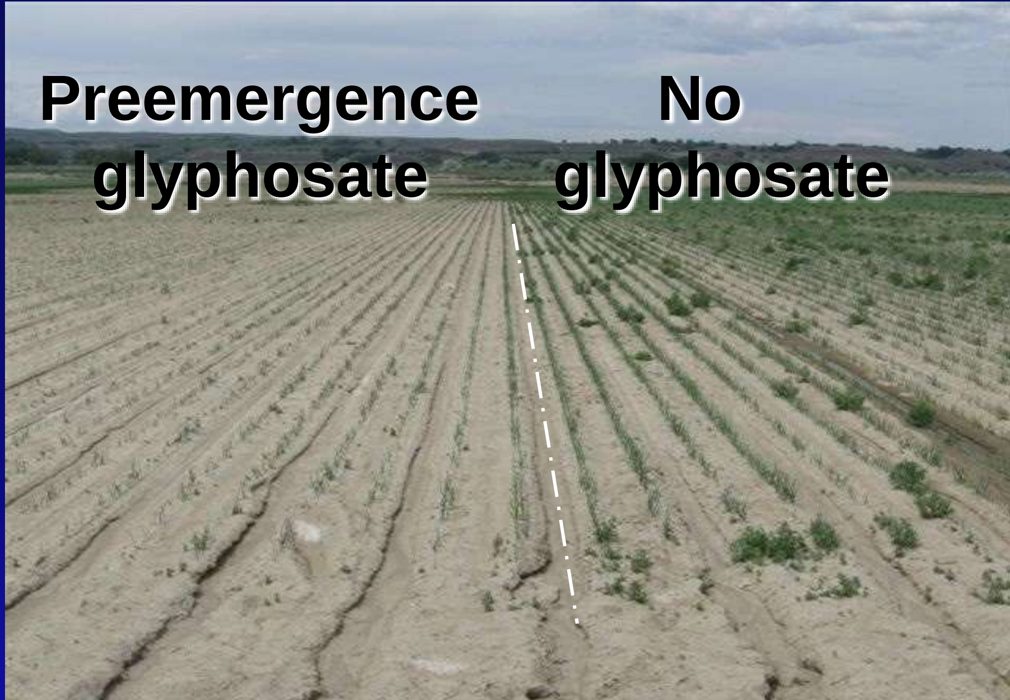
Winter Wheat

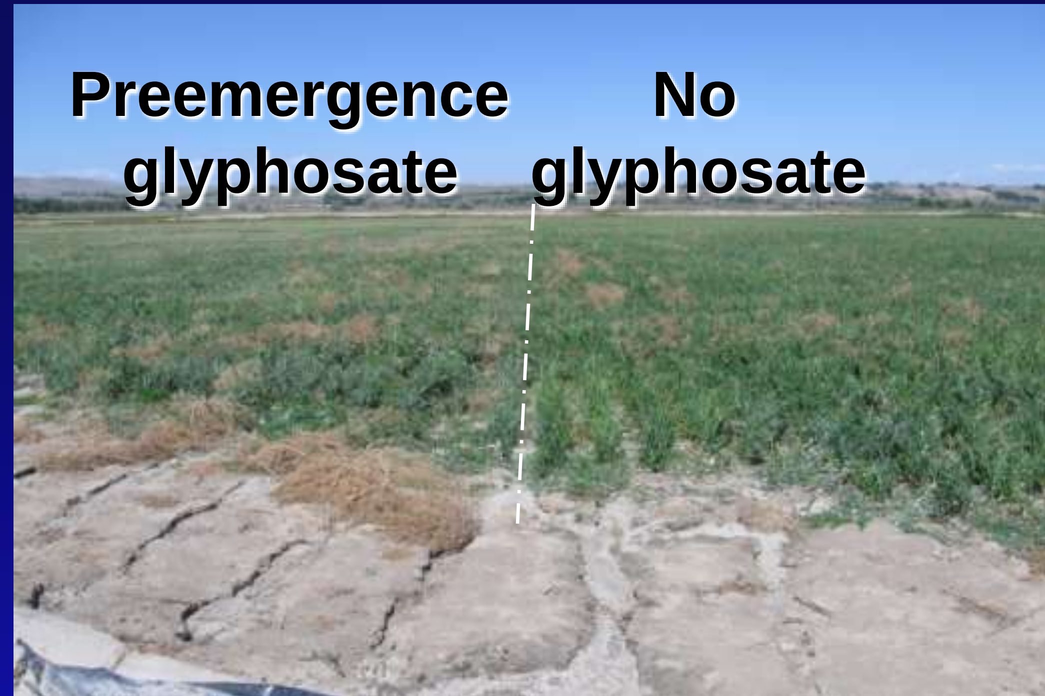

Effect of Residual Soil Glyphosate on Wheat, WI, 4-27-11
(Adjacent fields, same variety, planted same day, same fertilizer)
Organic Field
Six years of glyphosate ‘burndown’ use

Long-term Effect of Glyphosate

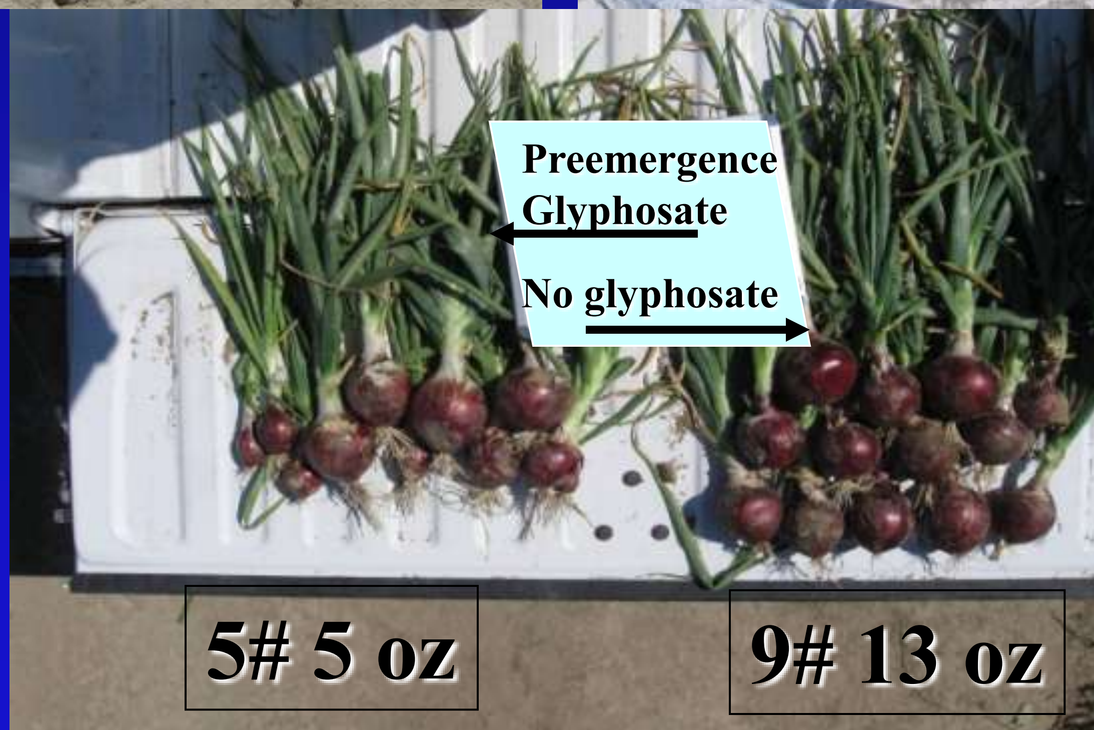
Field observations in winter wheat production systems in 2008 & 2009 point to potential negative side-effects of long-term glyphosate use.







Poor



Bulking

Effect of Residual Glyphosate in Soil on Plant Growth

- Soybeans and potatoes on the left side were planted after hand weeding;
- Soybeans and potatoes on the right side were planted six days after glyphosate was applied to hand weeded soil.

After Olson, 2011

Failure to 'Bulk' of Russet Potatoes

Glyphosate frequency	How applied	No. growers	% Potatoes over 10 oz
None in the previous 2 yrs	None	5	35.3
1-2 in the previous 2 yrs	Burn down	17	20.2
Preceding year	RR crop	5	5.4

Parent plant with glyphosate drift

Daughter seed pieces

Special Considerations in Fertilizing RR Crops

Two factors: 1) Chemical; 2) gene

1. Providing nutrient availability for yield and quality

Compensate for reduced plant efficiency
Compensate for reduced soil availability
[Timing and formulation are important]

2. Detoxifying residual glyphosate

In meristematic root, stem, flower tissues, etc.
In soil [Ca, Co, Cu, Mg, Mn, Ni, Zn]

3. Restoring soil microbial activity

Nutrient related (N-fixation, Fe, Mn, Ni, S, Zn, etc.)
Disease control related (nutrition, pathogen antagonists, etc.)
Biological amendment (N-fixers, PGPRs, etc.)

4. Increasing plant resistance to diseases and toxins

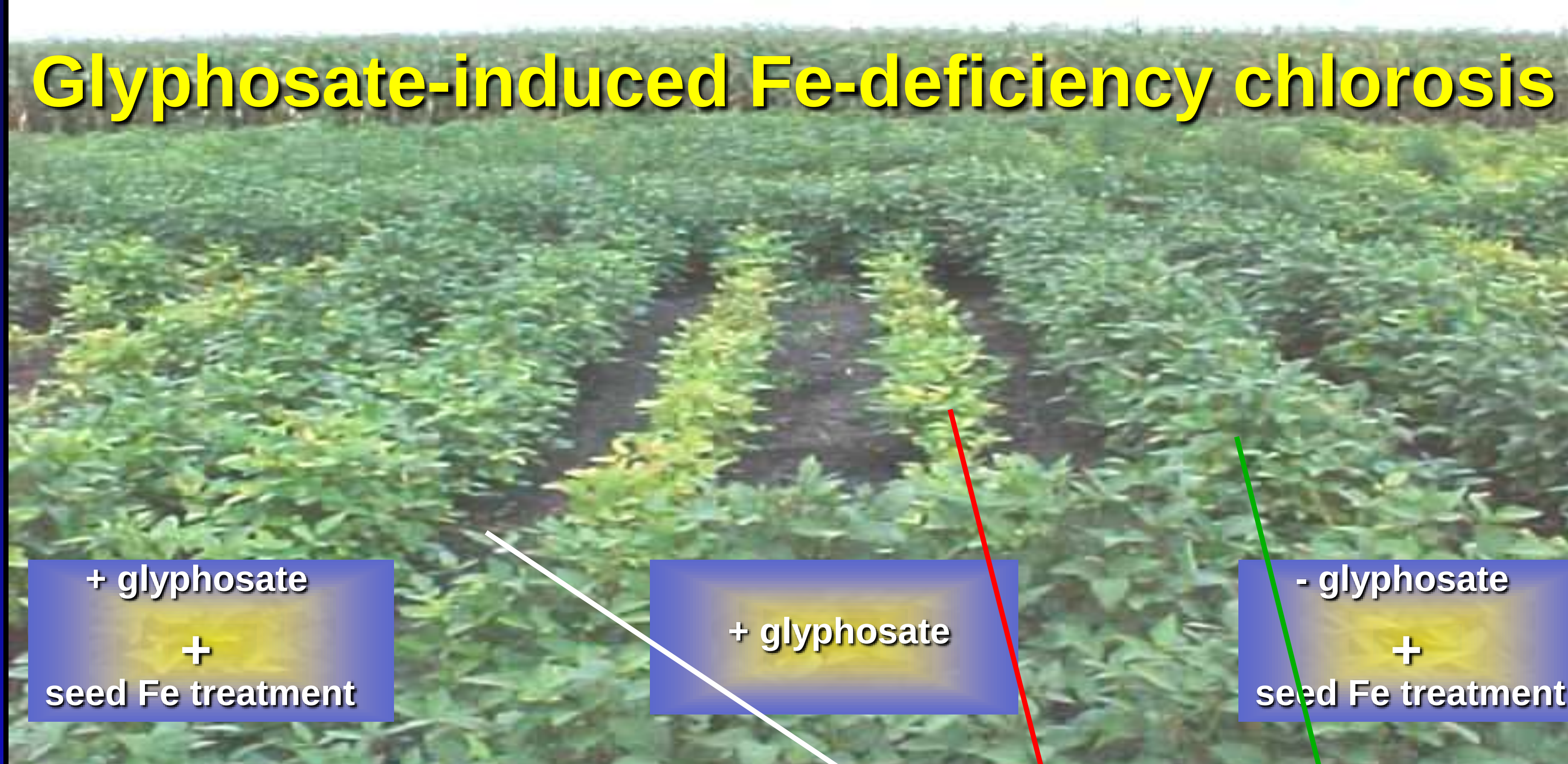
Nutrient-related pathways (Shikimate, AA, CHO, etc.)

5. Judicious use of glyphosate

Yield Response of Roundup Ready® Soybeans to Micronutrients

Treatment	Indiana	Michigan	Kansas	Minnesota
	----------------	Yield (bu/a)	--------------------	
Untreated	46	24	77	33
Glyphosate only	57	33	65	8
Glyphosate + Micronutrient	75 Mn	56 Mn	78 Mn	19 Fe

Glyphosate-induced Fe-deficiency chlorosis



Interaction of seed-applied Fe and glyphosate application on Fe deficiency chlorosis in soybeans; Minnesota, USA

Treatment	Visual chlorosis score [1 = green; 5 = yellow]		Grain yield (bu/a)	
	- Fe	+ Fe	- Fe	+ Fe
Control (no herbicide)	3.1	2.8	33	56
Glyphosate	3.7	3.3	8	19

Jolley et al., 2004, Soil Sci. and Plant Nutrition 50:973-981

Effect of Glyphosate on Roundup Ready© Corn

Colorado State University, 2007

Mike Bartolo, Sr. Res. Scientist

Treatment	Yield (bu/a)	% of control
Untreated*	234 a	100
Glyphosate**	195 d	83
Glyphosate + Zn, Mn	221 b	94
Glyphosate + Mn, Zn, Fe, B	208 c	89

*Hand weeded, **1 lb a.i. + 1 pt AMS per acre

Notes: UTC = genetic potential (with RR gene)

Glyphosate reduces genetic potential 39 bu/a

Application of high Mn & Zn recovers some genetic potential, lower Mn & Zn recovers less

Response of Roundup Ready© Corn to Zn & Mn, 2007*

NDSU Carrington

Treatment	Yield (bu/a)
Glyphosate control	144
Zn seed Treatment	156
Foliar applied Zn	158
Foliar applied Zn+Mn	173
Seed + Foliar Zn	175
Soil granular Zn sulfate	167

* All treatments received glyphosate

Herbicide Affects on RR Corn Yield Indiana, 2010

	RR Corn Hybrid			
Herbicide	6733HXR	6179VT3	5442VT3	5716A3
Surestart (11”)	266*	216	223	219
Cadet (V6)	227	219	219	213
Laudis (V6)	224	218	214	214
Integrity (pre-E)	231	217	215	204
Glyphosate (V6)	212	207	206	210
Steadfast (V6)	207	204	201	196
Status (V6)	187	195	193	192

*125.6 % of glyphosate yield (yields in bu/a - rounded)

All plots were hand weeded

Glyphosate & Manganese Effects on Cotton


Untreated Check (conventional herbicide)


Glyphosate @ 22 oz/ac plus ammonium sulfate (AMS)


Glyphosate @ 22 oz/ac plus AMS + Manganese

Effect of glyphosate and Manganese on Cotton Yield (Texas)

Treatment	% chlorotic plants	# seed cotton
Conventional herbicide	5	4885
Glyphosate	97	2237
Glyphosate + Mn, Zn	2	4693

after Ronnie Phillips, 2009

Effect of Tillage on Glyphosate Injury & Yield

Field History: 8 years Cons. Res. Program

2 qt blyphosate burndown 2008

1 qt glyphosate on RR corn 2009

1 qt glyphosate burndown 2010

No-till **Fall chisel**

Photos: Nesters Farm Services

Food and Feed Safety Concerns

- Increased levels of mycotoxins
  - Fusarium toxins (DON, NIV, ZEA)
  - Aflatoxins
- Nutrient deficiency
  - Cu, Fe, Mg, Mn, Zn
- Gene flow
  - Weeds
  - Soil microbes
  - Intestinal microbes

Aris & Leblanc, 2011
Benachour et al, 2007
Carmen, et al., 2011
Fernandez, et al., 2009
Gasnier, et al., 2009
Heiman, 2010
Matzk et al, 1996
Seralini et al., 2010, 2011
Smith, 2010
Walsh, et al., 2000
Watts, 2009

- Direct toxicity of residual glyphosate
  - Infertility - endocrine system
  - Birth defects, teratogenicity
  - Cell death - Disease resistance
- Allergenic reactions to foreign proteins

Mycotoxins in Straw and Grain

- ✓ *Fusarium* spp. act synergistically to cause death of glyphosate-treated plants
- ✓ Glyphosate-induced root colonization by *Fusarium* spp.
- ✓ Toxins (DON, ZEA) produced in roots is translocated to stem and grain - Well above 'clinically significant' levels!
- ✓ Toxin concentrations not always correlated with *Fusarium* damaged grain (FDG) - [Strobilurin fungicides increase mycotoxins]
- ✓ Head must be protected for 18 days (10 days after anthesis)

Deoxynivalenol and Zaeralenone Concentrations in plant parts

Toxin (ppm)	Grain	Chaff	Straw
Deoxynivalenol	4.7	16.9	3.5
Zaeralenone	4.4	42.9	55.5

Proc. Natl. FHB Forum 2009, Orlando, FL

% Reduction in Alfalfa Nutrients by Glyphosate*

Nutrient	% reduction compared with Non-RR
Nitrogen	13 %
Phosphorus	15 %
Potassium	46 %
Calcium	17 %
Magnesium	26 %
Sulfur	52 %
Boron	18 %
Copper	20 %
Iron	49 %
Manganese	31 %
Zinc	18 %

*Third year, second cutting analysis; Glyphosate applied one time in the previous year

Manganese Sufficiency in Bovine Fetus Livers

(After Schefers, 2011)

Fetal development	Mn mean	Manganese level*		
		Deficient	Normal	Above
Deformed	0.88 ppm	100 %	0	0
'Normal'	1.2 ppm	63 %	29 %	7 %

*Reference range: 1.75-2.8 ppm wet weight

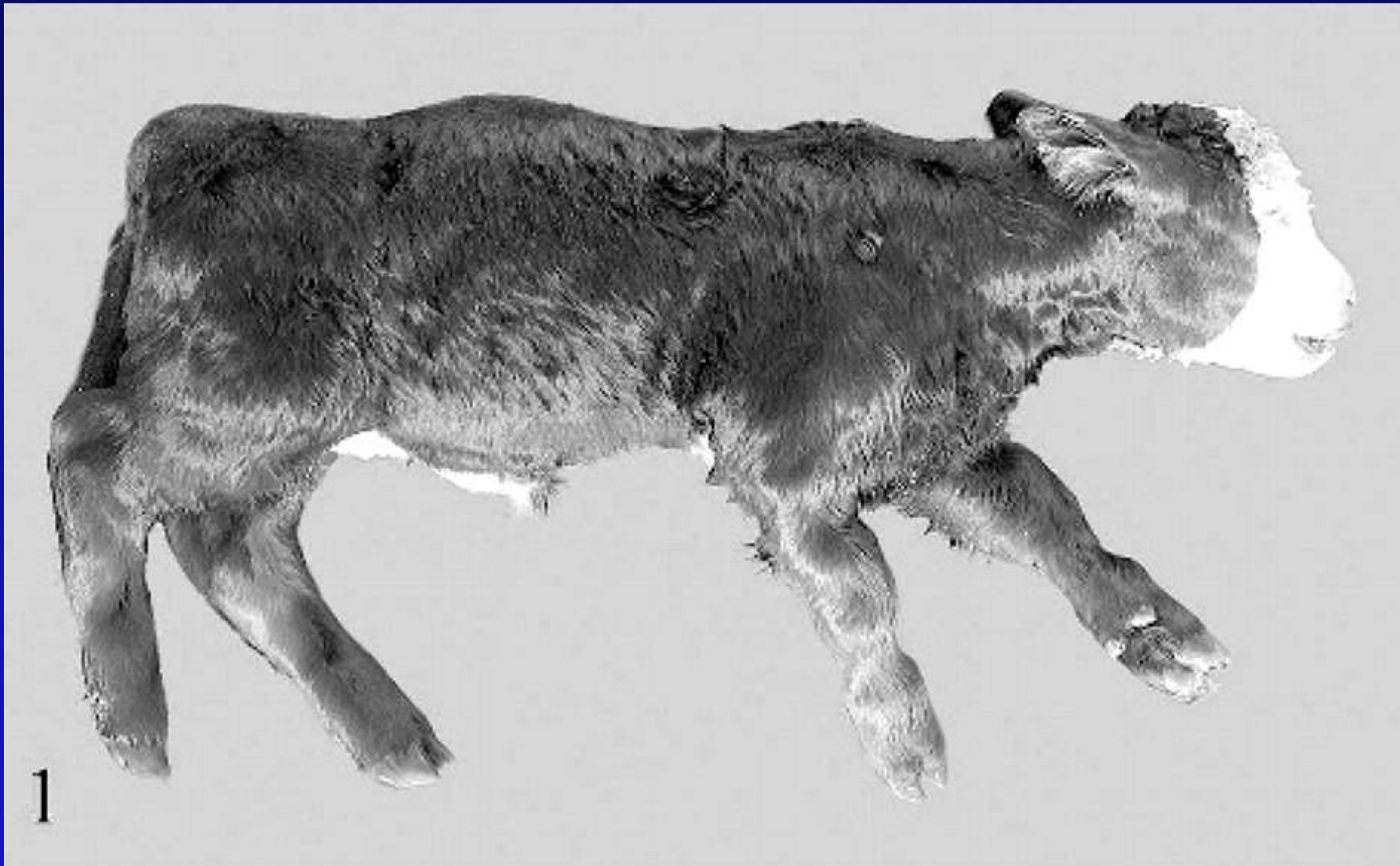
Feed Analysis:	Mean Mn	Range of samples
Shelled corn	15 ppm	0.01 - 57.65 ppm
Corn silage	37 ppm	0.01 - 89.43 ppm
Grass hay	50 ppm	0.01 - 125.20 ppm
Mixed haylage	57 ppm	0.55 - 113.45 ppm

Percent Decrease in Mineral Nutrients in Corn Silage - 2000 to 2010, Dairy One*

Mineral nutrient	Percent decrease
Calcium	22.0 % lower
Phosphorus	3.8 % lower
Magnesium	11.4 % lower
Potassium	16.1 % lower
Iron	5.2 % lower
Copper	9.6 % lower

*Based on 1629 samples

Stillborne Calf from Manganese Deficiency



McLaren P J et al. Vet Pathol 2007;44:342-354

Veterinary Pathology

U.S. Cattlemen's Association Statement to Congress

"Cattle ranchers are facing some puzzling - and, at times, economically devastating problems with pregnant cows and calves. At some facilities, high numbers of fetuses are aborting for no apparent reason. Other farmers successfully raise what look to be normal young cattle, only to learn when the animals are butchered that their carcasses appear old and, therefore, less valuable."

"The sporadic problem is so bad both in the United States and abroad that in some herds around 40-50 percent of pregnancies are being lost."

"Many pesticides and industrial pollutants also possess a hormonal alter ego."

"The viability of this important industry is threatened."

Source: Testimony of the Ranchers-Cattlemen Action Legal Fund, United Stockgrowers of America, to the Senate Agriculture Committee July 24, 2002.

Effect of the GM “Gene” Proteins in Corn/Soybeans on Pig Stomachs

After Carman et al., 2011

Non-GMO Feed	GMO Feed
	
Normal color	Inflamed, irritated

Feed Source Effect on Stomach Liner Color, Carmen et al, 2010

And the Mice Prefer……

GMO Corn

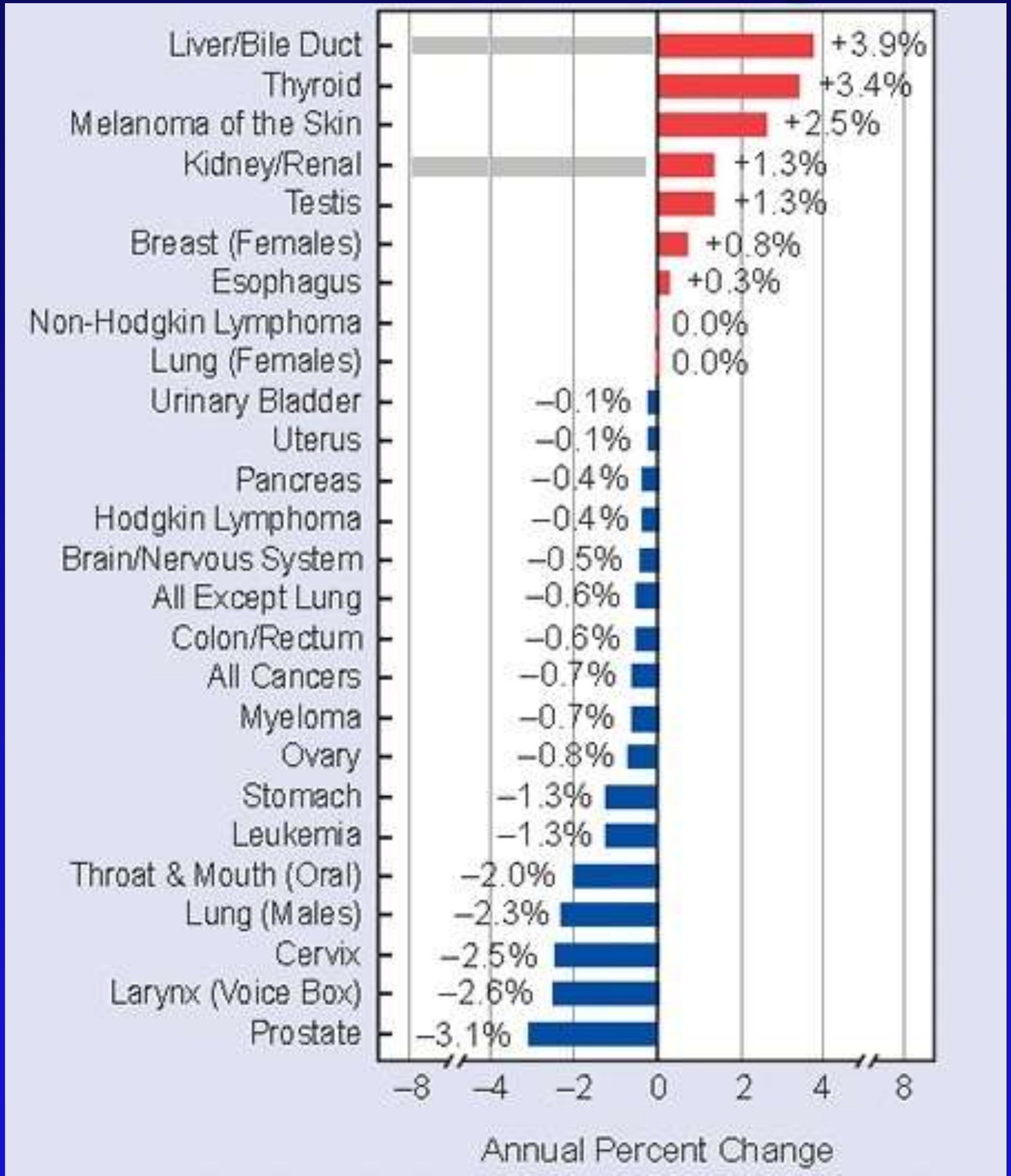
Non-GMO Corn

Photos: Gilbert Hostetler

Direct Toxicity of Glyphosate

Rate (ppm)	System affected	Reference
0.5	Human cell endocrine disruption	Toxicology 262:184-196, 2009
0.5	Anti-androgenic	Gasner et al, 2009
1.0	Disrupts aramatase enzymes	Gasnier et al, 2009
1-10	Inhibits LDH, AST, ALF enzymes	Malatesta et al, 2005
1-10	Damages liver, mitochondria, nuclei	Malatesta et al, 2005
2.0	Anti-Oestrogenic	Gasnier et al, 2009
5.0	DNA damage	Toxicology 262:184-196, 2009
5.0	Human placental, umbilical, embryo	Chem.Res.Toxicol. J. 22:2009
10	Cytotoxic	Toxicology 262:184-196, 2009
10	Multiple cell damage	Seralini et al, 2009
10	Total cell death	Chem.Res.Toxicol. J. 22:2009
All	Systemic throughout body	Andon et al, 2009
1-10	Suppress mitochondrial respiration	Peixoto et al, 2005
	Parkinson’s	El Demerdash et al, 2001
POEA, AMPA even more toxic		Seralini et al, 2009

Annual % Change in Cancers



Target Tissues for glyphosate;

Liver
Kidney
Testicle
Hormone system
Bone (Ca, Mn chelation?)
Thyroid (Mn chelation?)

Hello, my name is ____________. I am a veterinarian in Michigan.

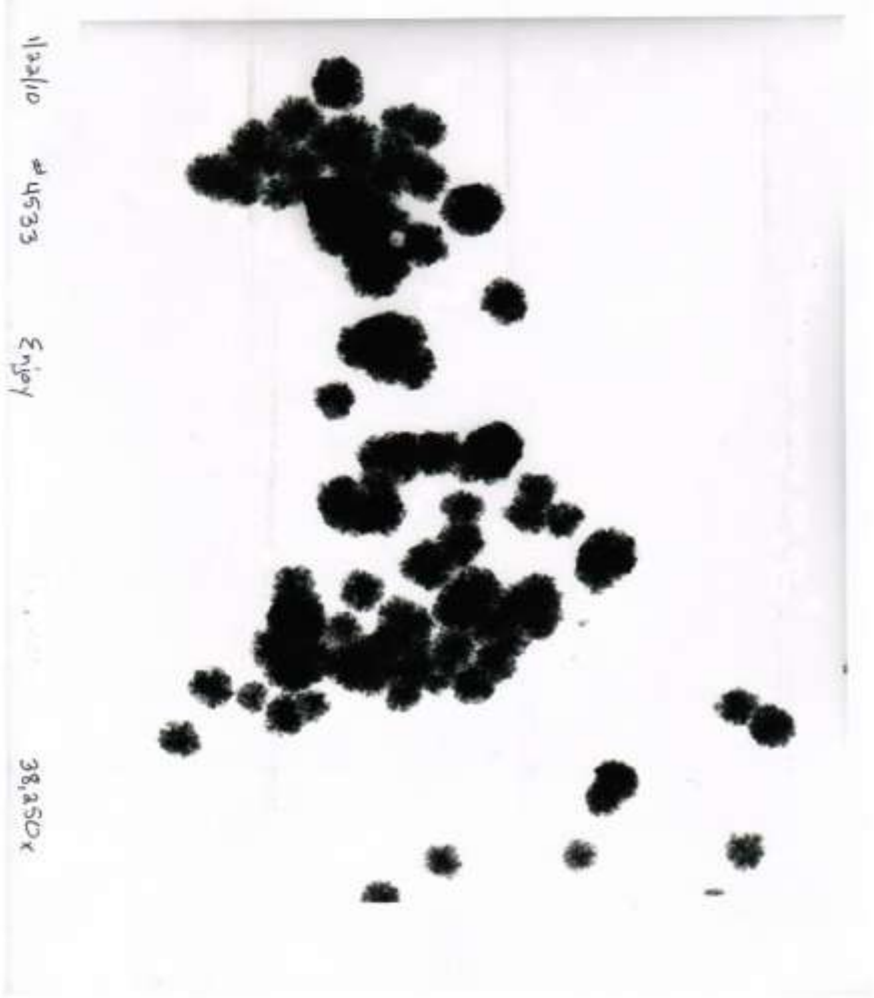
I am working with a sow herd that has had elevated death loss for over two years and very poor reproductive performance for the last 6-8 months. I have done extensive diagnostics (primarily at Iowa State) and can find nothing infectious that is routinely found to explain the problem.

I suspect there is a toxin involved; I have done extensive testing on liver, feed, and water but can find no evidence of those compounds either. We have had a few individuals mention that the use of GMO crops could be contributing to these problems.

The producer recently saw your article to the secretary of agriculture and forwarded it to me. We are very intrigued by the organism you mention. Could you tell me if any laboratory is looking for this agent? How do we go about finding it? *We are at the end of our rope and cannot figure this out.* Any help you can give us would be greatly appreciated.

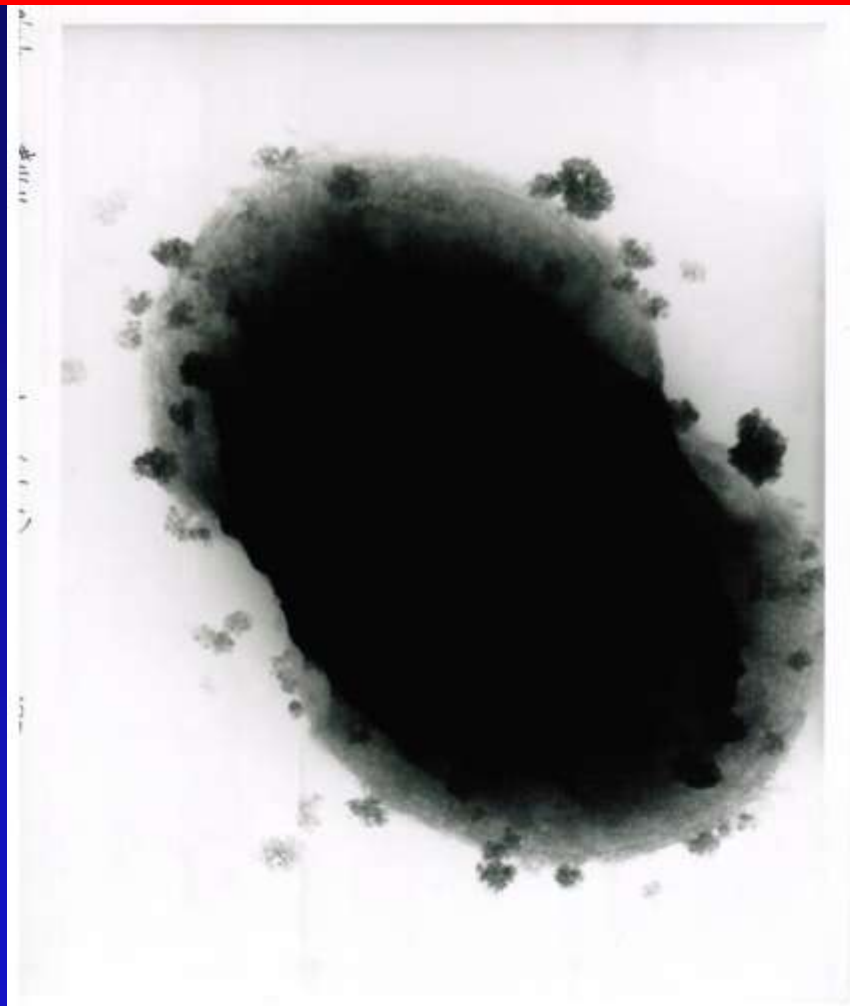
Late term 'Spontaneous Abortion' (Miscarriage)

‘Fungus-like’ Growth (transmission EM)



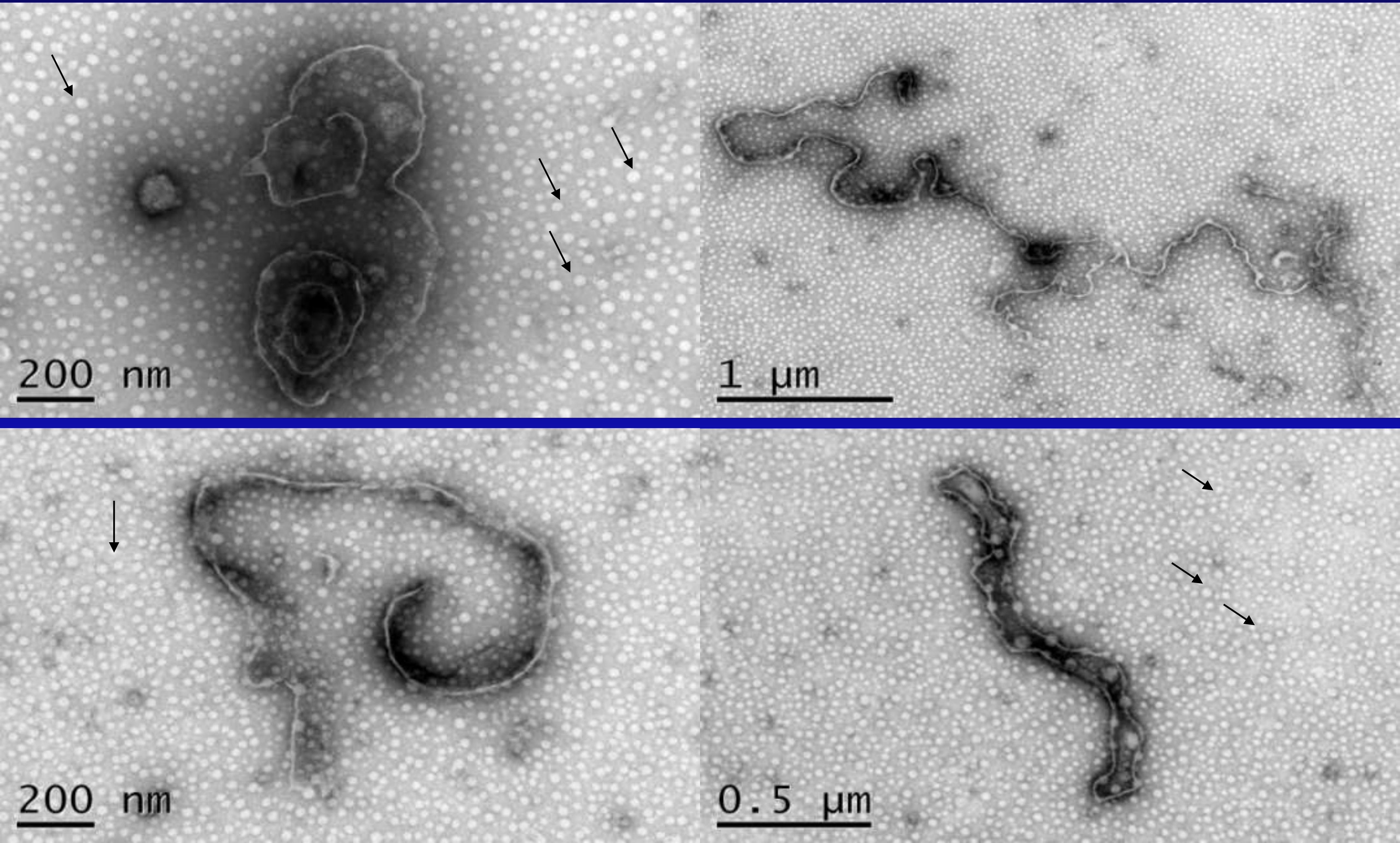
38,250 X magnification

Size of organism compared with alfa-*Streptococcus*



Size relative to gram^{+} bacterium

Suspect agent in Exported U.S. RR Soybean, 25,000X, 2010



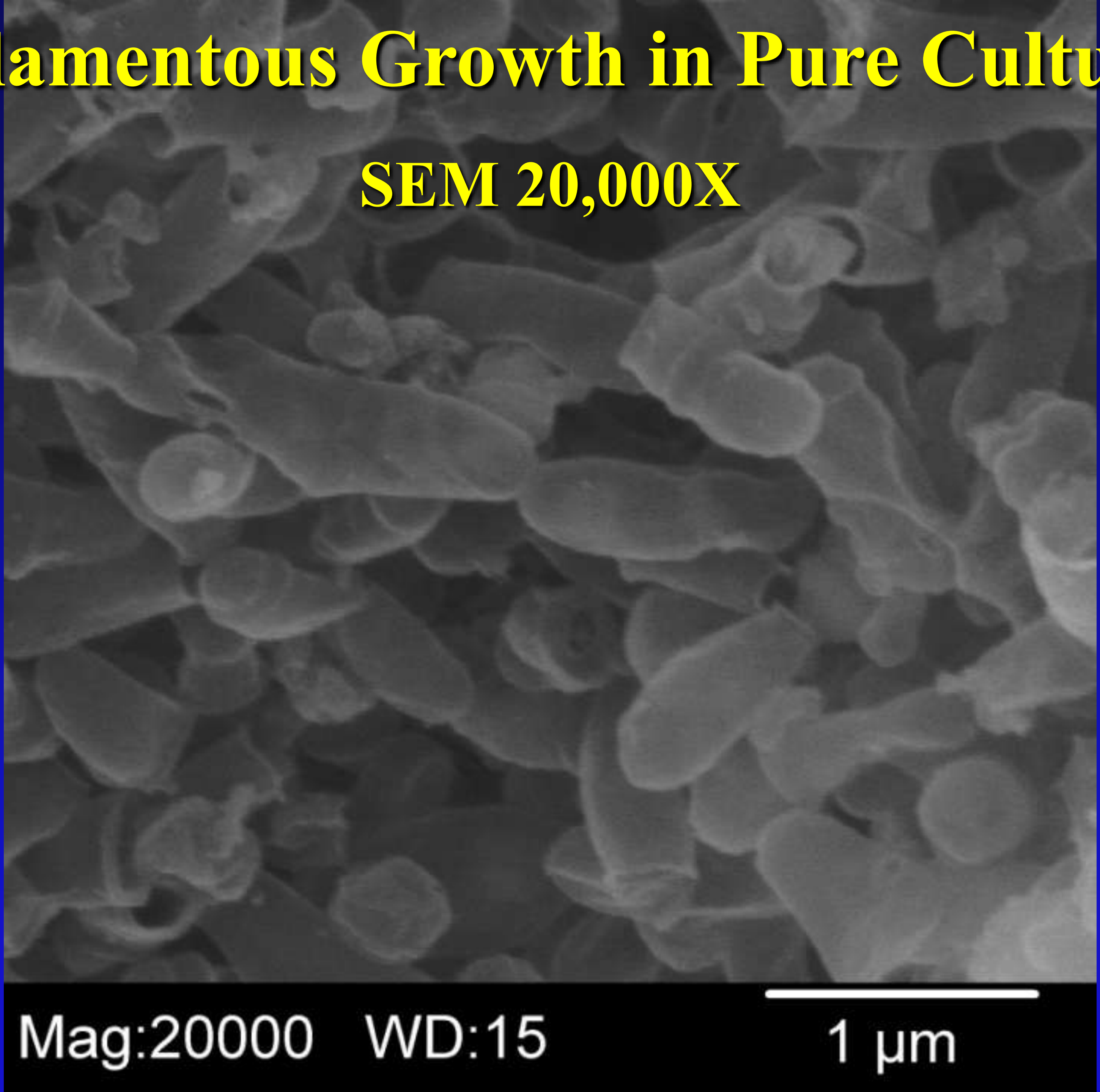
Suspect Agent in Fungal Mycelium

Scanning Electron Microscope Image of the Suspect Agent from a 60-day old Equine Fetus with Classic Symptoms of the Abortion Syndrome

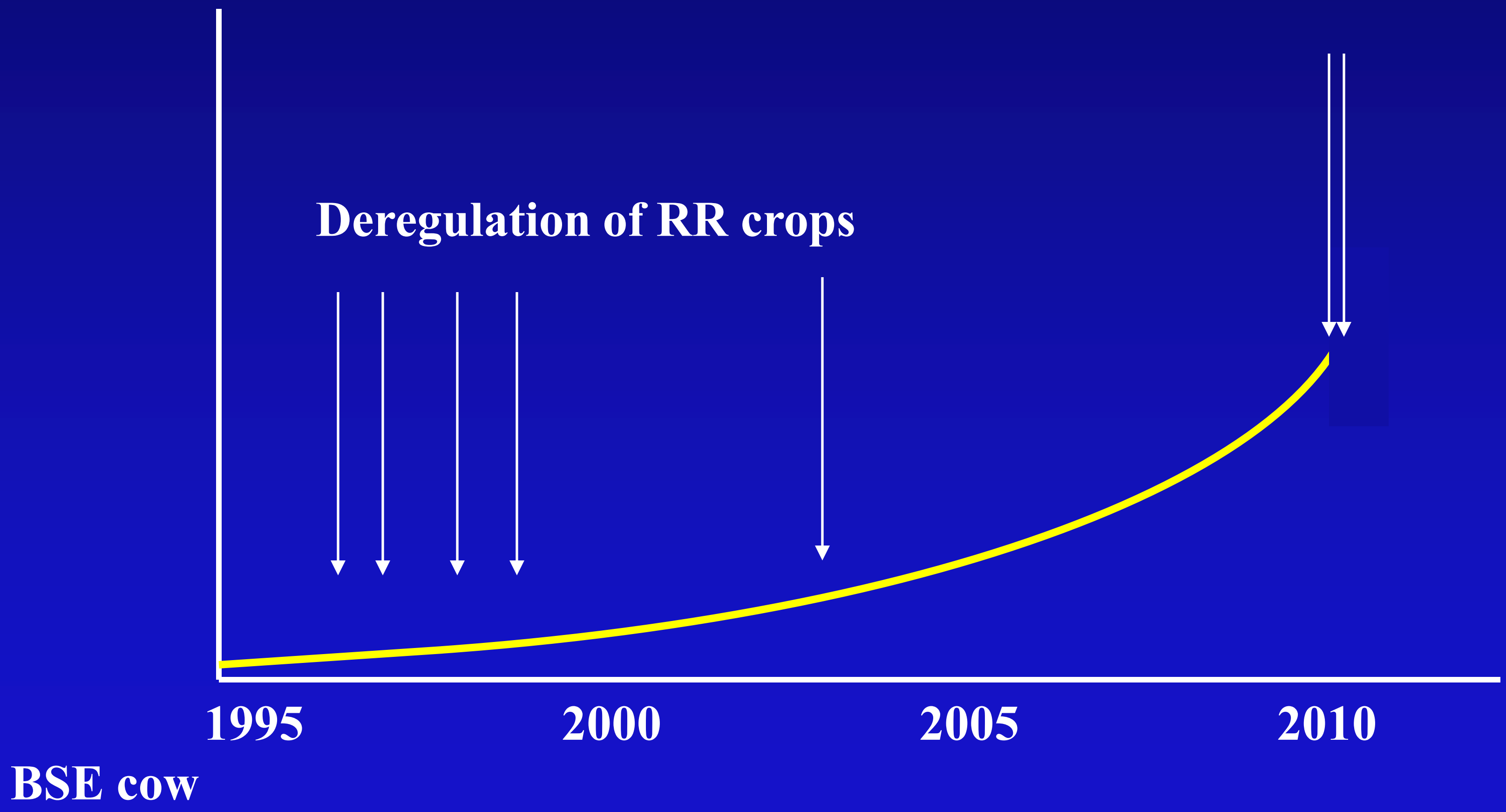
Low magnification of iregular circular bodies in aborted equine fetal tissue

High magnification of iregular circular bodies in aborted equine fetal tissue

Filamentous Growth in Pure Culture



Generalized Graph of Incidence

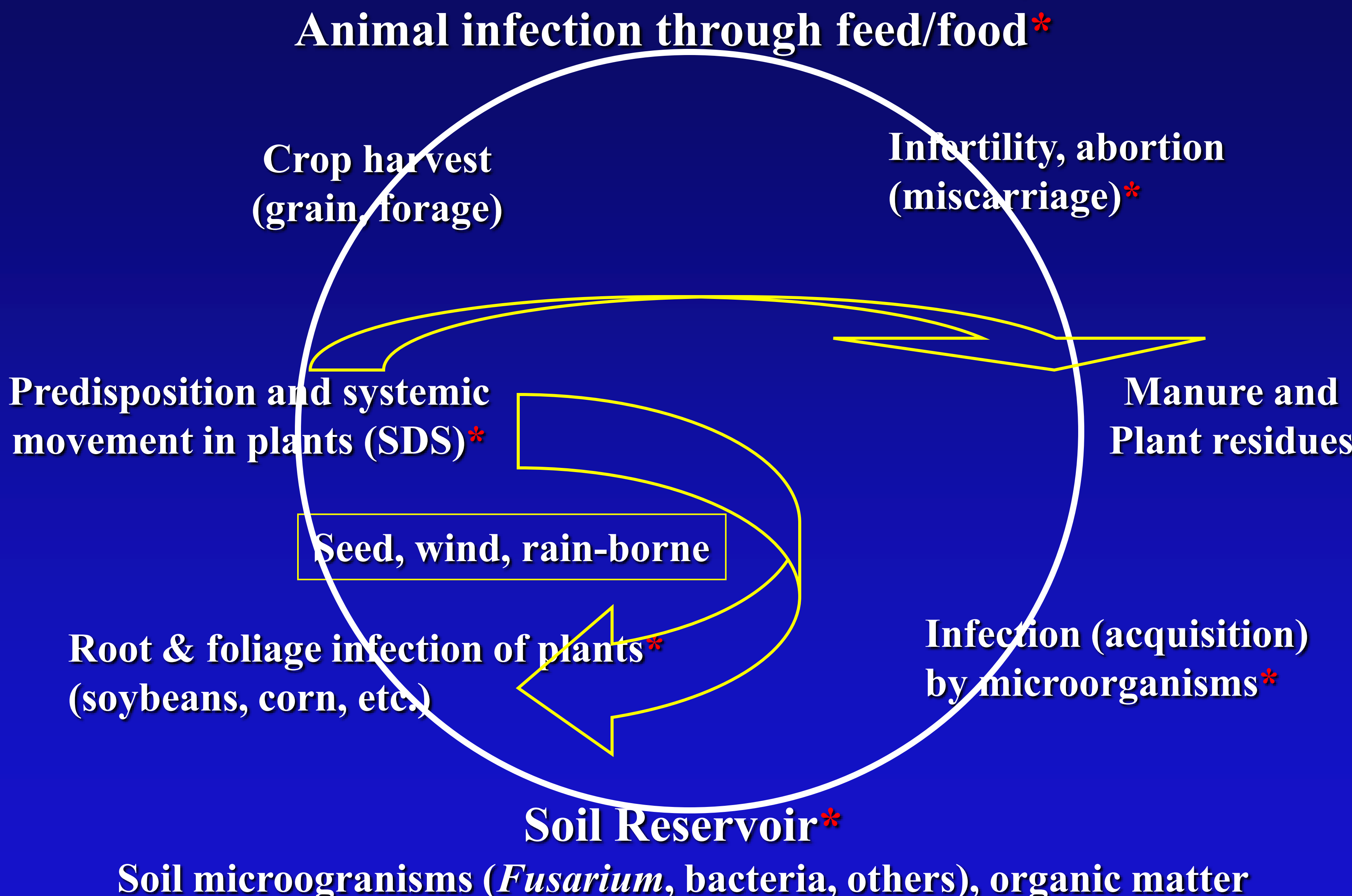


Occurrence

- Verified in IA, IL, KY, MI, NE, ND, SD, WI
- Sources:

‘Environmental’	Animal tissue
Soybean meal	Placental tissue
Wheatlage, haylage, silage	Amniotic fluid
Corn leaves and silage	Semen
SDS Soybean plants	Stomach contents
Oak ‘scorch’ leaves	Eggs
Manure	Milk
Soil	
Fusarium solani fsp *glycines* mycelium	

A Postulated Disease Cycle



* Areas where glyphosate could impact

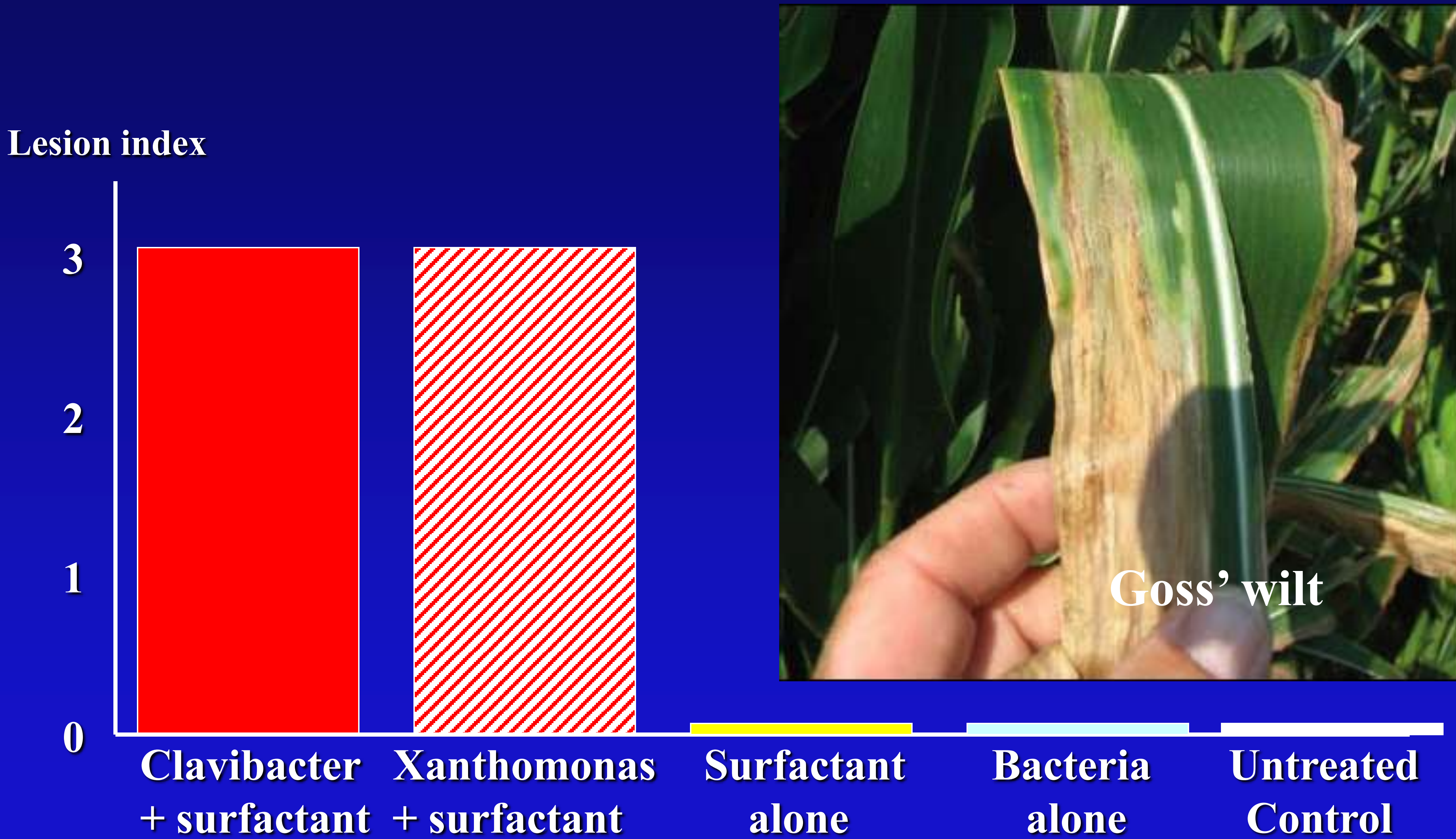
Potential Interactions of 'new organism' with Glyphosate

- **Glyphosate affects plants (predisposes):**
  - Inhibits plant defenses
  - Reduces nutrient content and efficiency [chemical and RR gene(s)]
  - Increases root colonization
  - Increases membrane permeability
  - Surfactant affect for penetration of natural openings and wounds
- **Glyphosate affects animals (predisposes):**
  - Inhibits aramatose system – endocrine hormone system
  - Toxic to liver, placental, testicular, and kidney cells
  - Reduced defense - liver function [from lower Mn, etc. in feed]
- **Glyphosate affects pathogens:**
  - Stimulates growth and virulence (direct/indirect)
  - Favors synergism, infection (as a carrier)
  - Increases movement into plant tissues (water film for plant infection)
- **Glyphosate affects the environment:**
  - Toxic to soil microbes that constrain plant pathogens
  - Micronutrient availability reduced

What has Changed?

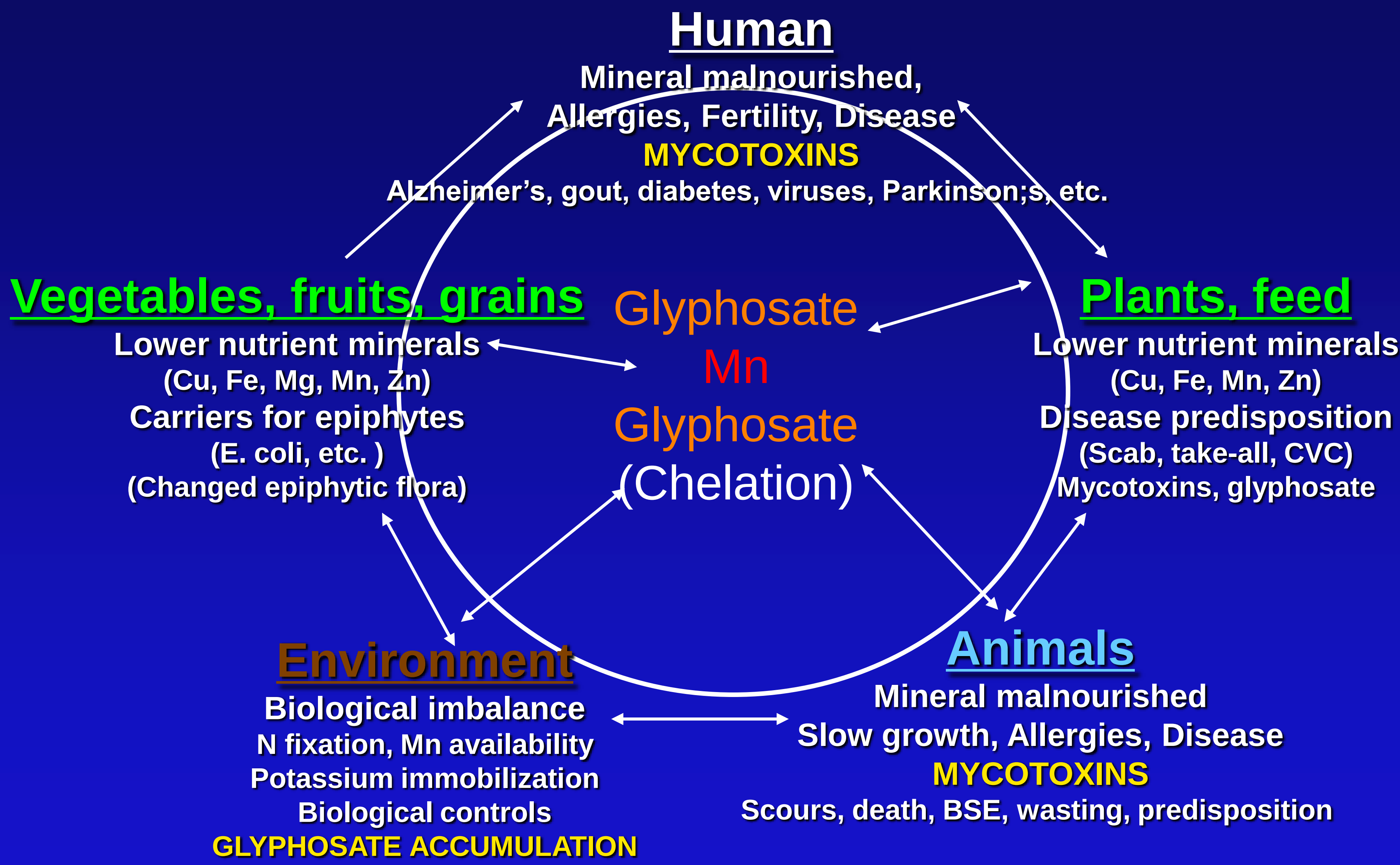
- **Change:**
  - Increased disease
  - New diseases
  - Low mineral nutrition
  - Resistant weeds
- **Precedent:**
  - Victoria blight (oats)
  - H. carbonum disease (toxin)
  - Texas male-sterile gene (corn leaf blight epidemic)
  - Glyphosate-resistance gene?????
  - Glyphosate nullifies genetic resistance in sugar beets
- **Why (vulnerability)?**
  - Predisposition
  - Direct toxicity
  - Gene flow
  - No relief - single source approach

Effect of Surfactants on Goss' & Stewart's Wilt*



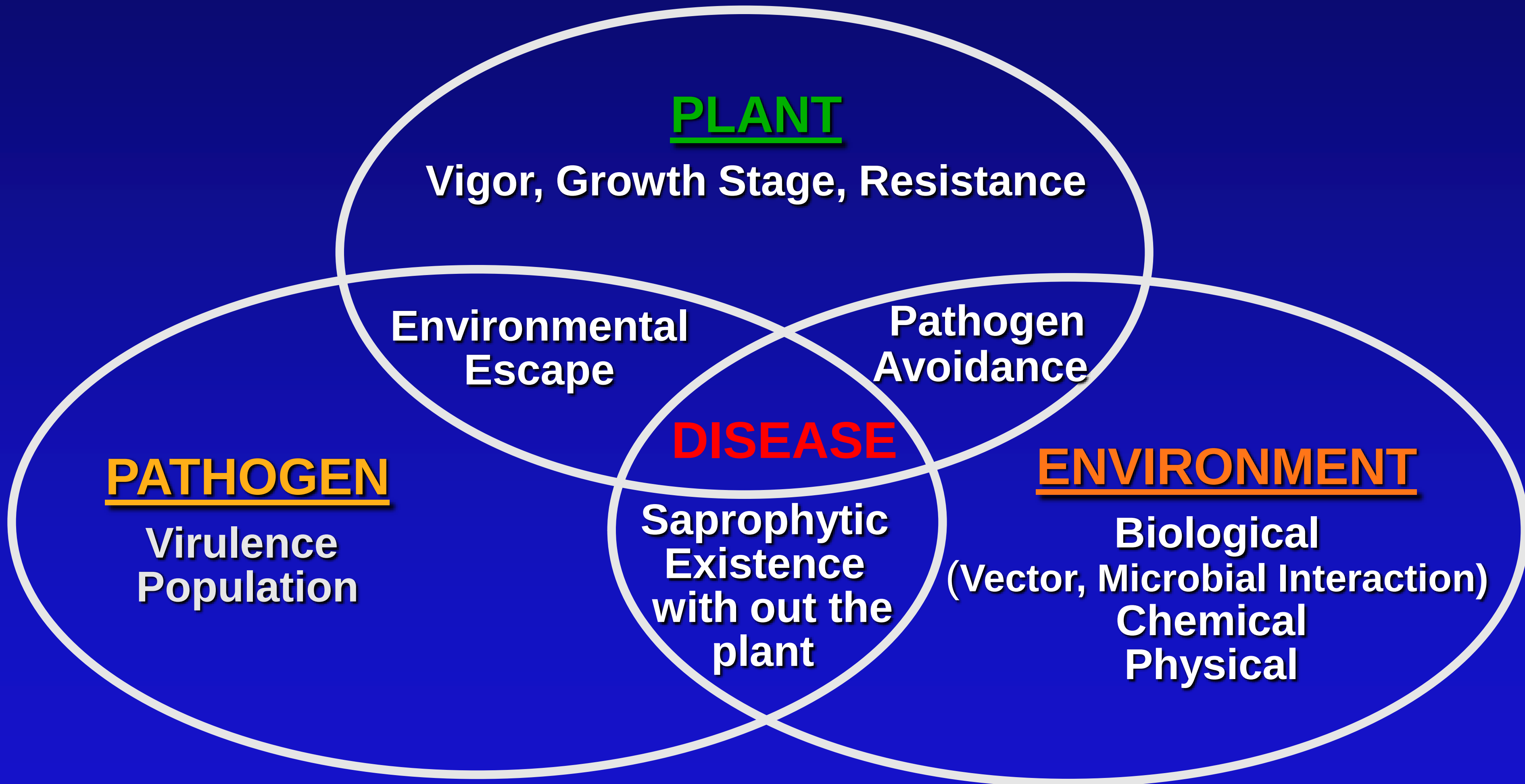
Bacterial wilt of Alfalfa - *Clavibacter insidiosum*

Potential Far-Reaching Impact of Glyphosate



Make Sure You Provide the Food!

The Interaction of Three Factors Over Time Determines if a Disease will be Latent or Severe



Tough Love Alternative to Spanking

When it comes to child discipline, most of us are looking for positive alternatives to spanking.

One that worked well when our child was having "one of those moments" was to take them for a car ride.

Some say it's the vibration from the car; others that its the time away from distractions such as TV, etc.

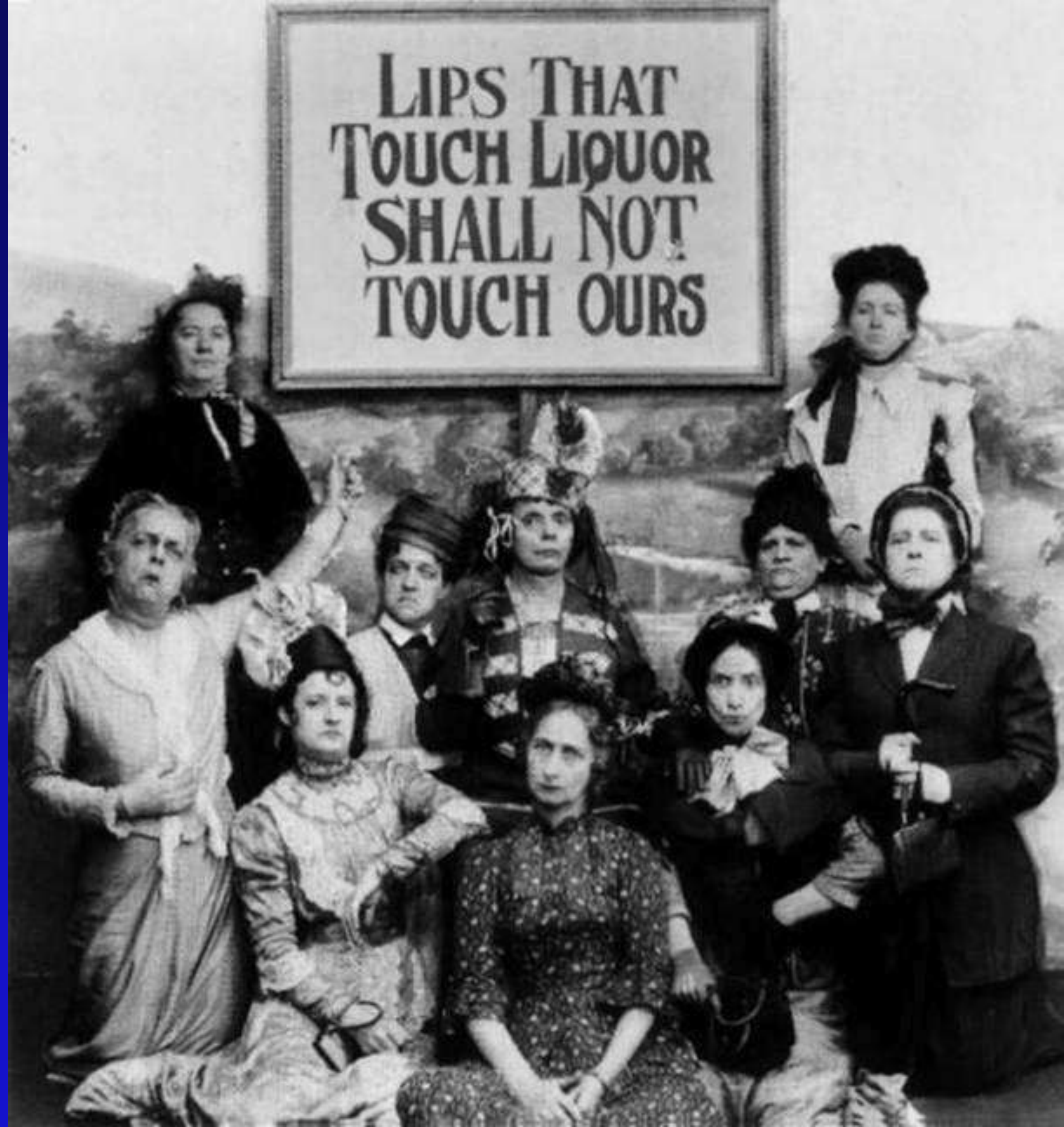
Either way, our kids usually calm down and behave after our car ride together.

Eye-to-eye contact helps a lot too as you can see from one of our sessions.

This works with grandchildren, nieces and nephews as well!

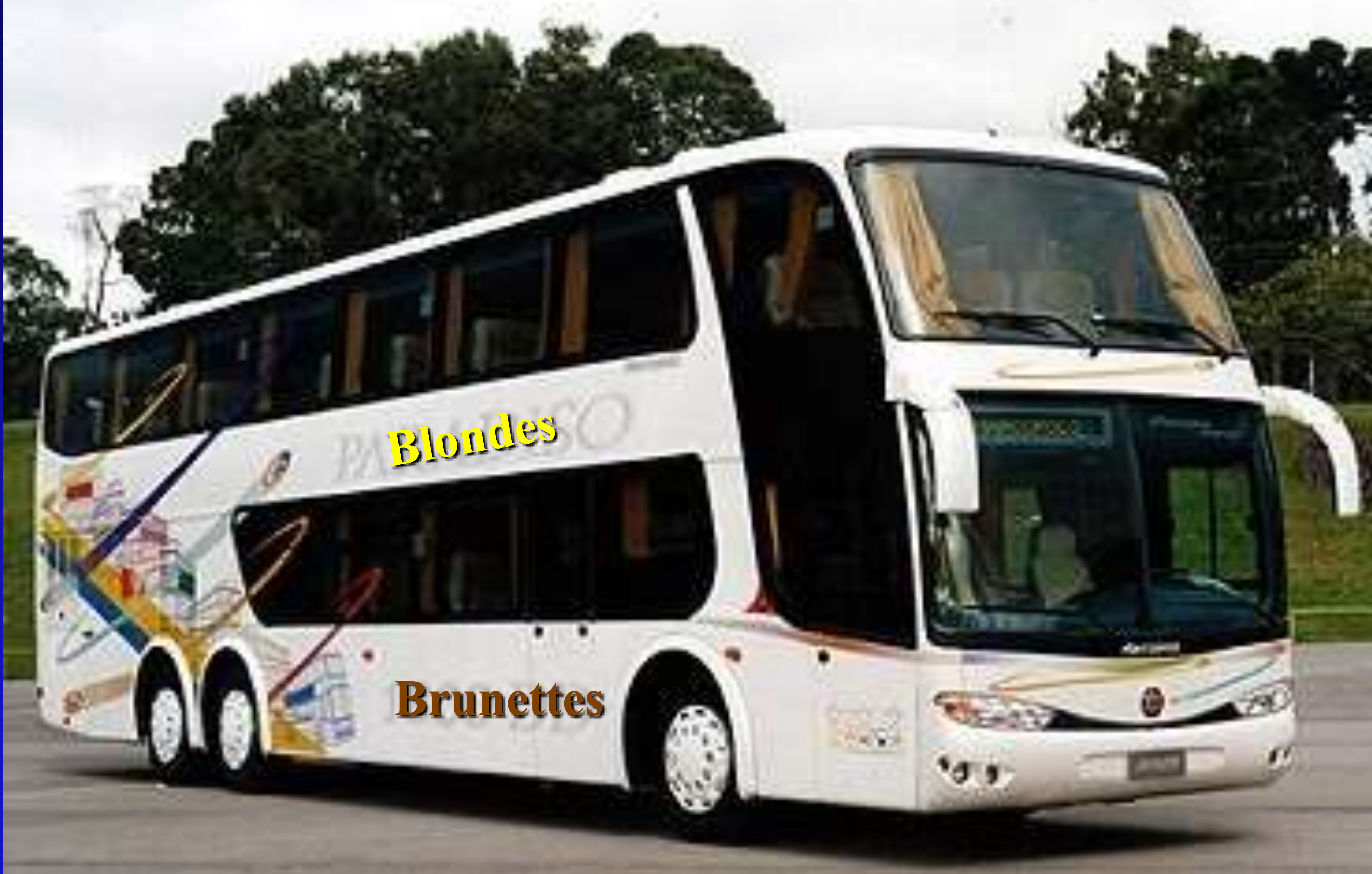
Ever Wondered if You were Your Mother's Favorite

If you came upon this ad in 1919,

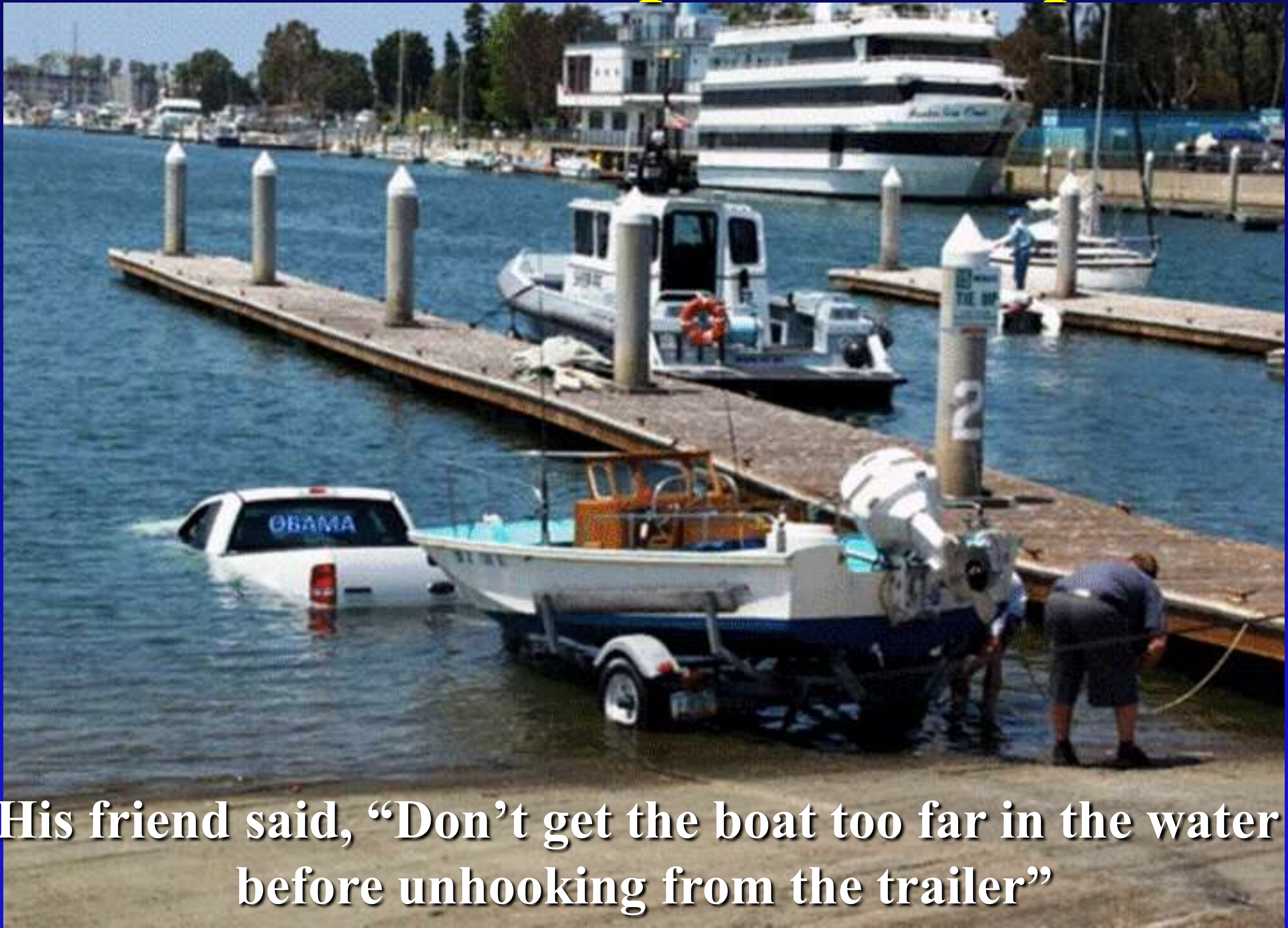


Wouldn’t you just keep drinking?

Women's Soccer Team Trip

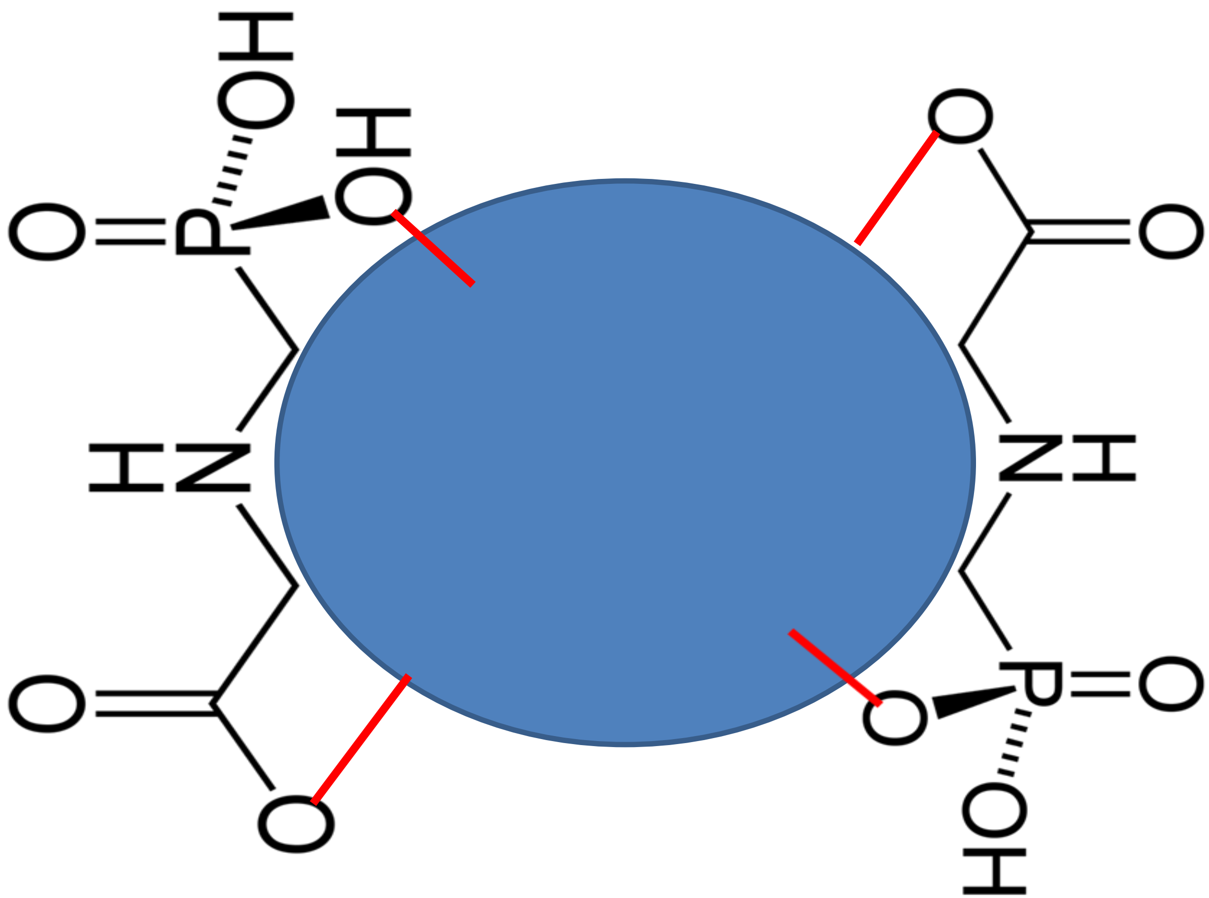


New Boat and Pickup - New Experience

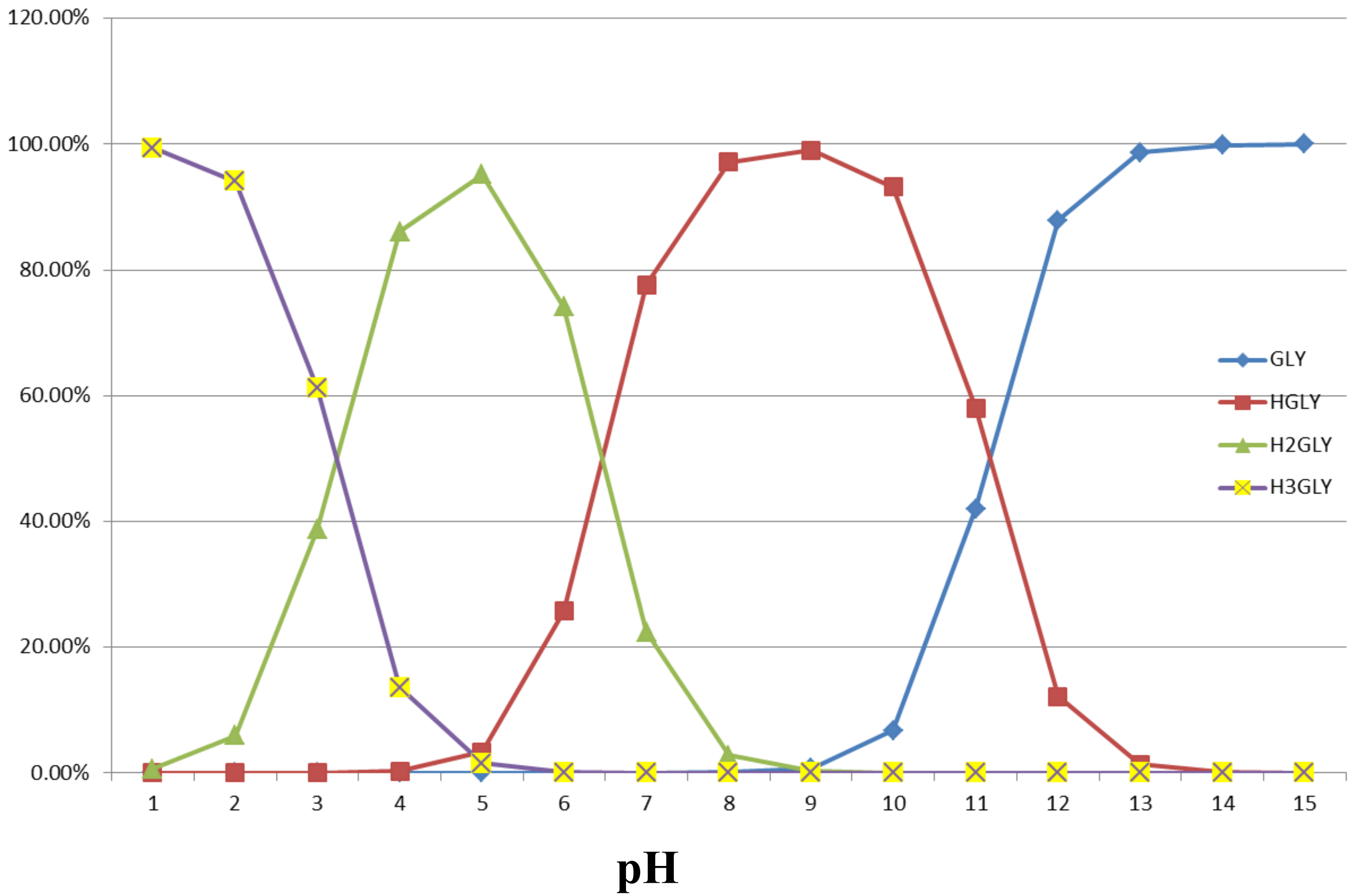


His friend said, "Don't get the boat too far in the water before unhooking from the trailer"

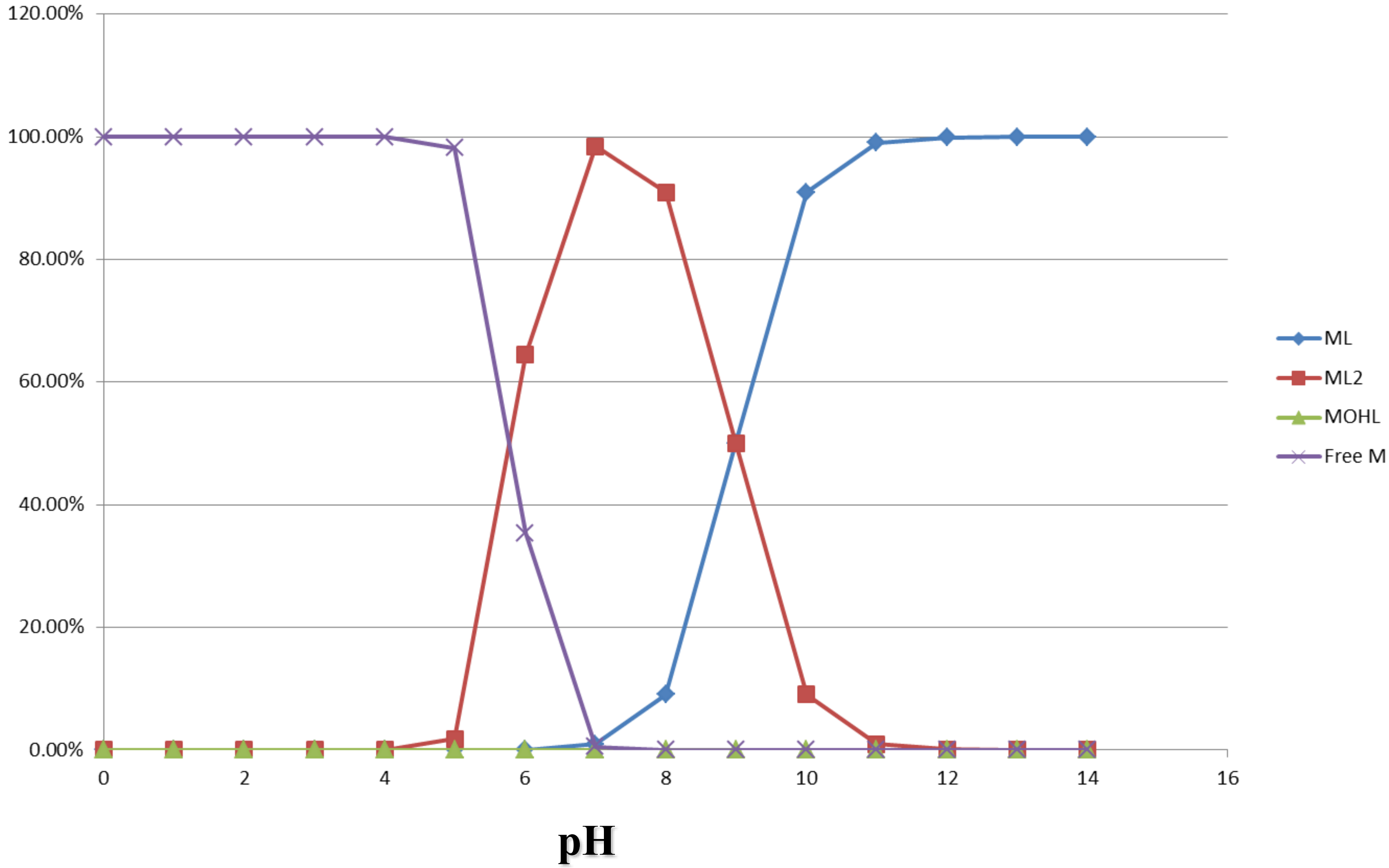
Glyphosate Chelate (Complex)



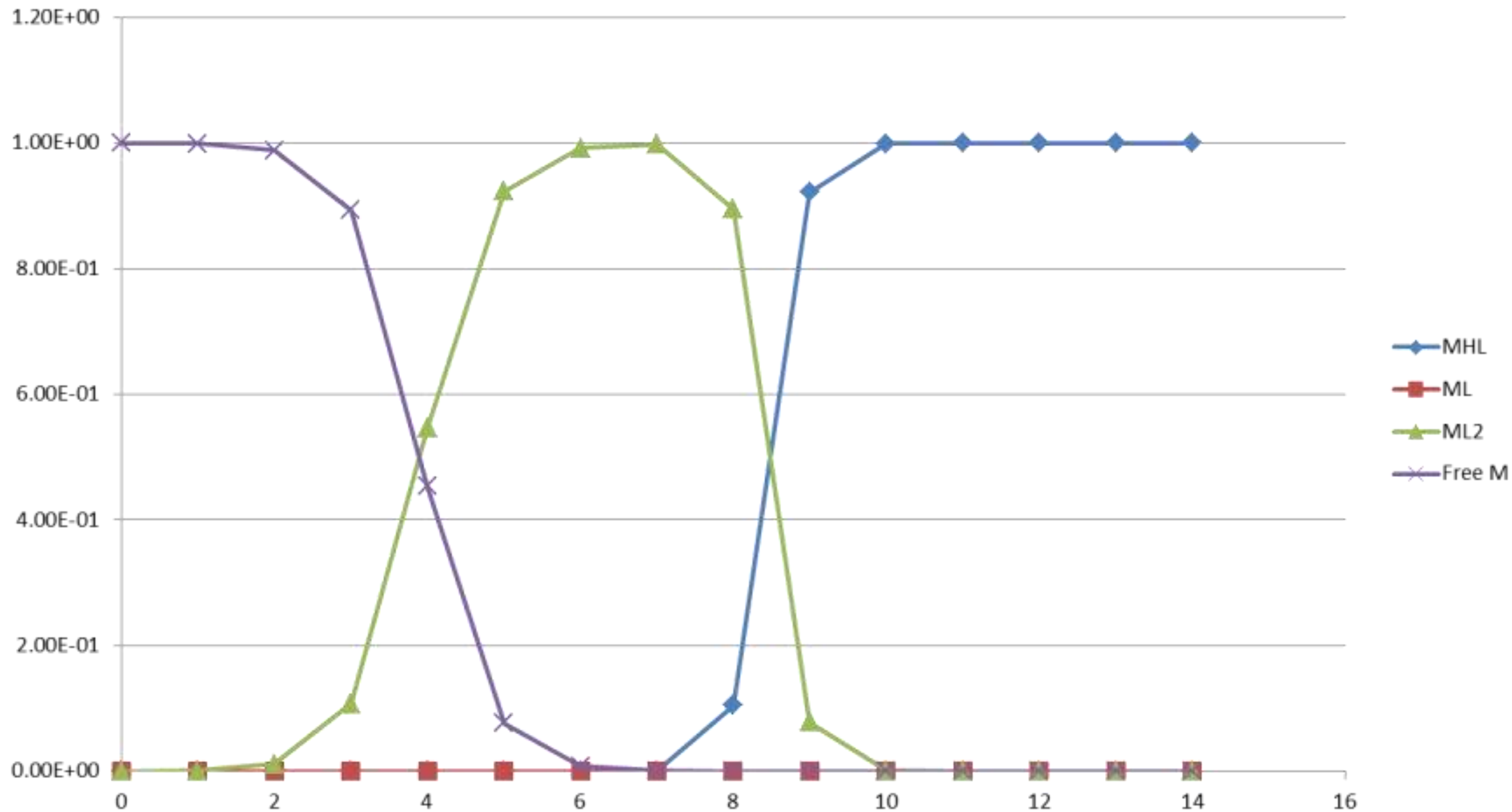
Glyphosate Species



Zinc Glyphosate Chelate



Copper Glyphosate Chelate



pH

Where's the Yield?

Photo: B. Streit

Mn Sufficiency* Range for Agronomic Crops

Crop	Range	Crop	Range
Barley	25-100	Sorghum	6-190
Bean	20-100	Soybean	20-100
Canola	25-250	Sugar beets	26-360
Corn	15-300	Sugar cane	25-400
Cotton	25-350	Sunflower	50-1000
Oats	25-100	Tobacco	26-400
Peanut	60-350	Tomato	25-35
Rice	150-800	Wheat, spring	25-100
Rye	14-45	Wheat, Winter	16-200

*Depends on: cultivar efficiency, growth stage, soil physical and biological environment

Types of Physical Stress

Stress effect on nutrition	STRESS	Nutrition effect on stress
Solubility	WATER DEFICIT	Ca, Fe, Mn, Mg N, Zn
Microbial activity (form)	WATER EXCESS	Root growth, physiology
Root growth, N-loss		Microbial activity
Microbial activity, N-loss	COMPACTION	Fe, Mn, Mg, Ca, S
Root growth, uptake, O_2	(GAS EXCHANGE)	Availability, resistance
Availability, uptake	pH	Ca, Fe, Mg, Mn, Mo, S, Zn
Microbial activity		Microbial activity
Translocation	LOW TEMPERATURE	Cu, Mn
Respiration	and	Physiology, hardiness
Microbial activity	HIGH TEMPERATURE	Co, Cu, Mg, Mn, Ni
Metabolism	LIGHT	Ca, Cu, Fe, Mn, S
Respiration		N-form, Ni

Types of Chemical Stress

Stress effect on nutrition	STRESS	Nutrition effect on stress
Chelate, imobilize	MICROBIAL METABOLITES	Fe, Mn, N, etc.
Chelate, complex Microbial activity Uptake, efficiency	AGRIC. CHEMICALS HERBICIDES	Specific to general N, Cu, Fe, Mn, Zn
Physiology, root growth	ALLELOPATHIC	Cu, Fe, Mn, S
Reduced availability	PLANT COMPETITION (weeds)	Most
Microbial activity, chelate	ORGANIC MATTER	B, Cu, Fe, Mn, Mo, Zn
Deficiency Amount, form, time available	NUTRIENT DEFICIENCY	All, physiology, resistance Specific to general

Micronutrients: Needs and Function

Symbol	Name	Need	Some functions
B	Boron	4-100	Carbohydrate met, cell wall, pollen germ.
Co	Cobalt	Trace	Carbohydrate, N-fixation
Cu	Copper	5-15	Protein, sugar, pollination, defense-stress
Fe	Iron	20-50	Photosynthesis, energy, N-fix., ox-red
Mn	Manganese	18-50	Photos, ox-red, AA, energy, TCA, defense-stress
Mo	Molybdenum	0.5-1	Sugar, AA, N-fix., N-red.
Ni	Nickel	Trace	N-metabolism, germination, yield
Zn	Zinc	20-150	Respir, hormone, AA, ox-red, permeability, stress

Micronutrient Deficiency Symptoms

Micro	Symptom
B	Stunting, die-back, cracking, poor flowering, yellows
Co	Slow growth, poor nodulation
Cu	Stunting, yellow, rolled leaf, die-back, poor flowering, disease
Fe	Stunting, yellow, few nodules
Mn	Stunting, Interveinal yellow, leaf spots, malformed leaves
Mo	Stunting, interveinal yellow, mottling, necrosis, no nodules
Ni	Small leaves, slow growth, bud drop
Zn	Stunting, rosette, yellow, necrosis, twisting

Nutrient	Soil Conditions Inducing Nutrient Deficiency
N	Leaching, low OM, residue burning, denitrification, microbial sinks
P	Acid, organic, leached & calcareous soils; excess liming
K	Sandy, organic, leached, eroded soils, intensive cropping
Ca	Acidic, alkali, or sodic soils
Mg	Low clay content, sodic low Mg soils
S	Low organic matter soils, high use of N and P
B	Sandy, acidic leached soils, alkaline soils with free lime
Cu	High pH, low or high organic soils
Fe	Calcareous soils, high P, Mn, Cu, or Zn; excess liming
Mn	Calcareous silt and clays, high organic matter, oxidative organisms
Mo	Highly podzolized soils, well drained calcareous soils, low pH
Zn	Highly leached acidic soils; well drained calcareous soils

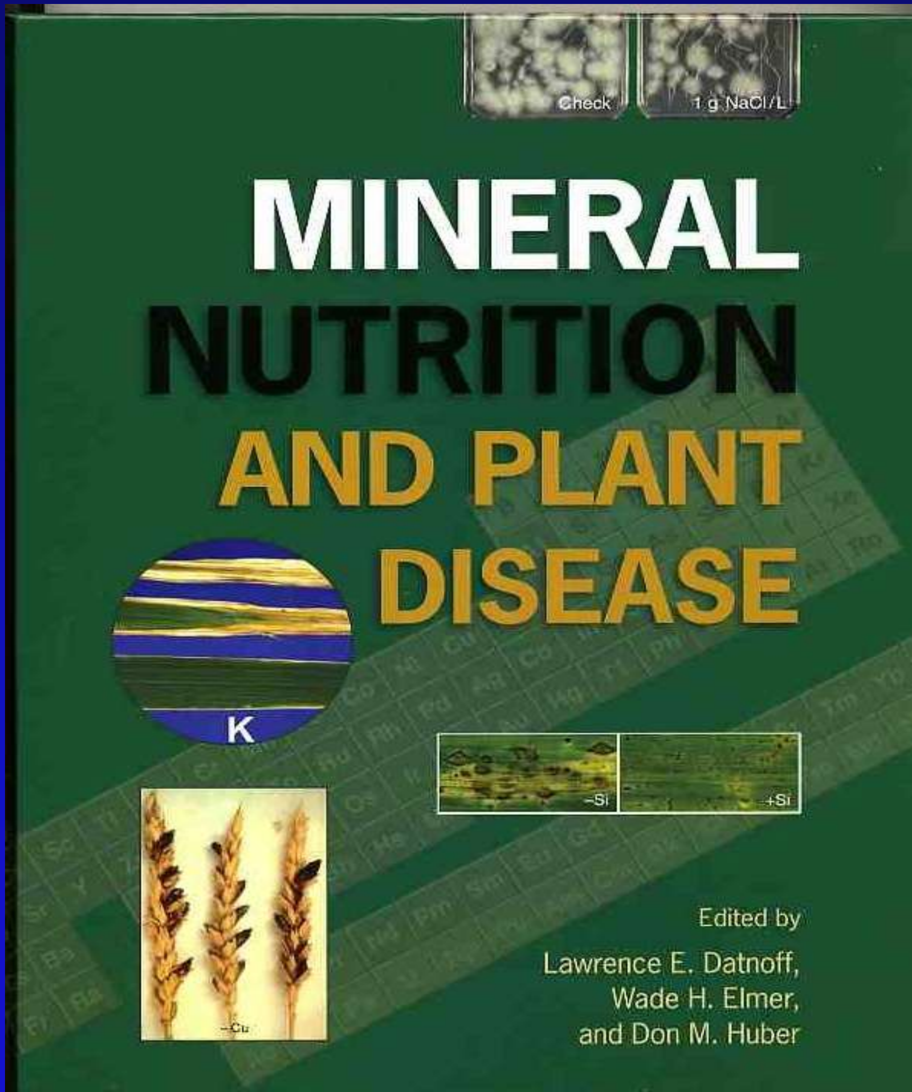
Root exudation of organic compounds from cotton, wheat and apple with different Zn levels

Zn Treatment	Amino acids	Sugars	Phenolics
	($\mu g\ g^{-1}$ root $6h^{-1}$)		
		COTTON	
-Zn	165	751	161
+Zn	48	375	117
		WHEAT	
-Zn	48	615	80
+Zn	21	315	34
		APPLE	
-Zn	55	823	350
+Zn	12	275	103

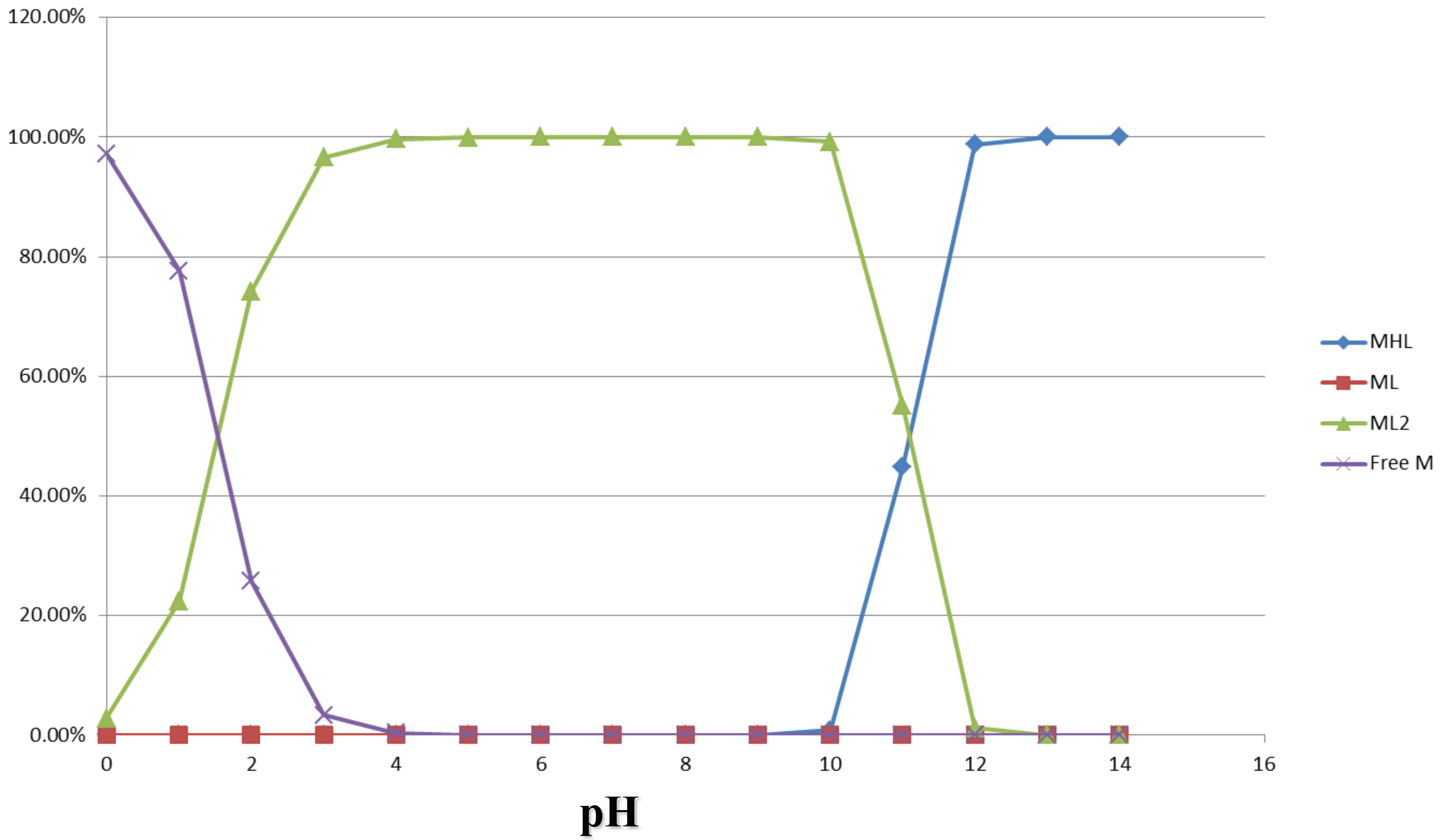
Cakmak and Marschner, 1988, J. Plant Physiol.

Nutrition Changes the Host Environment

- Specific nutrients
- Form of nutrient - esp. N
- Time applied
- Rate applied
- Nutrient interactions
- Herbicide interactions



Iron Glyphosate Chelate



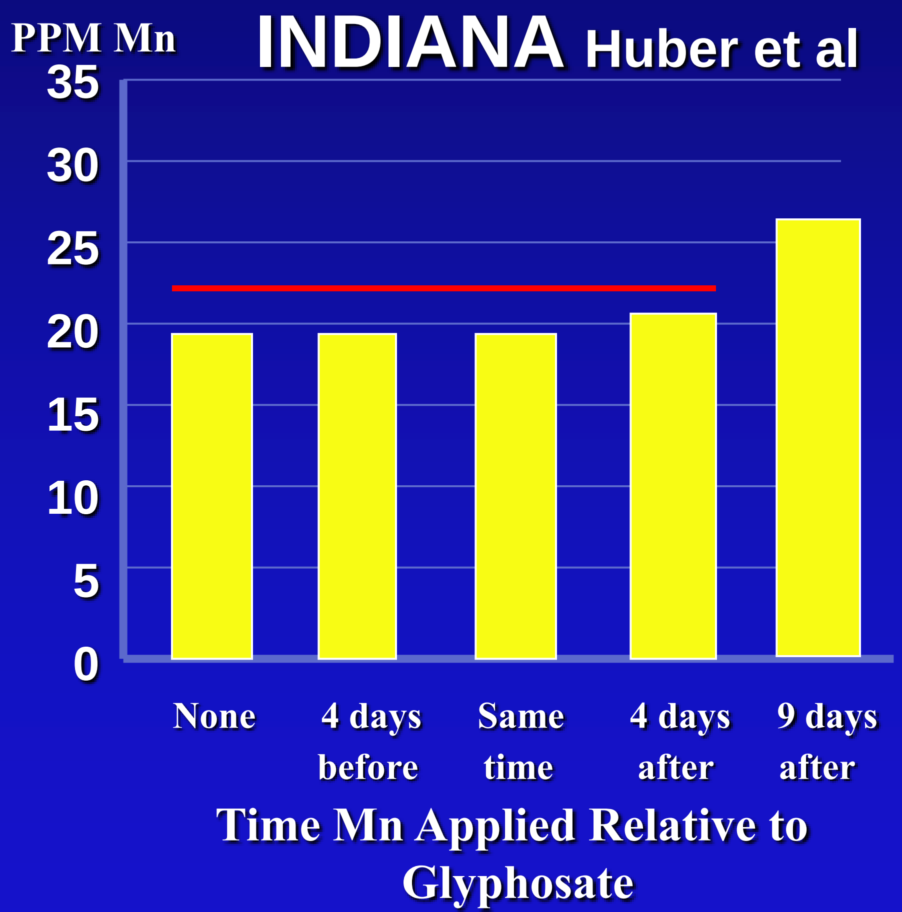
Evaluation of Roundup Ready® Yield Drag

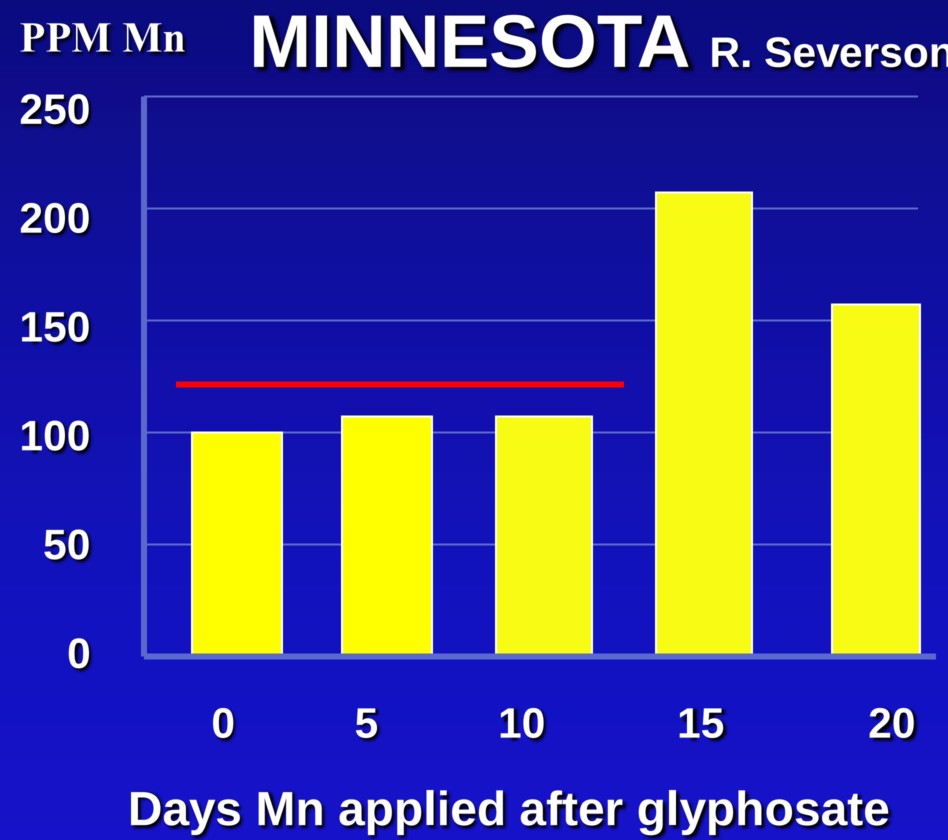
An Evaluation of 8,200 University-based Soybean Varietal Trials

Source: Benbrook. Ag Biotech Info. Net. Tech. Paper No. 1

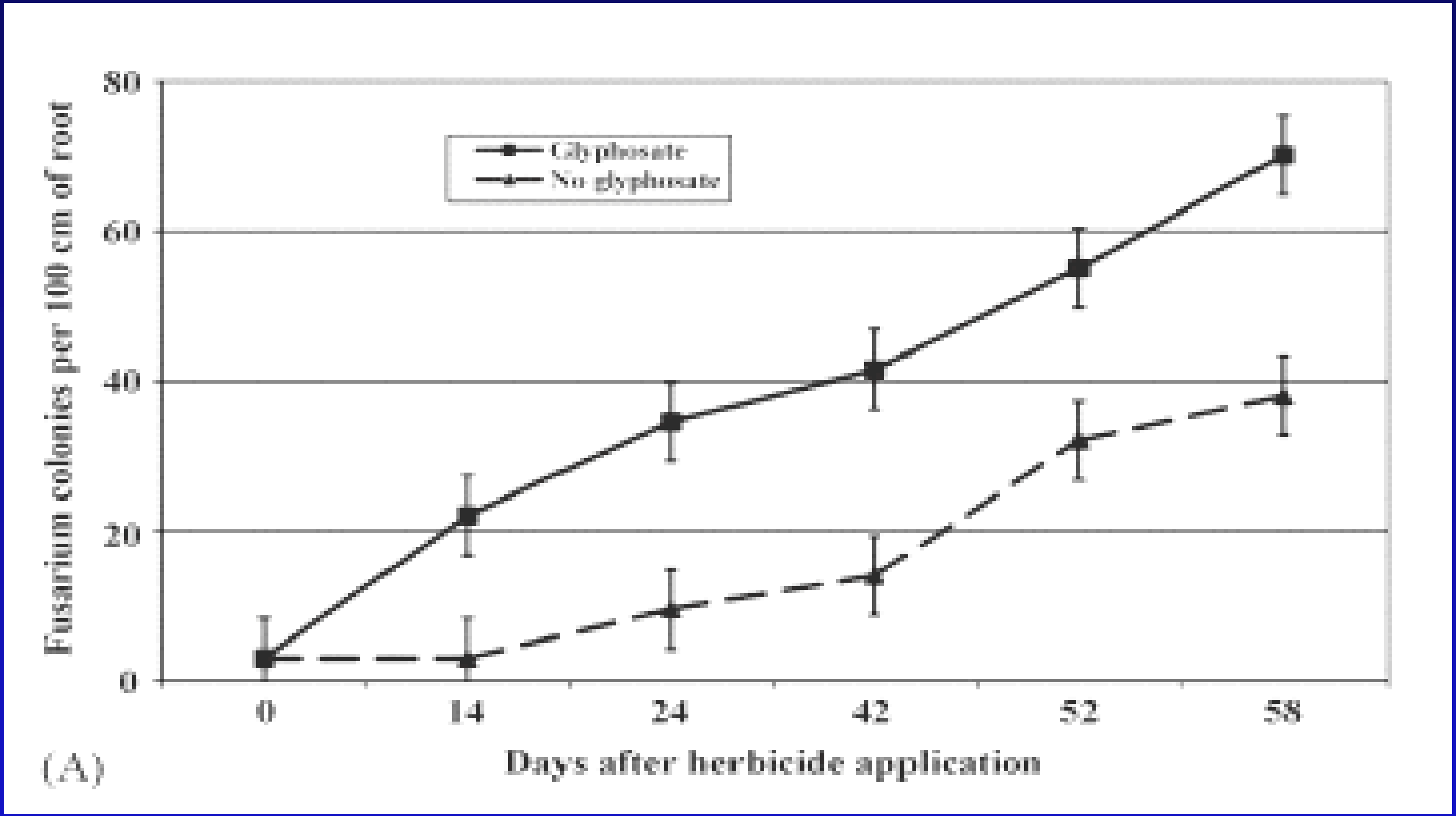
- 93 % showed lower yields for RR than non-GMO
  - RR averaged 6.7 % lower than non-GMO
  - RR were 10 % lower than best Midwest varieties
- RR yield drag could result in a 2.0-2.5 % lower national yield
  - Potentially the most significant decline in a major crop ever associated with a single genetic modification
- RR uses 2 - 5 times more herbicide than conventional
  - 10 times more than multitactic
- RR yield drag and Tech fee impose an indirect tax
  - as much as 12 % of gross income per acre

Effect of Time of Mn Application AFTER Glyphosate on Tissue Mn



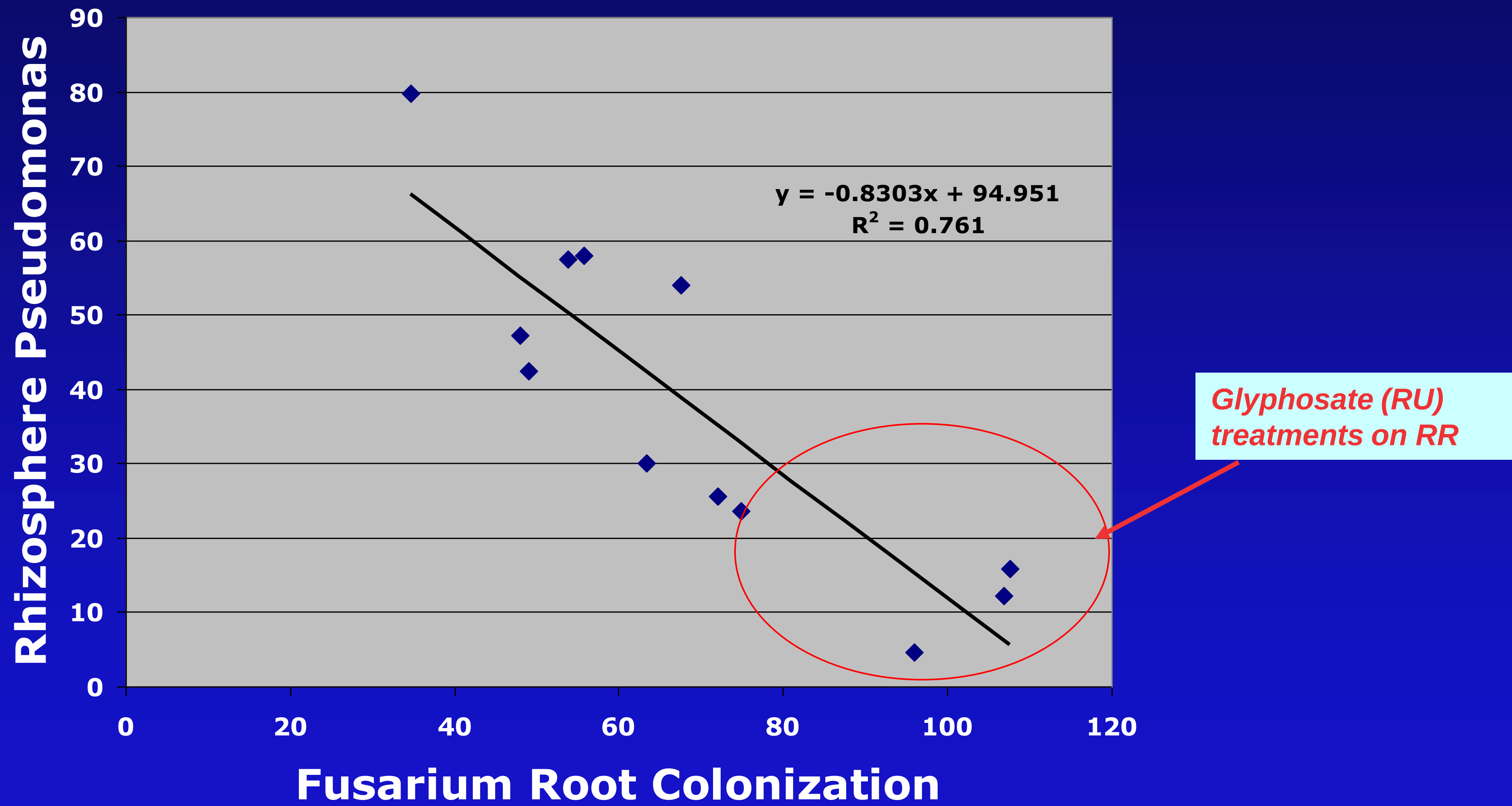


Typical trend in Fusarium colonization of RR roots



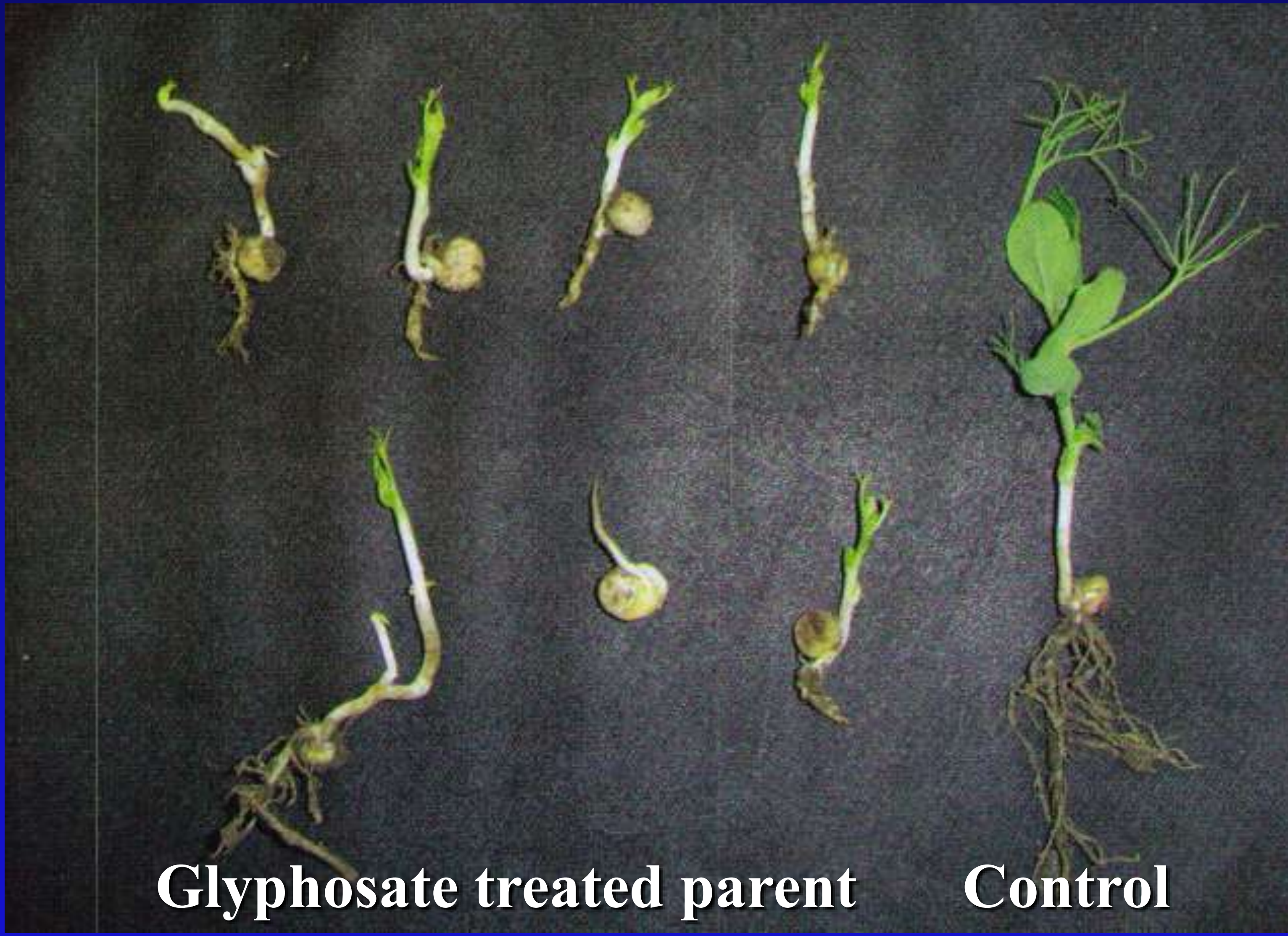
Glyphosate applied at 0.84 kg a.e./ha (0.75 lb/A) on Pioneer 94B01 Roundup Ready® soybean variety at the V4 growth stage, 1998 (Kremer & Means 2009)

Relationship Between Colonization of Soybean Roots by Fluorescent *Pseudomonas* spp. and by *Fusarium* spp.



Apparent antagonism of *Fusarium* growth by *Pseudomonas* spp., Kremer & Means 2009

Effect of Pre-harvest Glyphosate on Pea Seed Germination



Remember

1. **Glyphosate kills weed plants by increasing disease**
   Optimize crop nutrients for sufficiency

2. **Glyphosate-tolerant plants are less nutrient sufficient**
   Compensate for reduced efficiency

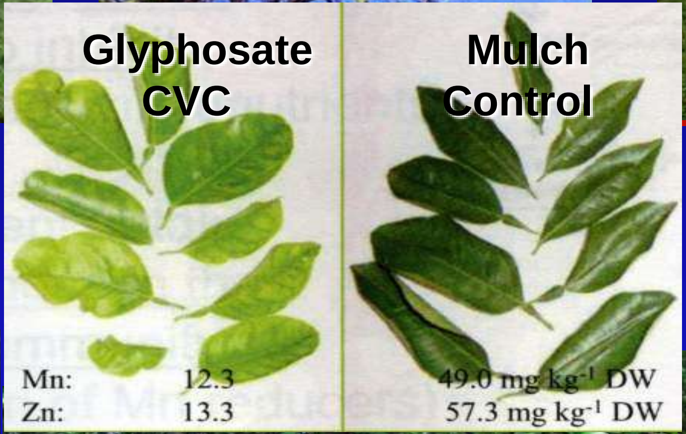
3. **Learn to recognize symptoms of glyphosate damage**
   Minimize by plant delay and detoxification
   Avoid interactions for other crops in the rotation

4. **Use glyphosate judiciously!**

Poor Boll Retention, Sterile Locules in RR Cotton. WHY?

Citrus Variegated Chlorosis

Predisposition to CVC (*Xylella fastidiosa*) by glyphosate



Glyphosate Resistant Weeds

It starts this way >>>>> and >>>>> Develops into this

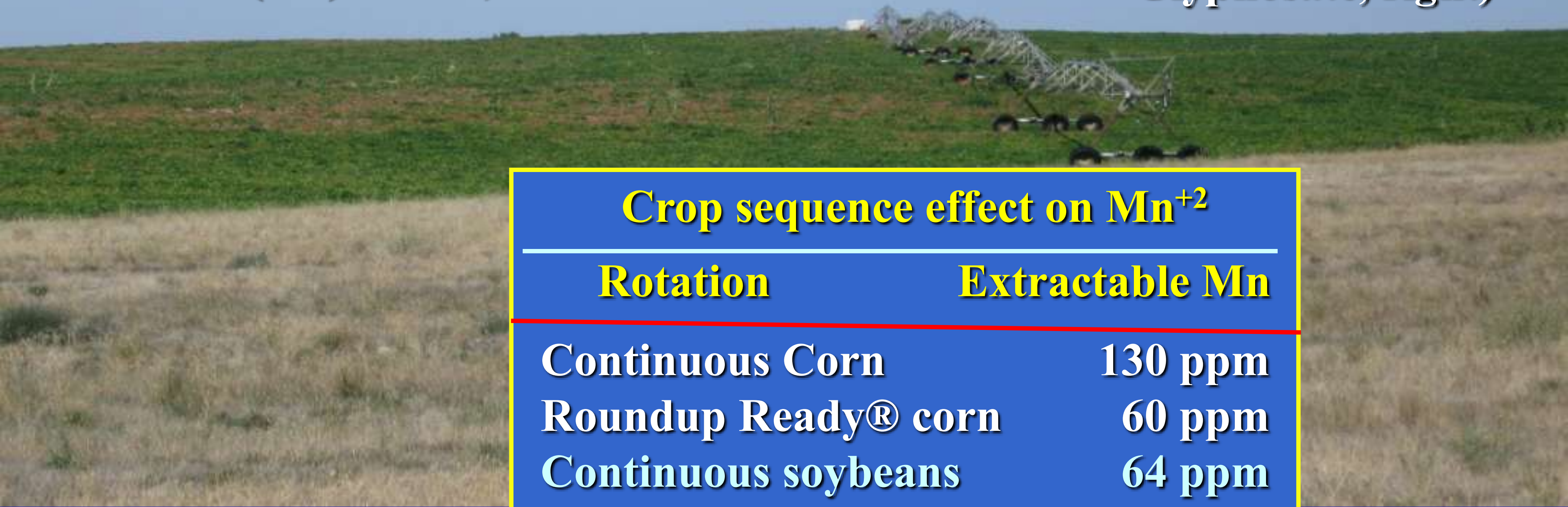
Increased Disease on Crops in the Rotation

- Beans (*P. vulgaris*) after RR sugar beets
  - Fusarium root rot
  - Rhizoctonia hypocotyl rot
- Alfalfa after RR corn or RR soybeans
  - Fusarium root and crown rot
  - Phytophthora root and crown rot
  - Aphanomyces root rot
- Wheat after RR canola
  - Fusarium root and crown rot
  - Fusarium head scab
- Potatoes after RR corn (RR sugar beets?)
  - Verticillium wilt
  - Fusarium dry rot
  - Rhizoctonia stolon canker
  - Common scab

Residual Soil & Crop Sequence Effects of Glyphosate

Severe Verticillium wilt after 1 year of RR corn (left) Idaho, 2009

Mild Verticillium after wheat (no Glyphosate, right)



Crop sequence effect on Mn^{+2}

Rotation	Extractable Mn
Continuous Corn	130 ppm
Roundup Ready® corn	60 ppm
Continuous soybeans	64 ppm
Soybean, wheat, <u>corn</u>	91 ppm
Wheat, corn, <u>soybean</u>	79 ppm

Remember

1. **Glyphosate reduces nutrinet efficiency**
   Compensate for reduced nutrient availability & efficiency

2. **Glyphosate accumulates in growth points**
   Detoxify glyphosate in plant tissues and soil

3. **Glyphosate has strong biological activity**
   Manage soil microflora, inoculate legumes

4. **Residual glyphosate effects other crops in the rotation**
   Manage diseases, weeds, pests effectively

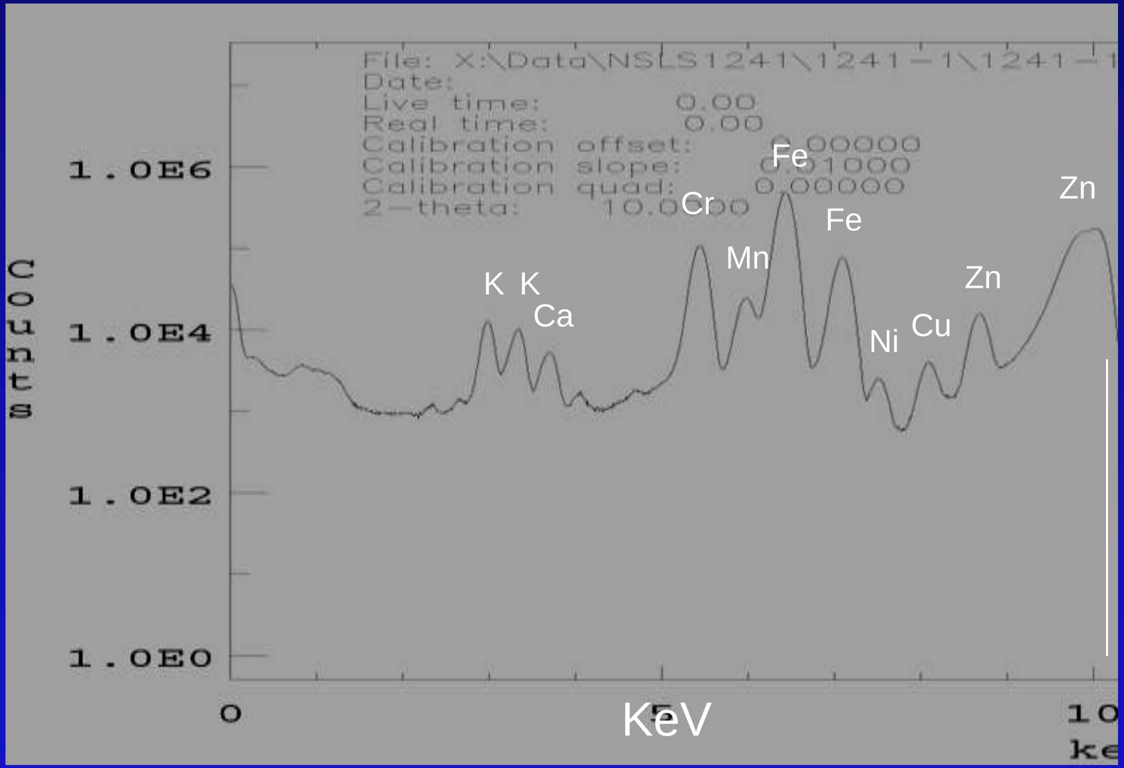
5. **Glyphosate and glyphosate tolerance can reduce crop quality**
   Compensate for lower nutrients by fertilization
   USE glyphosate judiciously

Mineral Composition of 'New" Organism*

Mineral	Wet sample	Dry sample
K	2.1	3.2
Ca	1.4	4.2
Mn	0.4	2.5
Fe	15.9	74.2
Cu	2.5	6.7
Zn	4.9	19.6
Ni	---	1.9
Cr	0.5	8.3

*'Swabbed' from agar surface

Fluorescent Spectra for Dried Sample



What is Known About the Organism

- **Characteristics**
  - Very small (EM visible at 38,000 X) - (size of a virus)
  - Filterable - passes through a bacterial filter
  - Culturable - self replicating
  - Common in nature (ubiquitous? - in soil) - IA, IL, KY, MI, NE, ND, WI
  - Unknown taxonomic position (genetic sequencing in progress)
  - Synergist with bacteria (gram+, e.g. alfa-Streptococcus) and other microbes
- **Infectious nature** - infects animals, plants, fungi (systemic)
- **Affect in animals** (horses, cattle, pigs, poultry)
  - Causes infertility
  - Causes spontaneous abortions (miscarriage-man)
  - Death of chicken embryos
  - In milk from cows fed high infected feed
- **Affect in plants**
  - High population in 'scorch' type diseases
  - 'Extends' symptoms of Goss' wilt (corn) and SDS (soybean)
  - Seed-borne (?) - in soybean seed and feed/food products

What Does it Mean to You?

La Niña Corn Yield Risk

Yield per acre risk computed by Elwynn, Likely harvest price on DEC contract is derived from Wisner "Balance" sheet of 20 Apr 2011. Risk zones are sized assuming that La Niña conditions persist into July.

Dr. Wisner's projections: 151Bu:$7.70, 161Bu:$6.05, 168Bu:$5.25

Using the Wheel

If the DEC contract is trading @ $6.65½ ▼, there is a 66% chance that the harvest price (for DEC corn) will be higher. (Assuming a persisting La Niña)

Trend yield (30-yr USDA linear regression) is at yellow-blue contact. Green represents the (7%) chance of US corn yield exceeding the trend by more than 10%. Red represents the (30+%) chance of yield 10% (or more) below the trend ("legal" drought). [During a "normal" year the trend point is located near the bottom of the wheel (50/50 chance of yield being above or being below the trend)] The most likely La Niña yield is 148BPA.

The electronic DEC corn market (9AM 4/22/2011) assumes a US yield of 157BPA

About $0.15/bushel difference

Photo: B. Streit

Dr. E. Taylor, IA State University, Ames, IA

Remember

1. **Genetic potential & nutrient sufficiency are reduced by glyphosate**
   Optimize crop nutrients for yield and quality

2. **Nutrition is important for disease and stress resistance**
   Optimize crop nutrients for yield and quality

3. **Recognize symptoms of glyphosate damage**
   Minimize by plant delay and detoxification
   Avoid interactions for other crops in the rotation

4. **There are health and safety concerns with glyphosate use**
   USE GLYPHOSATE WISELY and JUDICIOUSLY!

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**
   Detoxifiy glyphosate in roots and rhizosphere
6. **Disease severity increases**
   Use alternate weed control -Minimize glyphosate use

Remember

1. **Nutrient sufficiency is critical for efficient crop production**
   Determined by the interactions of the plant, environment and microbes
   Balance the nutrients to meet the plant needs

2. **Know your soil, Know your seed**
   Soil and tissue test as needed, keep records

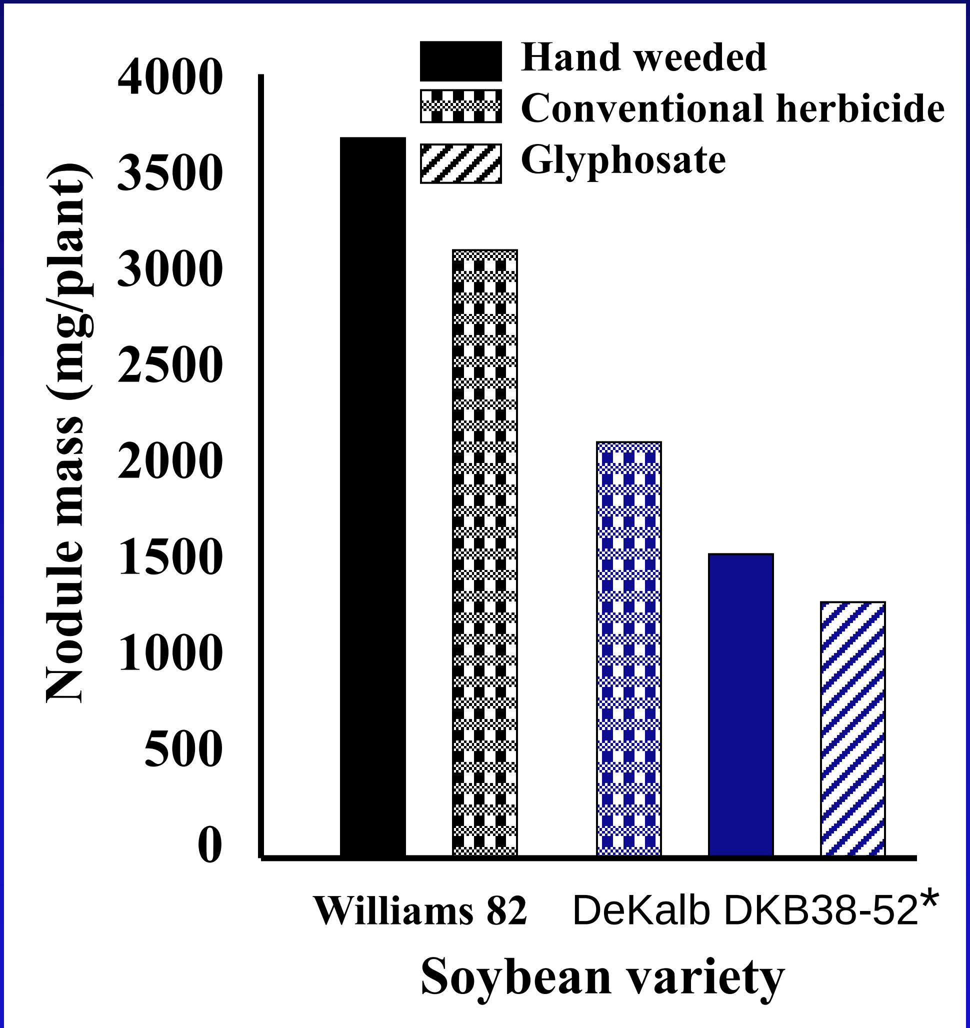
3. **Glyphosate is a strong nutrient immobilizer to influence function**
   Select cultivars with highest nutrient efficiency

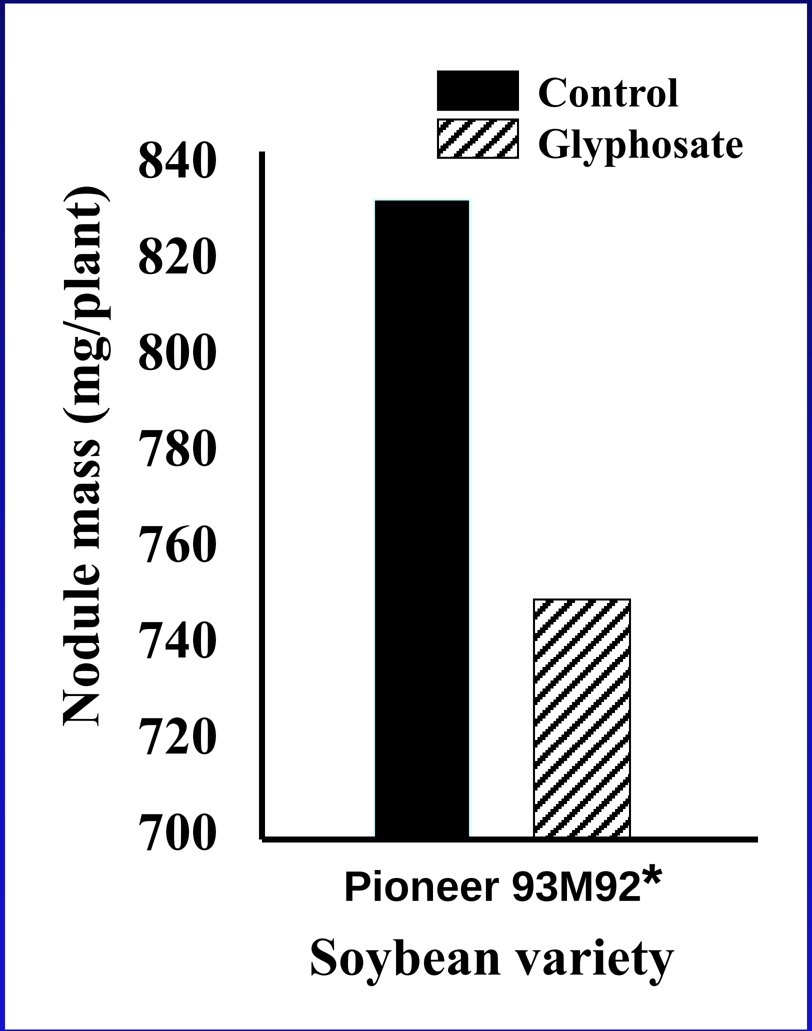
4. **Glyphosate is released in root exudates to reduce microbe populations**
   Consider inoculation of legumes and stimulating beneficials

5. **Insertion of the glyphosate tolerance genes result in a yield drag**
   Compensate for the reduced nutrient efficiency

Effect of the RR Gene & Herbicide on Root Nodule Mass

After Kremer & Means, 2009



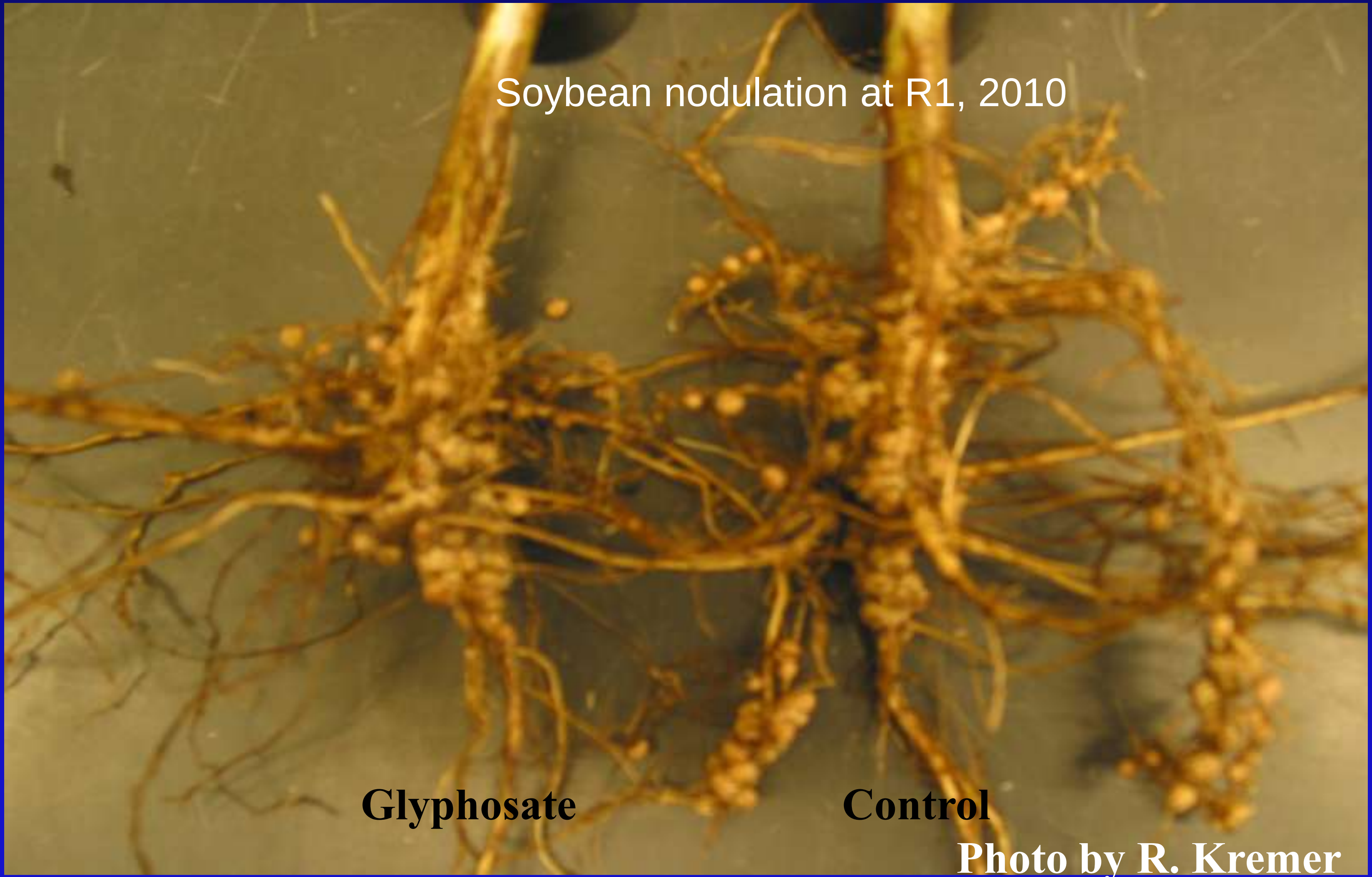


*Roundup Ready®

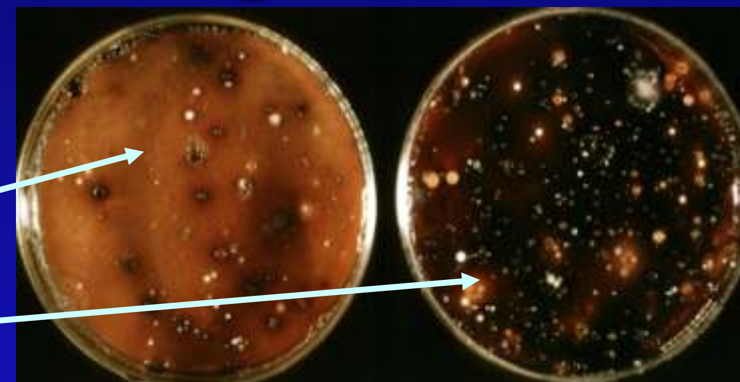
Effects on Nitrogen Fixation

(After Kremer, 2010, Zobiole et al, 2010)

Soybean obtains 25 – 75% of its N from N_2 fixation; the remaining is from soil N (Heatherly & Elmore 2004). Under some conditions, soil N may be depleted, requiring greater reliance on biologically fixed N – residual glyphosate in GR plants and that released into the rhizosphere affects efficiency of N_2 fixation!



Take-all and Populations of Mn-oxidizing Rhizosphere Bacteria



Mn Availability & Biological Activity

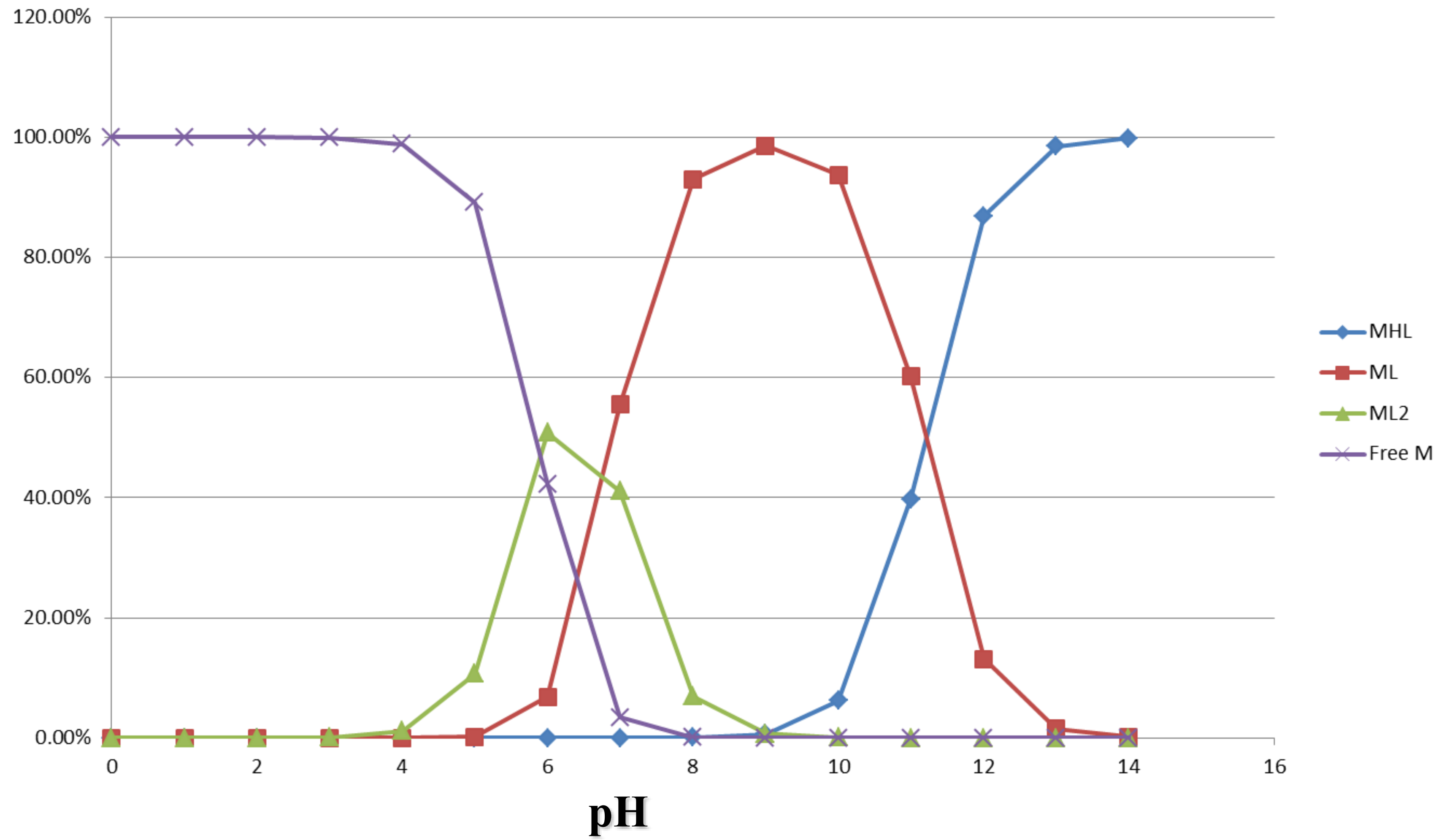
pH: 5.2 ⟷ 7.8

Biological Activity

Mn form: Mn^{2+} → Mn^{+4}

Available: Yes → No

Manganese Glyphosate Chelate



Yellowing of leaves ('flashing' in GR soybean after glyphosate application suggests:

1) Immobilization of essential nutrients for chlorophyll development & photosynthesis; or

2) Toxicity of glyphosate breakdown product (AMPA)

(Bott et al. 2008, Neumann et al. 2006, Sprankle et al. 1975)

Chlorosis on Asgrow AG3539 soybean ("second generation") after glyphosate application at V4 growth stage

(Zobiole et al. 2011. J. Plant Nutr. Soil Sci.

Poor Bud Break, Small Leaves, Stem Epinasty

Nickel Deficiency