Ag Chemical and Crop Nutrient Interactions: Current update

Fluid Fertilizer Foundation Forum
February 15, 2010

Don M. Huber

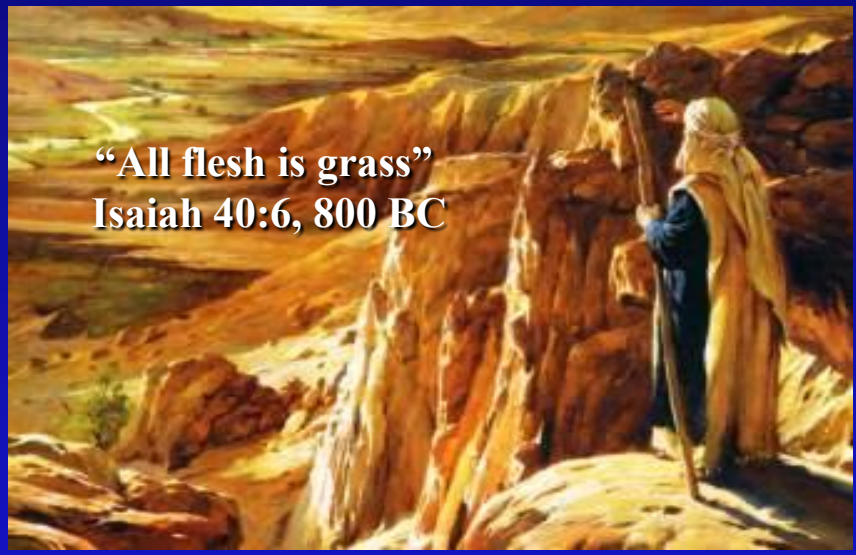
Emeritus Professor of Plant Pathology

Purdue University, West Lafayette, IN

9322 Big Foot Road, Melba, ID 83641

Ag Chemical and Crop Nutrient Interactions: Current update

- **Background** - Nutrition and disease in the agricultural production system
- Understanding glyphosate
- Glyphosate-tolerance
- Remediation
- Reminders and Recommendations

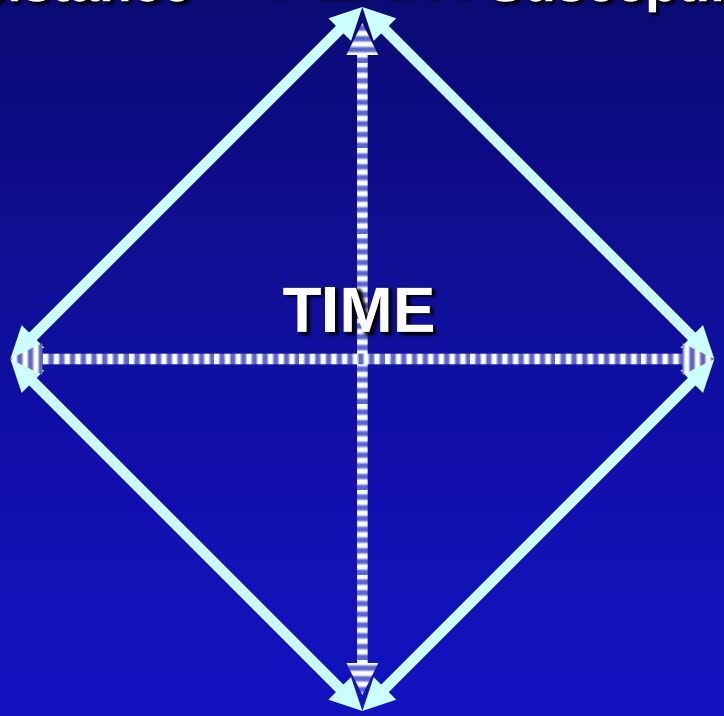


The Importance of Reducing Stresses

Potential - Stresses = Yield

There is no free lunch! *Dr. Andre Comeau*

Interacting Factors Determining Nutrient Availability and Disease Severity



Glyphosate has Changed Agriculture for 30+Years:
Understanding Characteristics of Glyphosate

- **A strong chemical chelator**
  - Small amount needed
  - Tightly binds mineral elements
  - Immobilizes Cu, Fe, Mg, Mn, Zn
- **Non-specific herbicidal effect**
- **Tank mix 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

Physiologic Roles of Manganese

Mn

CHO

Photosynthesis

Glycolysis (energy reactions)

Mn

Shikimic Acid

Glyphosate (EPSPS)

Carbohydrate, hormone &

Amino Acid Synthesis

Mn

Root Growth

Amino Acids

Cyanogenic Glycosides

Phenylalanine

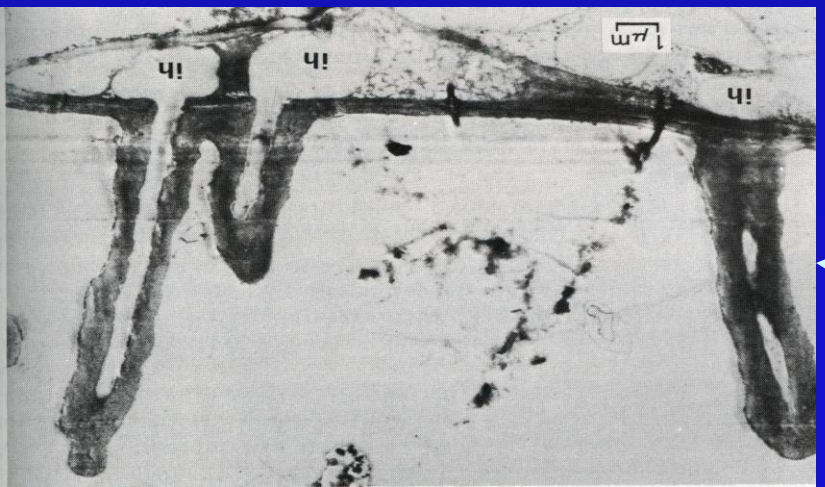
ammonia-lyase

Mn

COUMARINS

LIGNINS

FLAVANOIDS = Defense materials

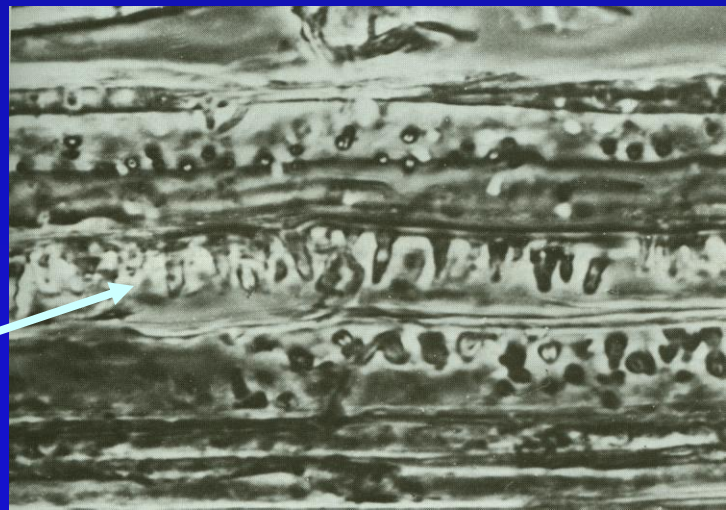


"Lignituber" formed in response to cell Penetration.

Wheat

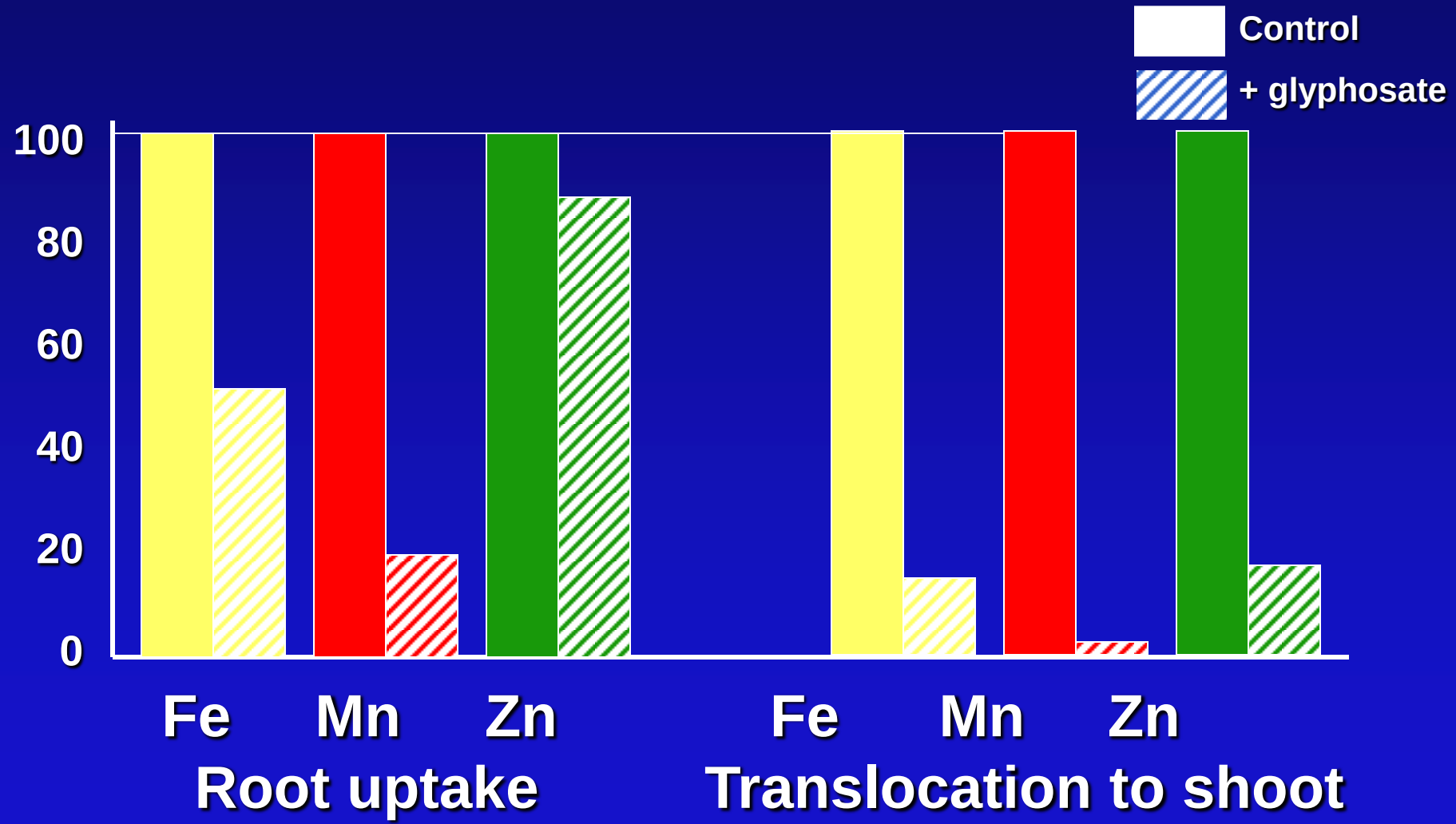
Triticale

(After Skou, 1975)



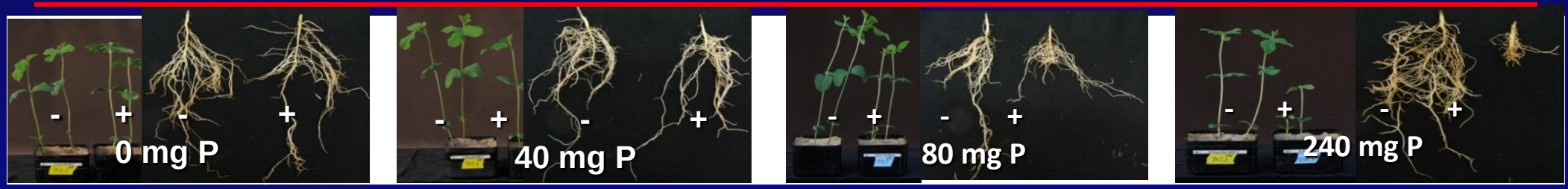
Effect of Residual/'drift' Glyphosate on Percent Nutrient Uptake and Translocation by Plants

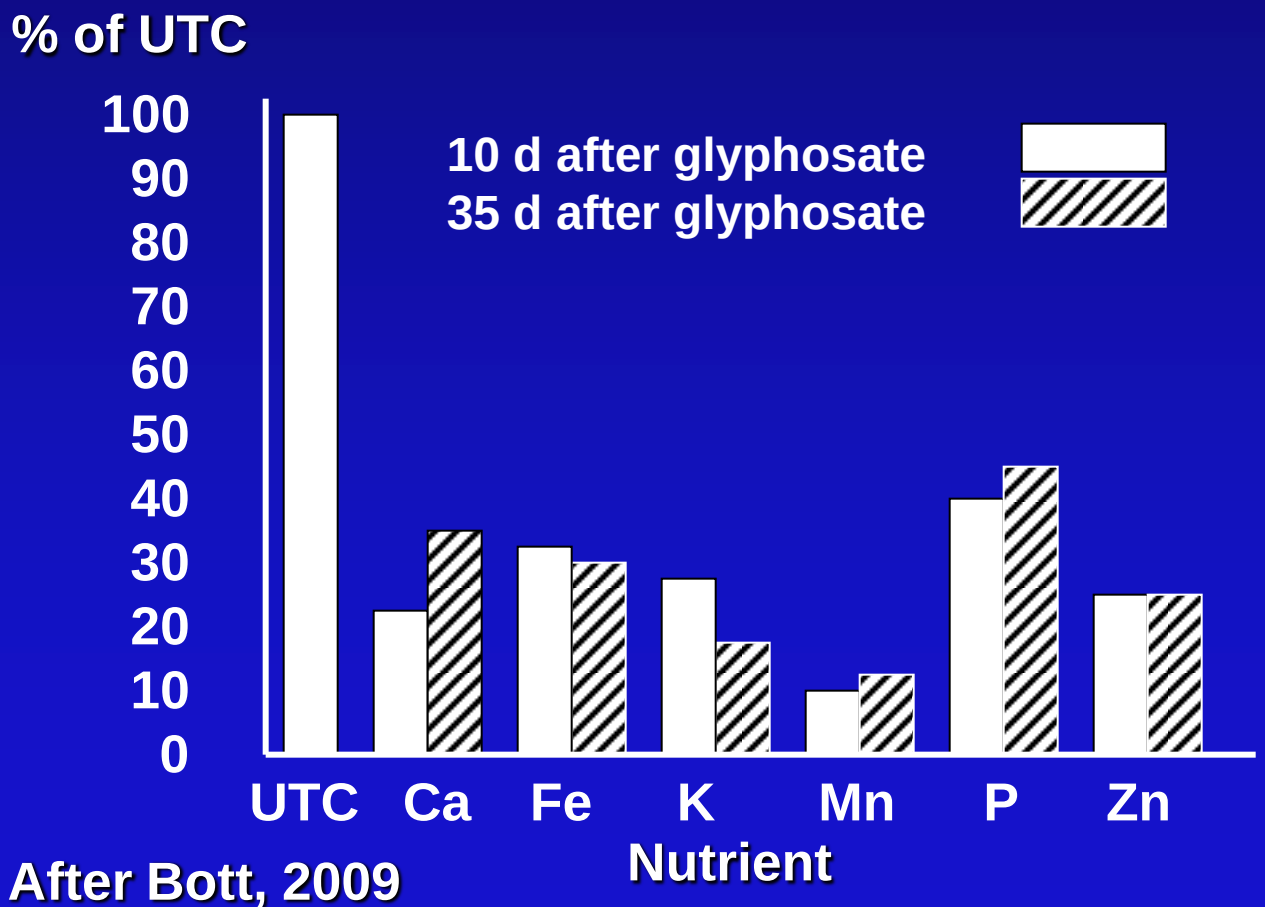
After Eker et al 2006*

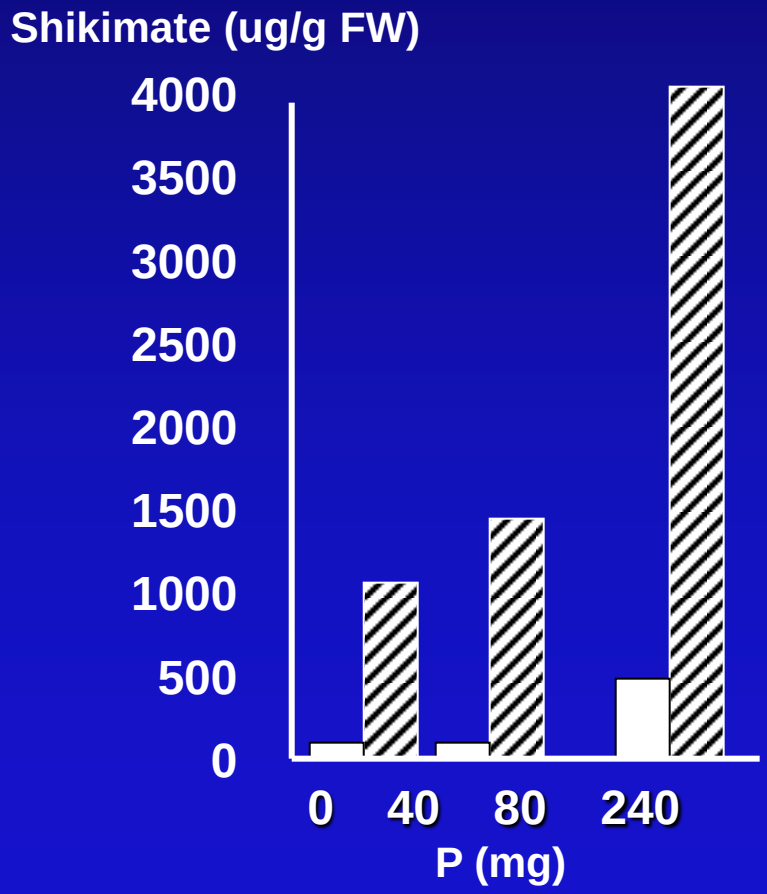


* 1/40th of recommended herbicidal rate

Effect of Phosphorus Desorption/Remobilization of Glyphosate in Soil on Nutrient Content

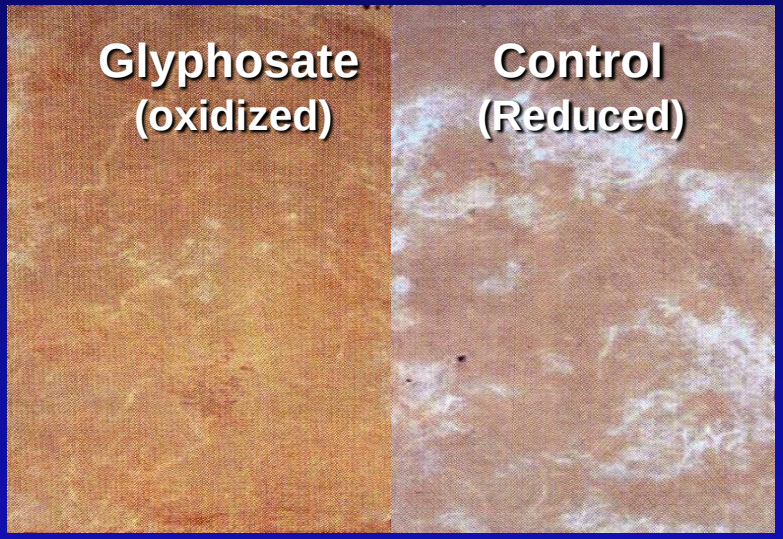






After Bott, 2009

Mn Oxidation/Reduction in Soybean Rhizosphere Soil



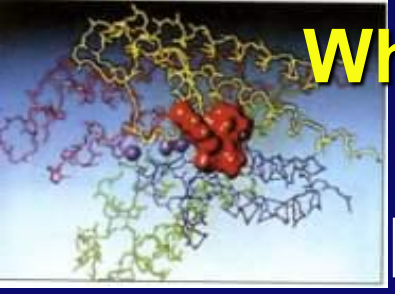
Fungal Mn oxidation in soil (increased virulence)

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

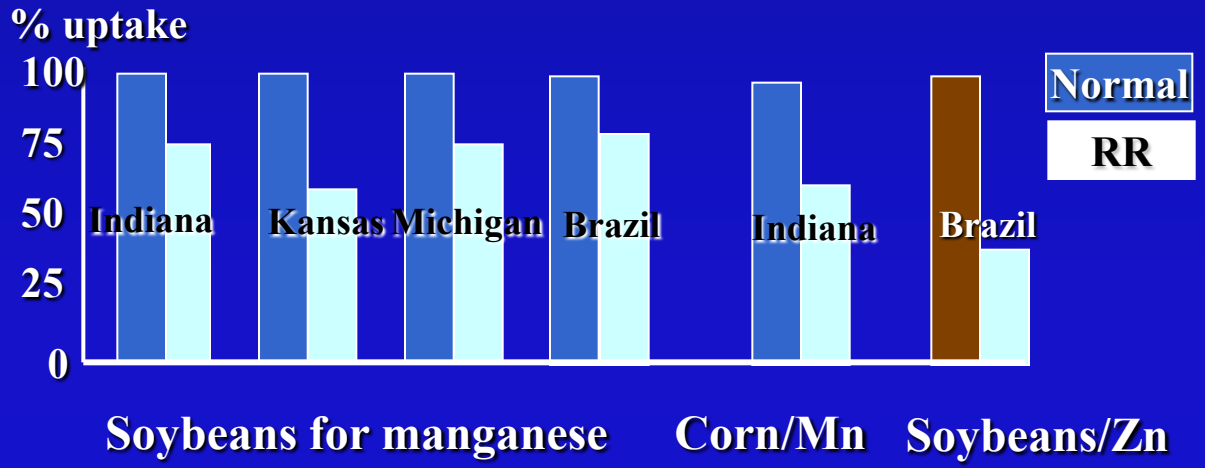
*Colonies per gram of soil



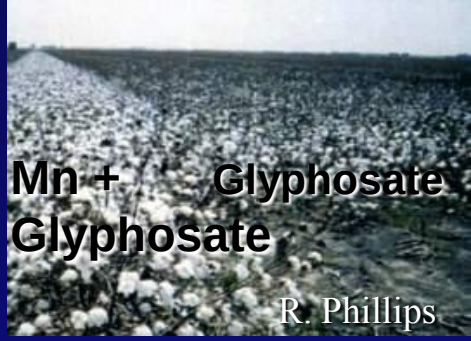
What's Special About Glyphosate Tolerance? Roundup Ready® Gene!

[Greatly expanded usage of glyphosate]

- **The technology inserts an alternative EPSPS enzyme that is not blocked by glyphosate in *mature* tissue**
- Incomplete "protection" of meristematic and reproductive tissues - glyphosate concentrates there
- Changes N physiology of the plant
- "Yield Drag"



Reminder That:



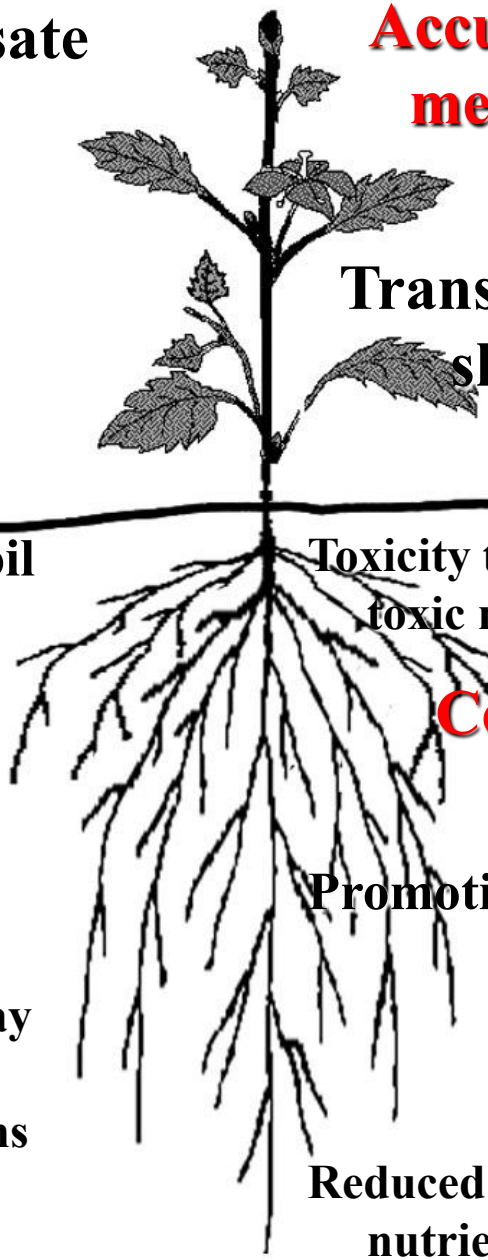
- **There is nothing in the RR plant that operates on the glyphosate applied to the plant**
  - **Glyphosate chelation is not selective**
    - **It immobilizes Ca, Co, Cu, Fe, Mg, Mn, Ni, Zn (& affects availability of other mineral ions)**
    - **Reduces root and top growth for poor nutrient absorption**
    - **Increased drought stress**
    - **Earlier maturity**
- **Glyphosate is there <u>for the life of the plant</u> - or until exuded into the soil through root exudates**

Foliar application of glyphosate

Systemic movement throughout the plant

Chelation of micronutrients

Intensifies drought 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 (slow to no 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
- 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

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

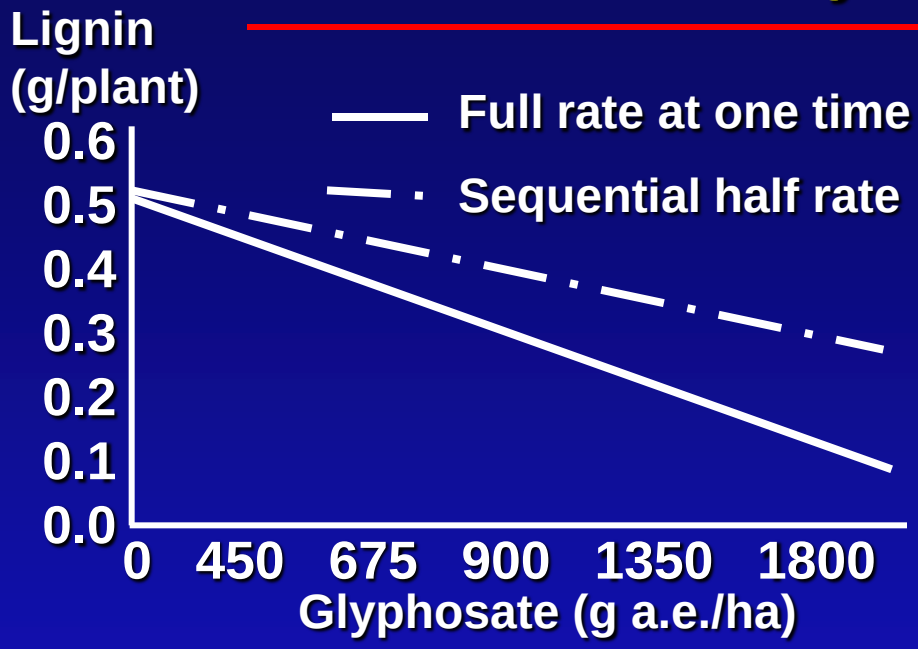
Plant tissue	K	Ca	Mg	Fe	Mn	Zn	Cu
Young leaves	16	40	28	7	29	NS	NS
Mature leaves	4	30	34	18	48	30	27
Mature grain	+4	26	13	49	45	+30	+18

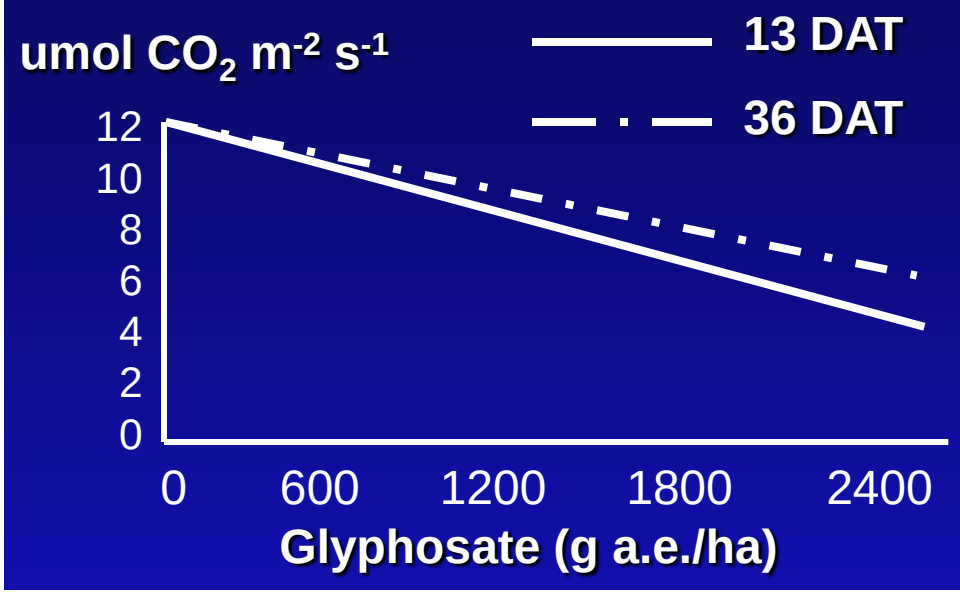
Reduced:

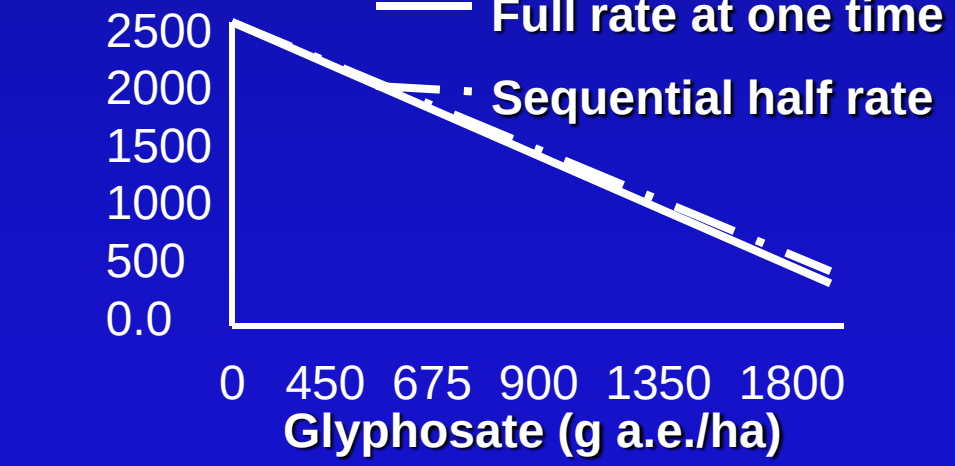
Yield	26%
Biomass	24%

After Cakmak et al, 2009

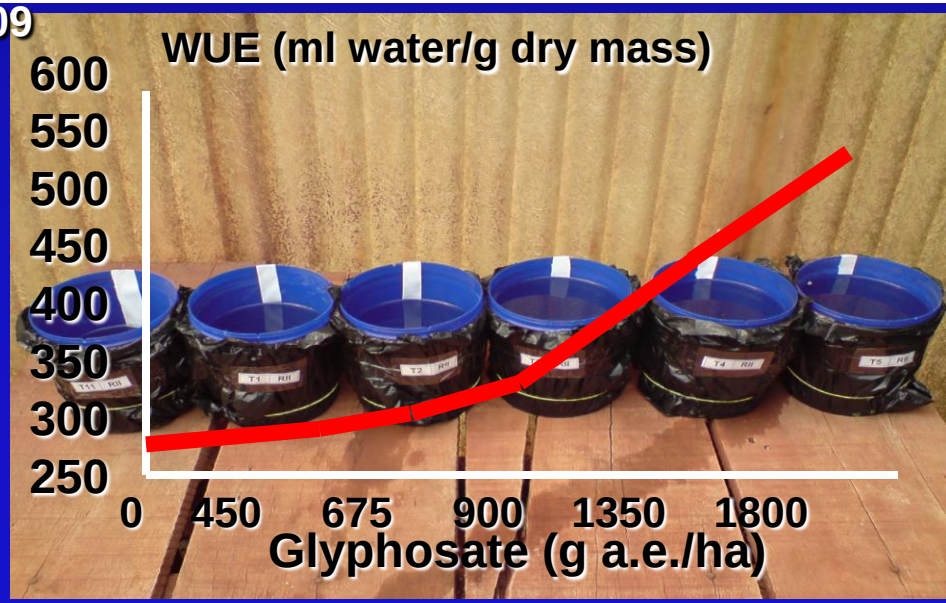
Effect of Glyphosate on Lignin, AA, Water Use Efficiency, and Photosynthesis of GR Soybeans





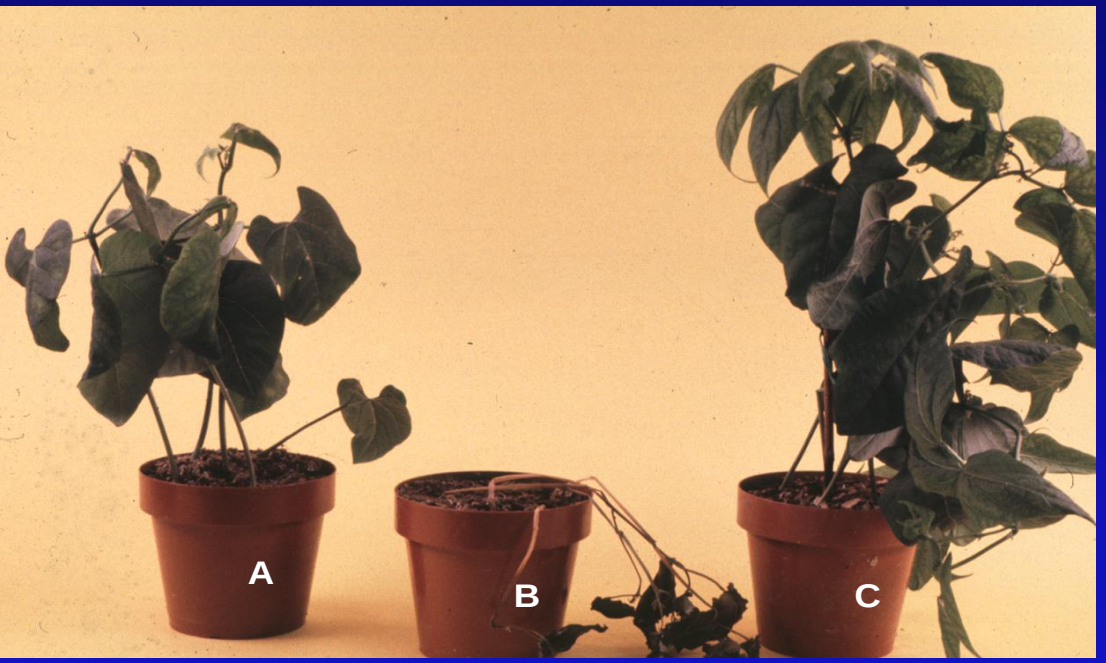


After Zobiole, 2009



Glyphosate Kills Plants by Increasing Disease Susceptibility

Herbicide action is by chelating (immobilizing) Mn for EPSPS, etc.



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

Plant Pathogens Affected 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	**Decreased (obligate pathogens):**
Gaeumannomyces graminis	*Phykopsora pakyrhiza*
Magnaporthe grisea	*Puccinia graminis*

Fungal Mn oxidation in soil (increased virulence)

("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	*Corynespora cassicola*
Soybeans	Target spot	*Corynespora cassicola*
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

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 for disease and toxins:
  - Flowering
  - Moisture
  - Previously applied glyphosate

These changes also affect rust for "resistance"

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…**

(Fernandez et al. 2005, *Crop Sci. 45: 1908-1916*)
(Fernandez et al., 2007, Crop Sci. 47:1574-1584)

Number of glyphosate applications the previous three years	% Increase in head scab
None	00
1 to 2	52 ***
3 to 6	295 ***

Mycotoxins in Straw and Grain

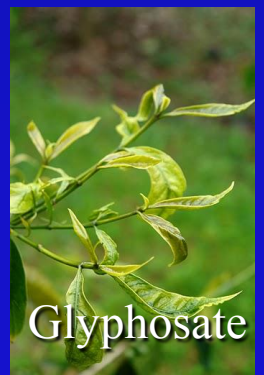
- ✓ *Fusarium* spp. act synergistically in causing death of glyphosate-treated plants
- ✓ Glyphosate-induced root colonization by *Fusarium* spp.
- ✓ Toxins (DON, ZEA) produced in crown and translocated to stem and grain - Well above 'clinically significant' levels!
- ✓ Toxin concentrations not always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

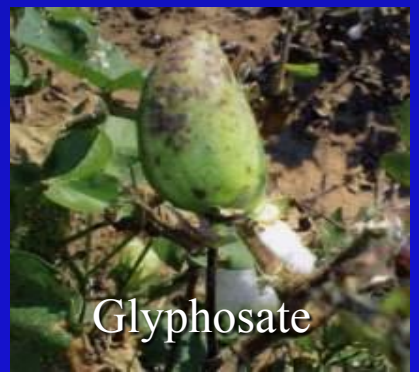
Deoxynivalenol and Zaeralenone Concentrations in plant parts

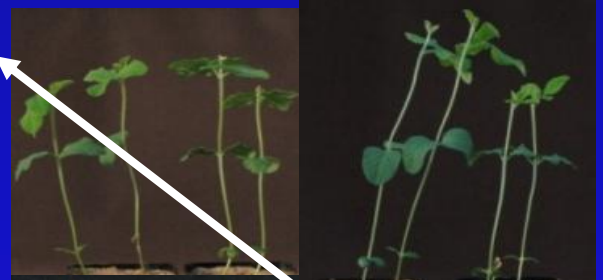
Toxin (ppm)	Grain	Chaff	Straw
Deoxynivalenol	4.7	16.9	3.5
Zaeralenone	4.4	42.9	55.5

Proc. Natl. FHB Forum 2009, Orlando, FL

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 University of Hawaii; Ohio State University

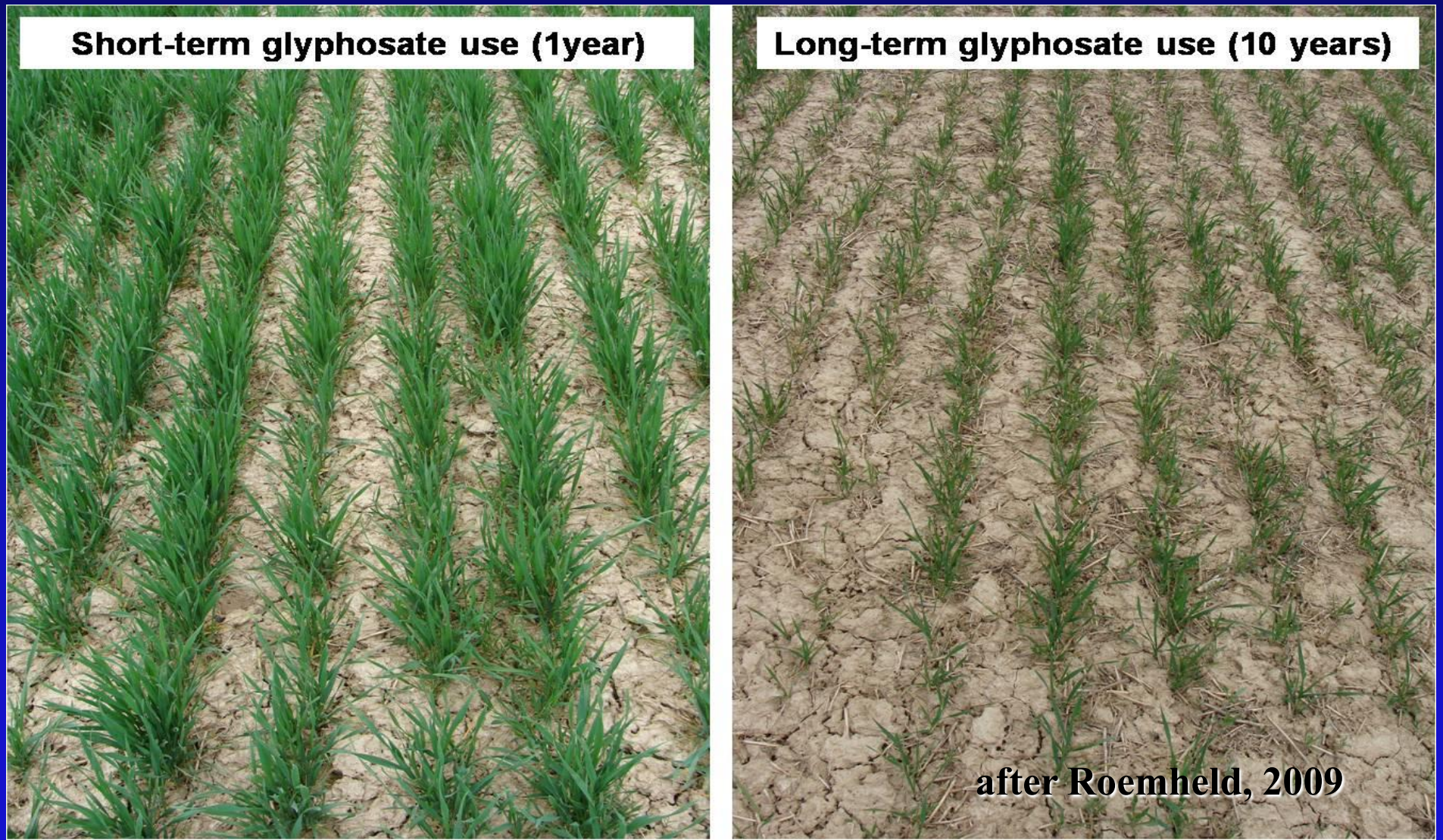
Effect of Planting Delay after Glyphosate (Residual Glyphosate in Soil)

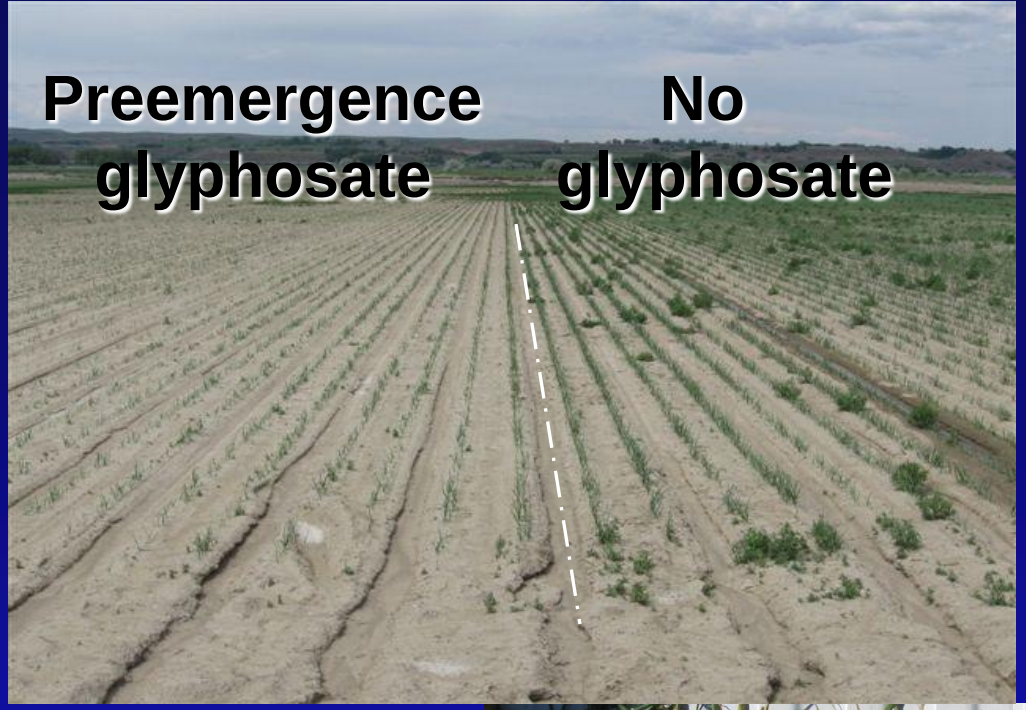
Winter Wheat

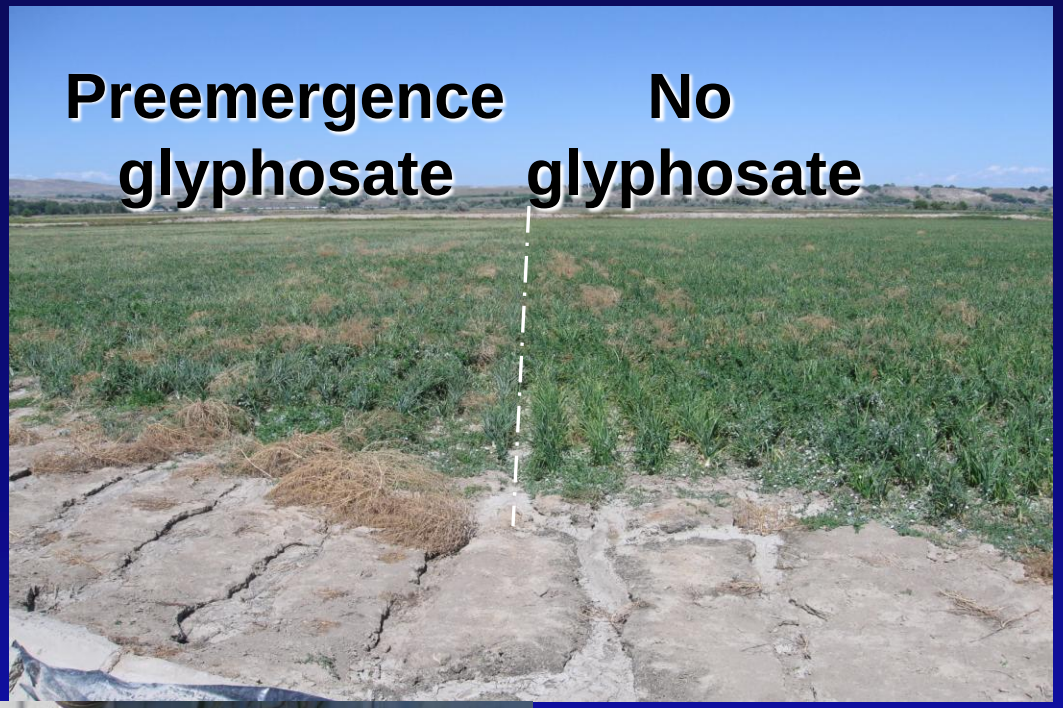
Weiss et al., 2008

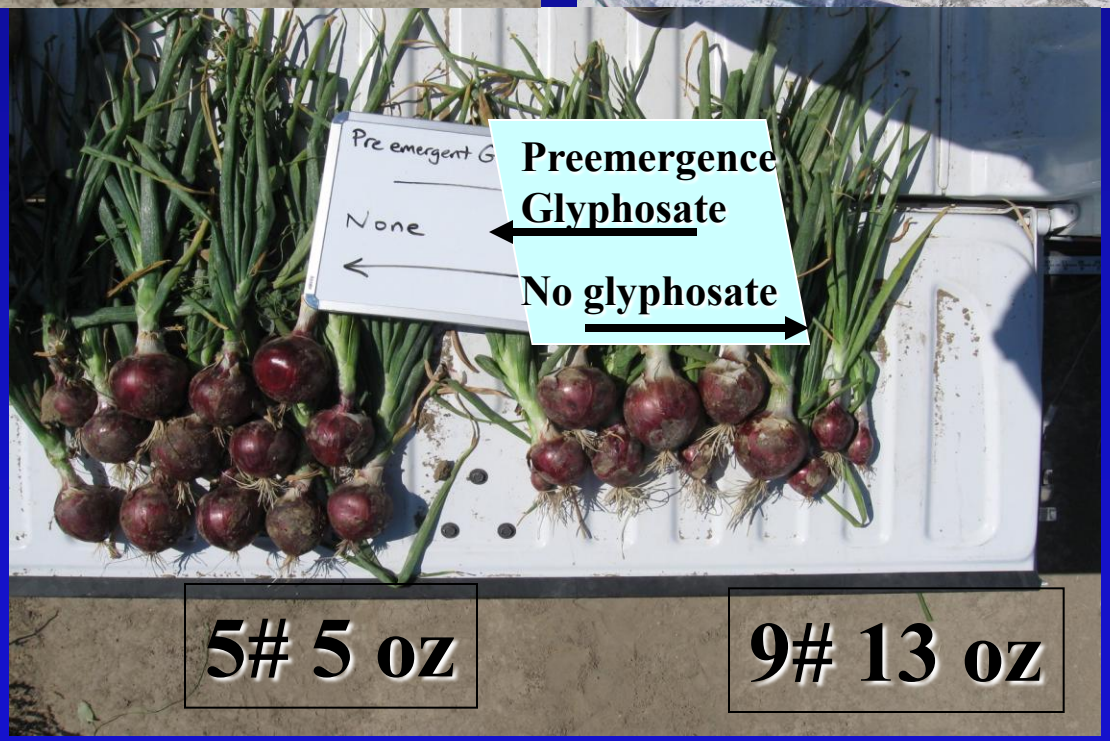
Long-term Effect of Glyphosate

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




Preemergence glyphosate
No glyphosate


Preemergence glyphosate
No glyphosate


Pre emergent G
None
Preemergence Glyphosate
No glyphosate
5# 5 oz
9# 13 oz

Duration of Glyphosate Damage Symptoms

~~(depends on amount, exposure duration, plant, nutrient status)~~

- **Transient in highly fertile soils - *a few days to weeks***
  - **Rapid immobilization of glyphosate - plant and soil**
  - **Rapid replenishment of immobilized nutrients**
  - **Absence of glyphosate-induced diseases**
- **Short time - *weeks to months in moderately fertile soils***
  - **Time to immobilize glyphosate - in plant and soil**
  - **Time to replenish immobilized nutrients**
  - **Time to restore soil microbial activity**
  - **Desorption of glyphosate chelated in soil and decaying plant tissues**
- **Long time - months to years**
  - **Persistent and accumulative in perennial plants for life of plant**
  - **Ability to immobilize residual glyphosate - plant and soil**
  - **'Desorption' of immobilized glyphosate in soil and organic matter**
  - **Restoration of soil microbial activity - 'balance'**

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 - Alternative weed control

Yield Response of Roundup Ready® Soybeans to Micronutrients

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

Effect of Glyphosate on Roundup Ready© Corn

Colorado State University, 2007

Mike Bartolo, Sr. Res. Scientist

Treatment	% grain moisture	Yield (bu/a)	% of control
Untreated*	15.6	234 a	100
Glyphosate**	15.6	195 d	83
Glyphosate + Zn, Mn	15.6	221 b	94
Glyphosate + Mn, Zn, Fe, B	15.6	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

Glyphosate & Manganese Effects on Cotton


Untreated Check (conventional herbicide)


Glyphosate @ 22 oz/ac plus ammonium sulfate


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	2	4693

after Ronnie Phillips, 2009

Detoxifying Glyphosate

- **In meristematic/reproductive tissues**

  Ca, Mn, Si+Mn, Mn+Cu, Zn, Mn+Zn, Ni

- **In root exudates in soil**

  Broadcast:

  Gypsum

  In furrow (or stem drench) treat

  Gypsum ($CaSO_4$)
  Manganese
  Ca + Mn
  Nickel, Zinc

Effect of in-furrow treatments on Soybean tissue Mn

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

Conclusions & Recommendations

1. **The glyphosate-resistance gene reduces micronutrient uptake**
   Select cultivars with highest Mn efficiency
2. **Application of glyphosate reduced Mn translocation in tissues**
   Apply foliar micronutrients 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

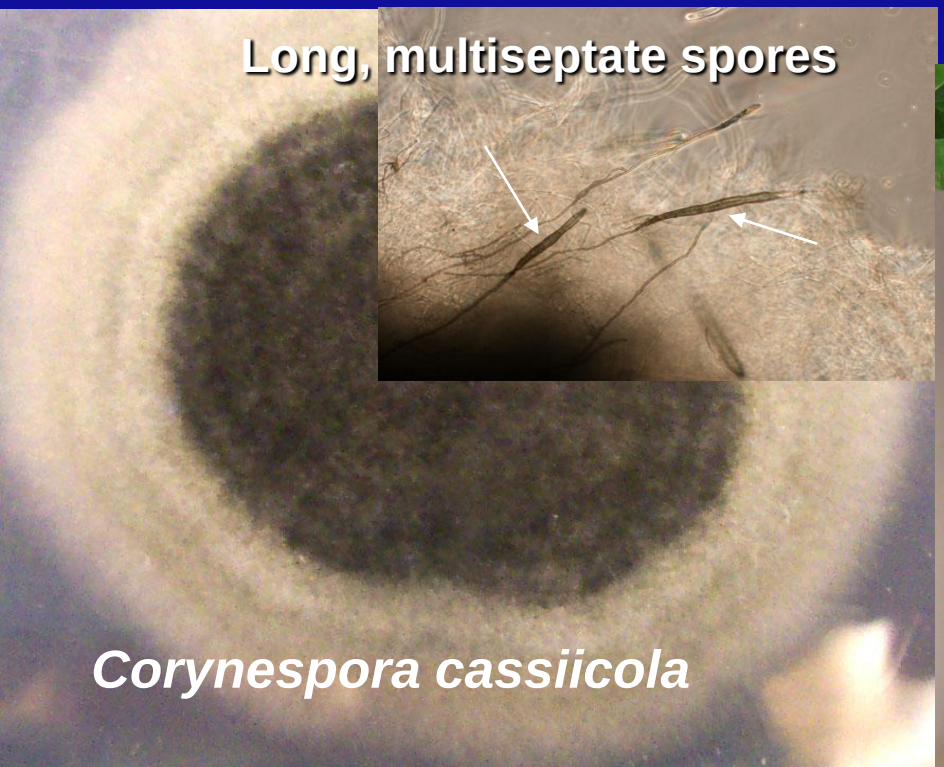
REMEMBER

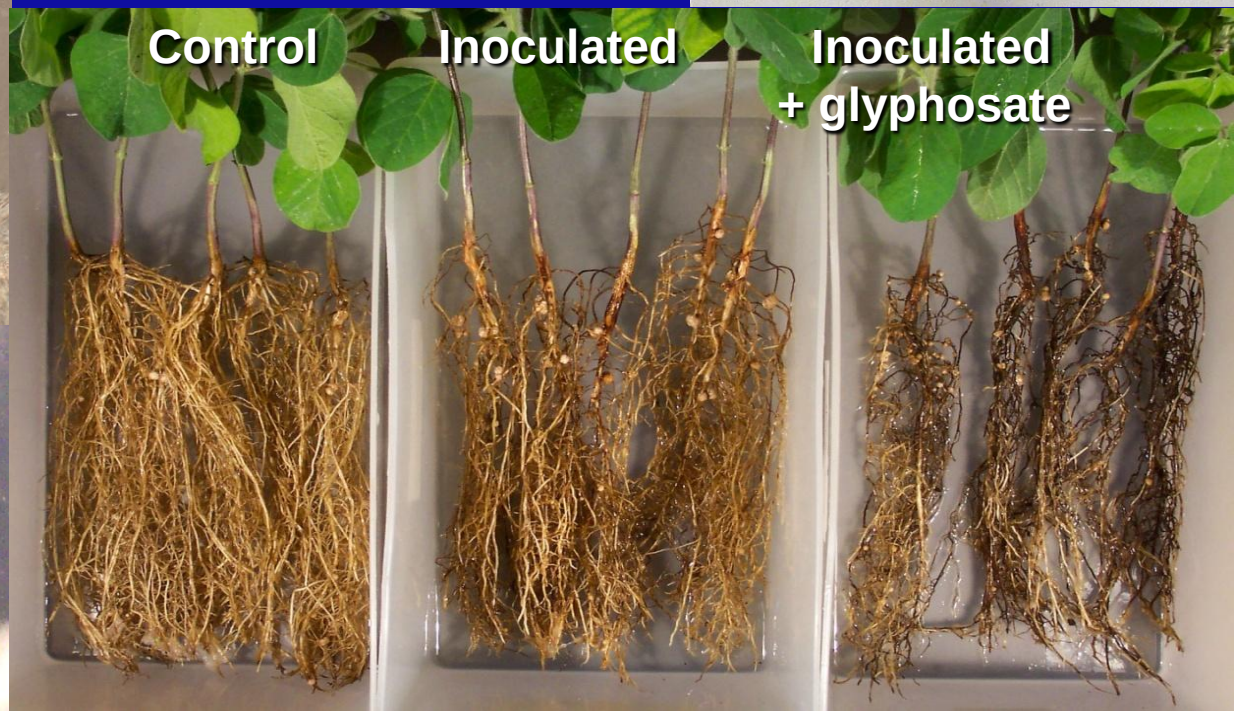
1. Nutrition is an integral part of efficient crop production
    - A. Crop quality and quantity
    - B. Disease control
2. No nutrient controls all diseases
    - A. Consider each nutrient-disease-environment interaction
    - B. Use nutrient form, rate, and time effectively
3. Cultural practices that reduce disease influence nutrition
4. Integrate nutrition and cultural practices for optimum yield and disease control.

Make Sure You Cover ALL the Basics!

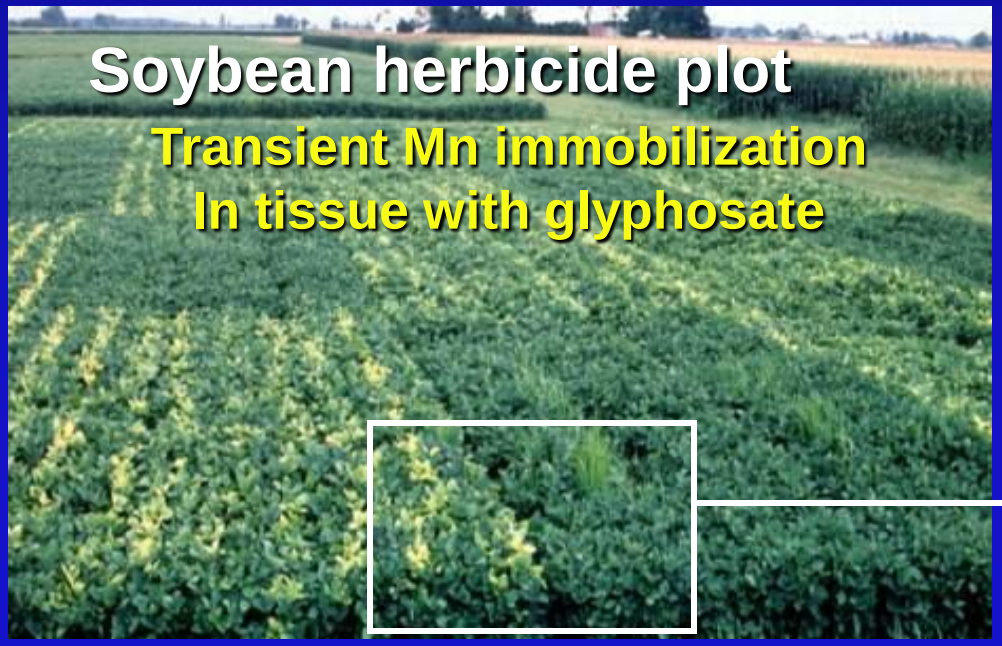
Corynespora Root Rot

- 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



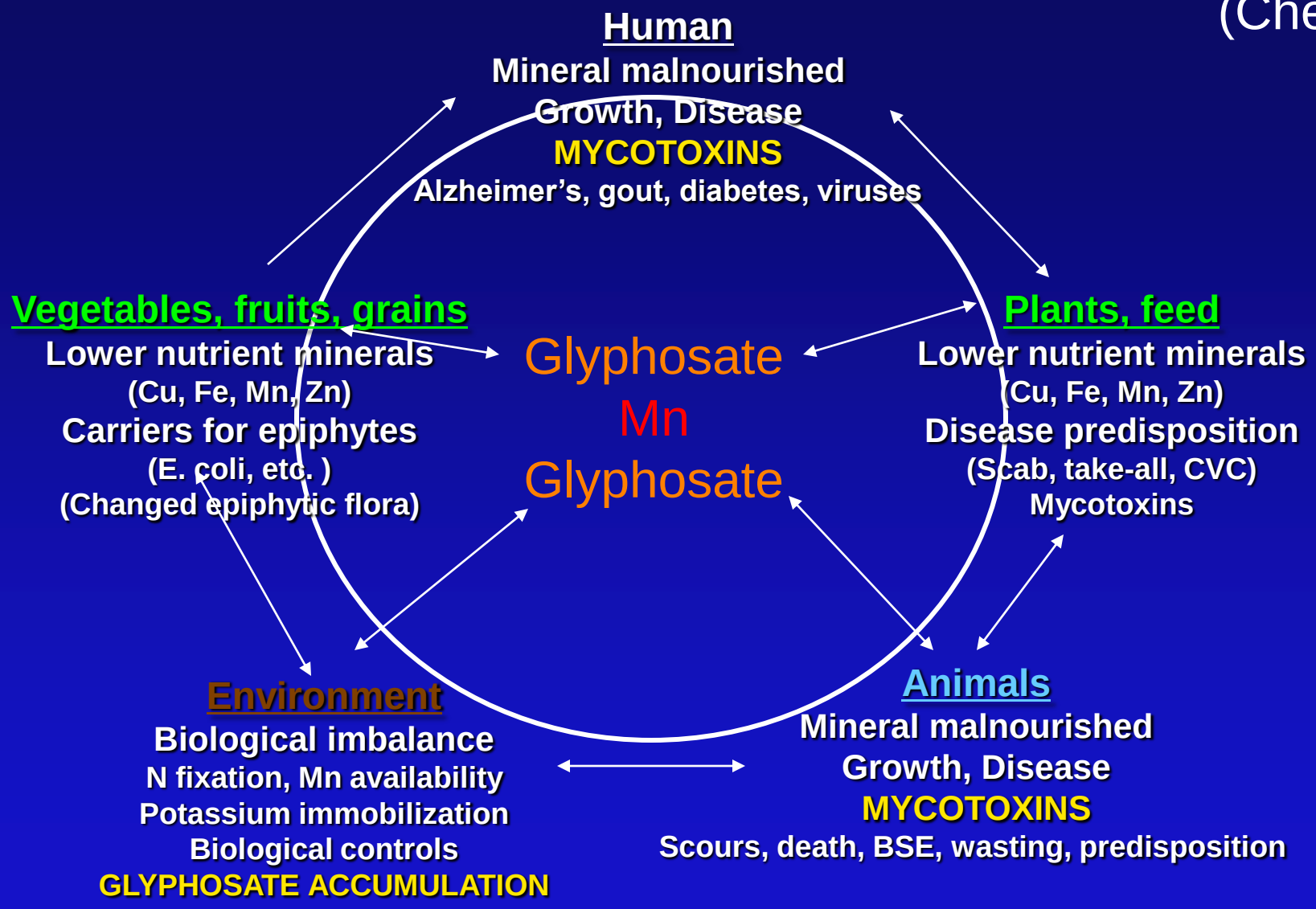


Impact of Glyphosate on Take-all



Potential Far-Reaching Impact of Mn Entrapment

(Chelation)



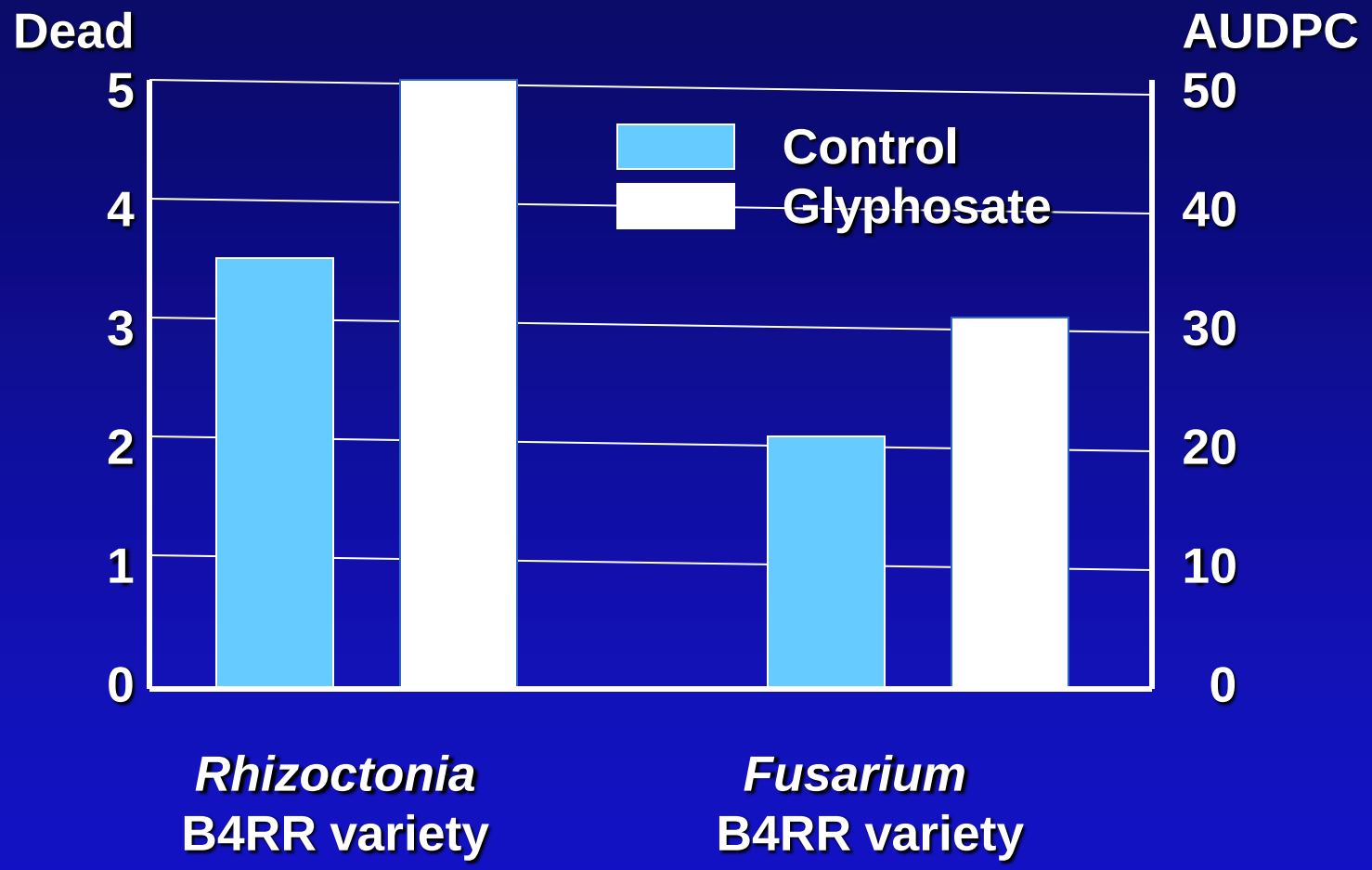
Disease Effects Nutrition

- **Availability**
  - Immobilization (sink, form)
  - Nutrient balance
  - Toxicity
- **Uptake**
  - Root rots, blights
  - Nutrient balance
- **Distribution**
  - Wilts, plugs, sinks, necrosis
- **Function**
  - Necrosis, toxins, plugging, viruses
- **Loss**
  - Rots, blights, theft, sinks

Nutrient Mechanisms that Reduce Disease

- **Increased plant resistance**
  - Physiology, inhibitors
  - Defenses - callous, cicatrix, etc.
- **Disease escape, tolerance**
  - Increased root, leaf growth
  - Shorter susceptible stage
  - Compensate for disease damage
- **Modify the environment**
  - Ph, other nutrients
  - Rhizosphere biology interactions
- **Inhibit pathogen activity**
  - Reduced virulence, survival
  - Biological control and growth

Impact of Glyphosate on Sugar Beet

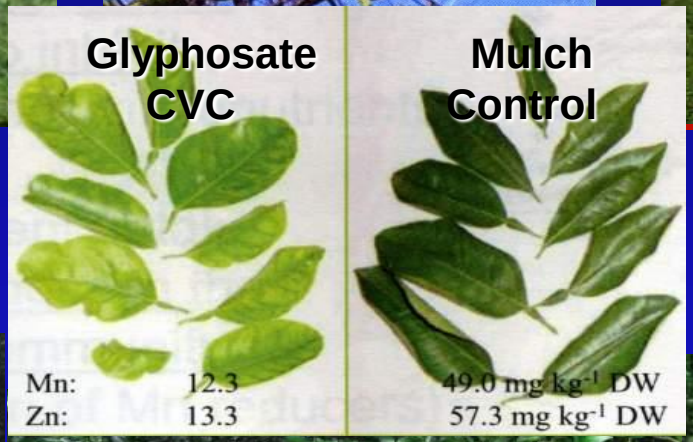


"Precautions need to be taken when certain soil-borne diseases are present if weed management for sugar beet is to include post-emergence glyphosate treatments." Larson et al., 2006

Citrus Variegated Chlorosis

Predisposition to CVC (*Xylella fastidiosa*) by glyphosate

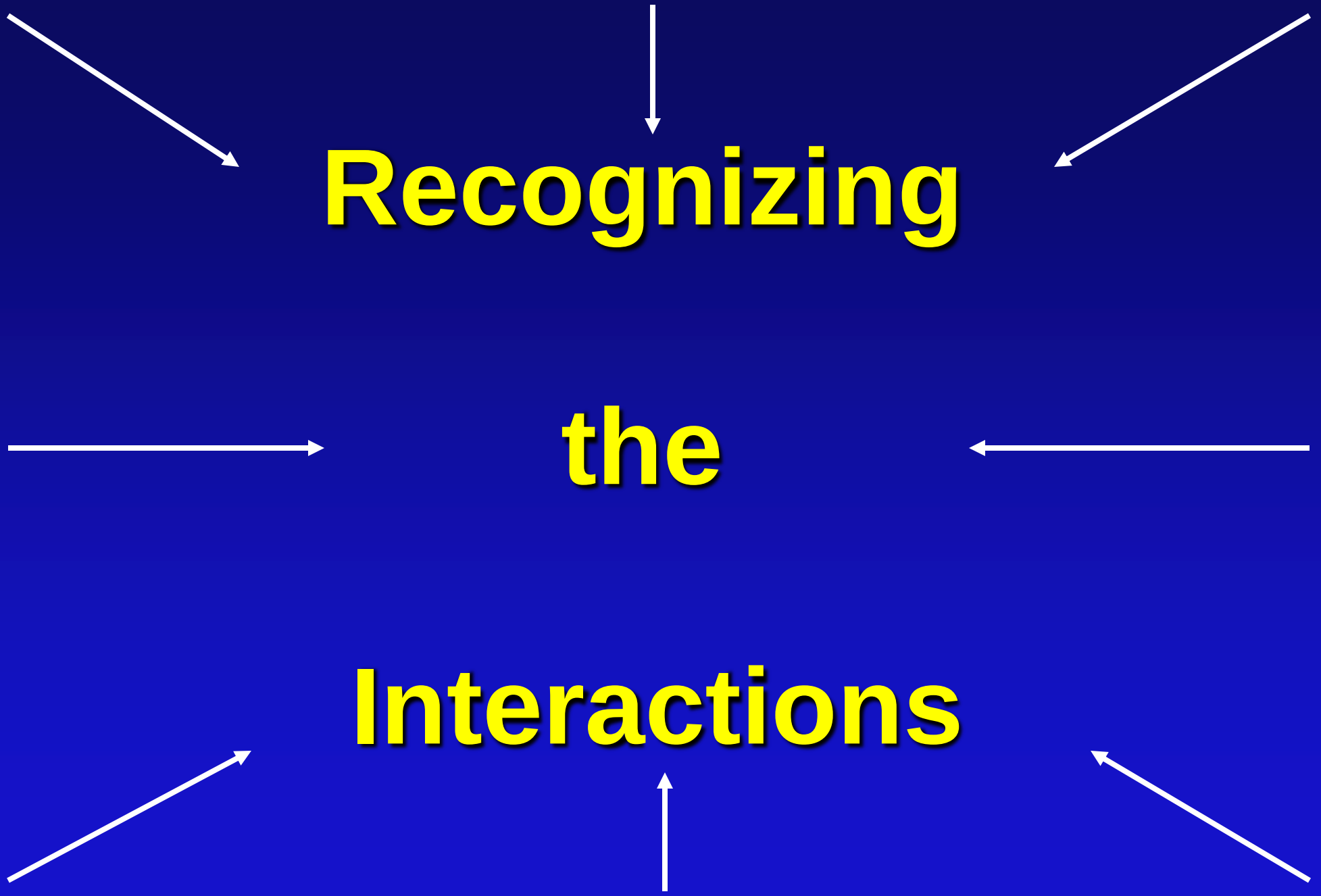
CVC with typical glyphosate weed control



Alternative mulch program of T. Yamada

Grass mulch under trees

After T. Yamada


Recognizing
the
Interactions

Poor Boll Retention, Sterile Locules in Cotton

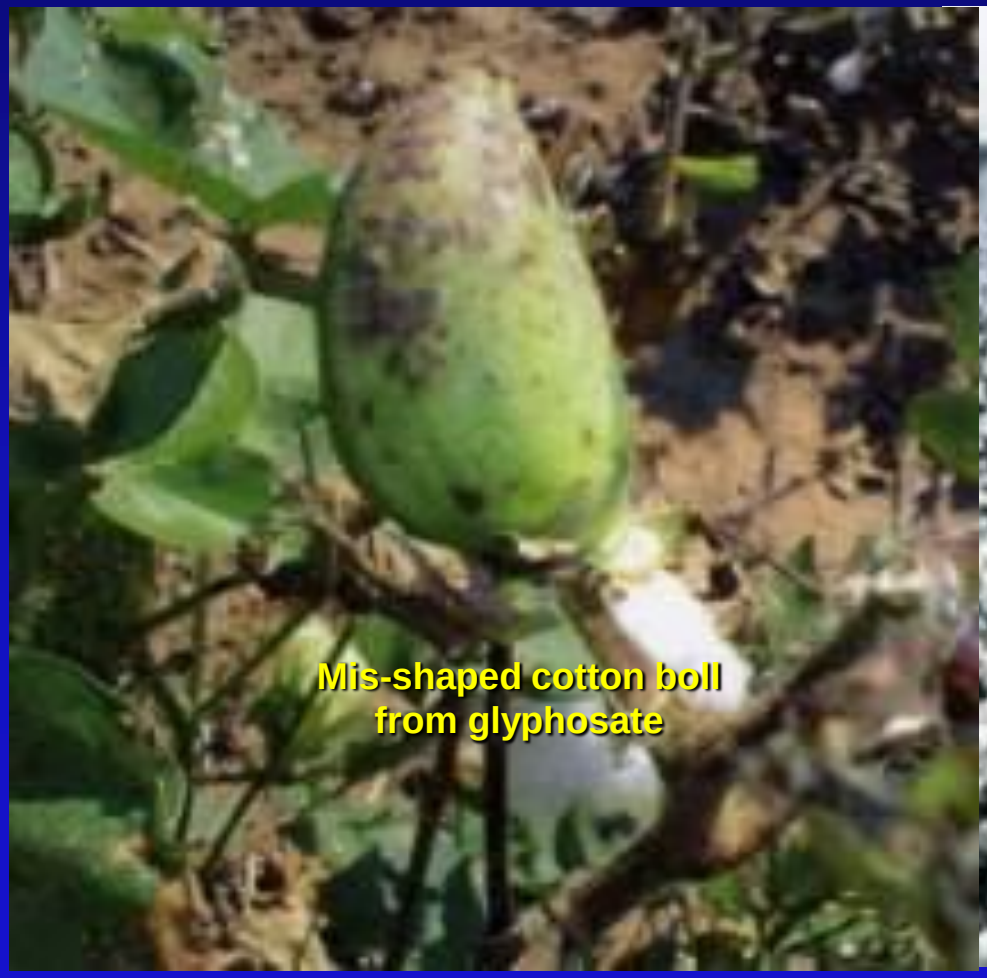
WHY?

Draught stress!

Nutrient stress?

Temperature stress?

Poor Boll Retention, Sterile Locules in Cotton. WHY?



Poor Stand Establishment of Winter Wheat

WHY?

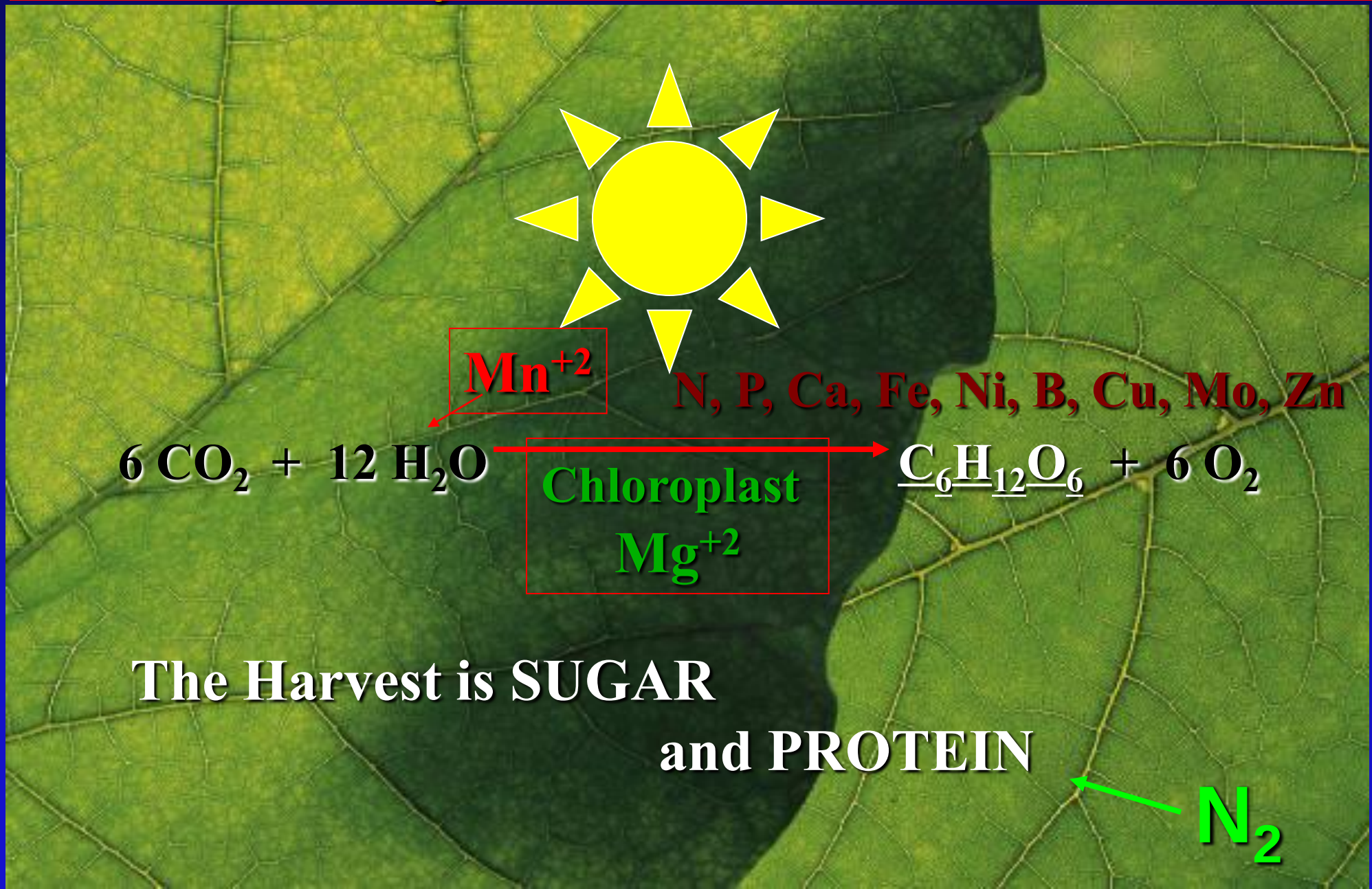
- "Planted in dry soil"
- "Cold soil"
- "Seeded too deep"
- "Bad seed"
- "Too much residue on top"

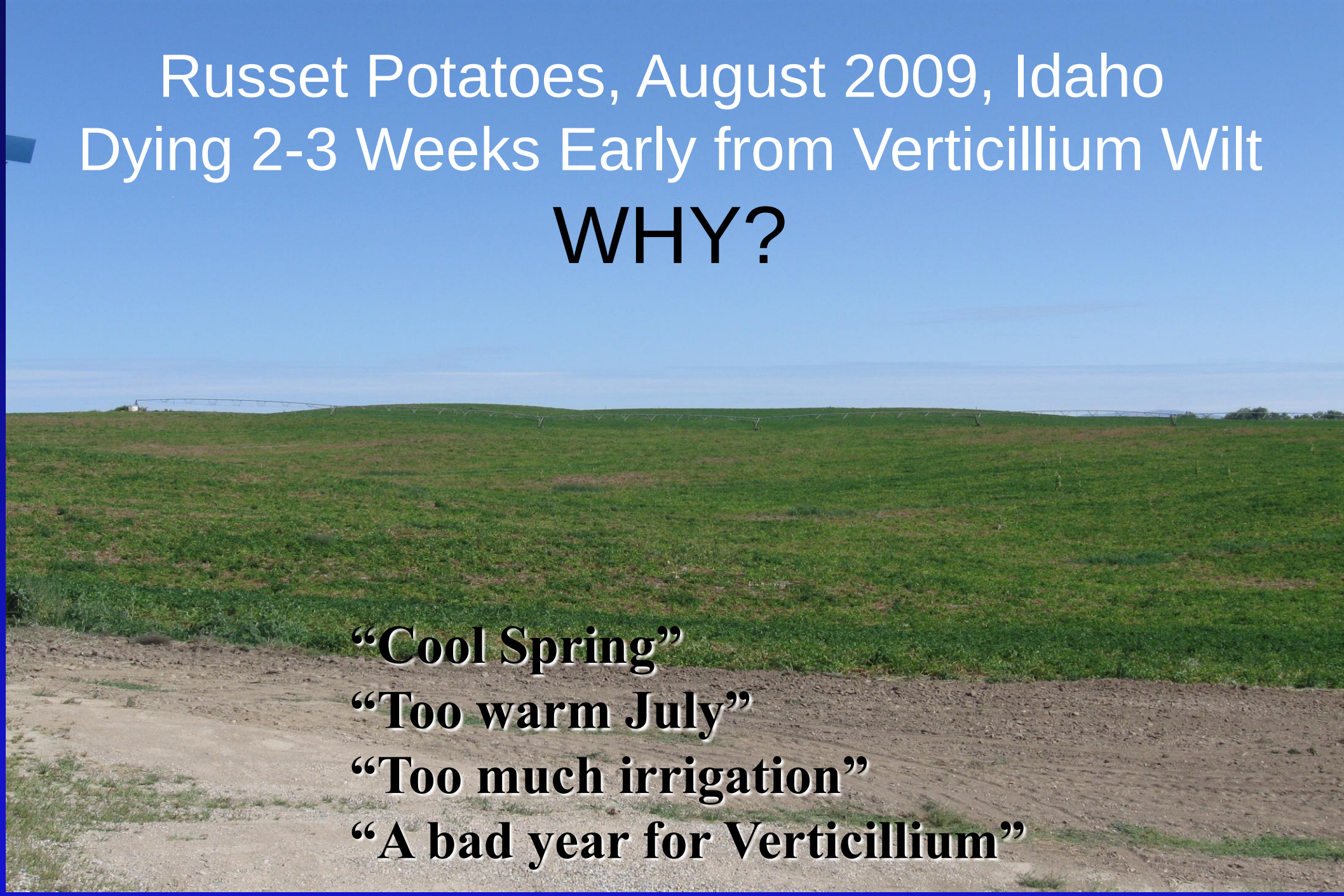
Effect of Planting Delay after Glyphosate (Residual Glyphosate in Soil)

Winter Wheat

Weiss et al., 2008

Photosynthesis and N-fixation

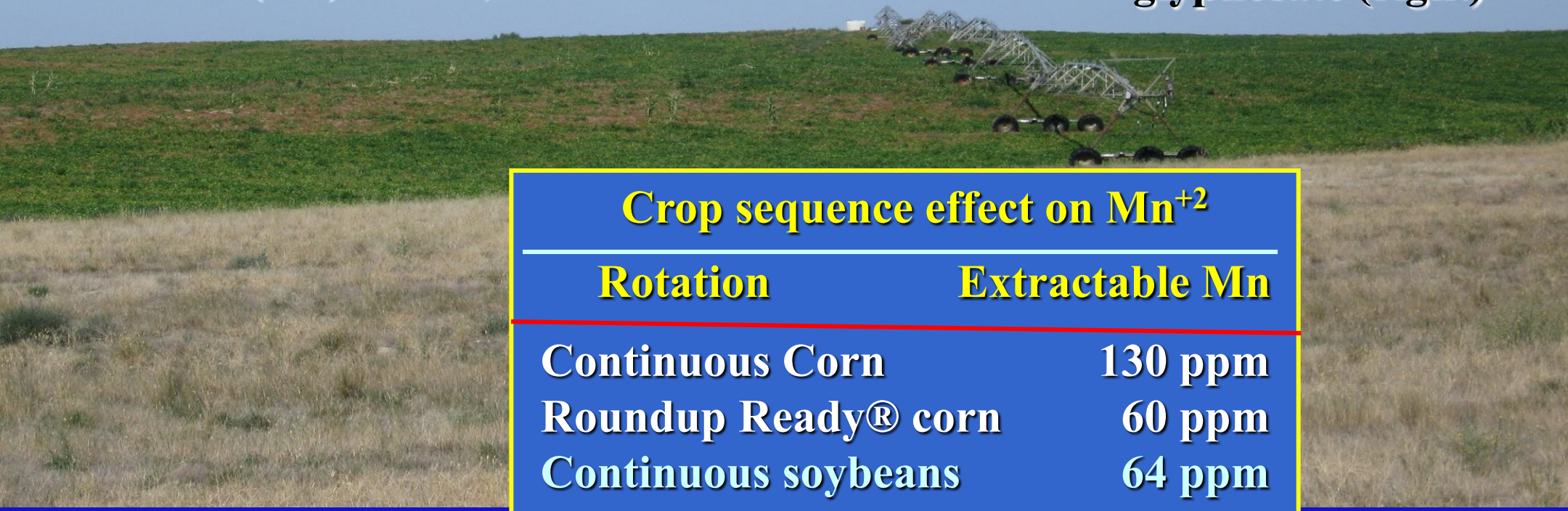



Russet Potatoes, August 2009, Idaho
Dying 2-3 Weeks Early from Verticillium Wilt
WHY?
“Cool Spring”
“Too warm July”
“Too much irrigation”
“A bad year for Verticillium”

Residual Soil & Crop Sequence Effects of Glyphosate

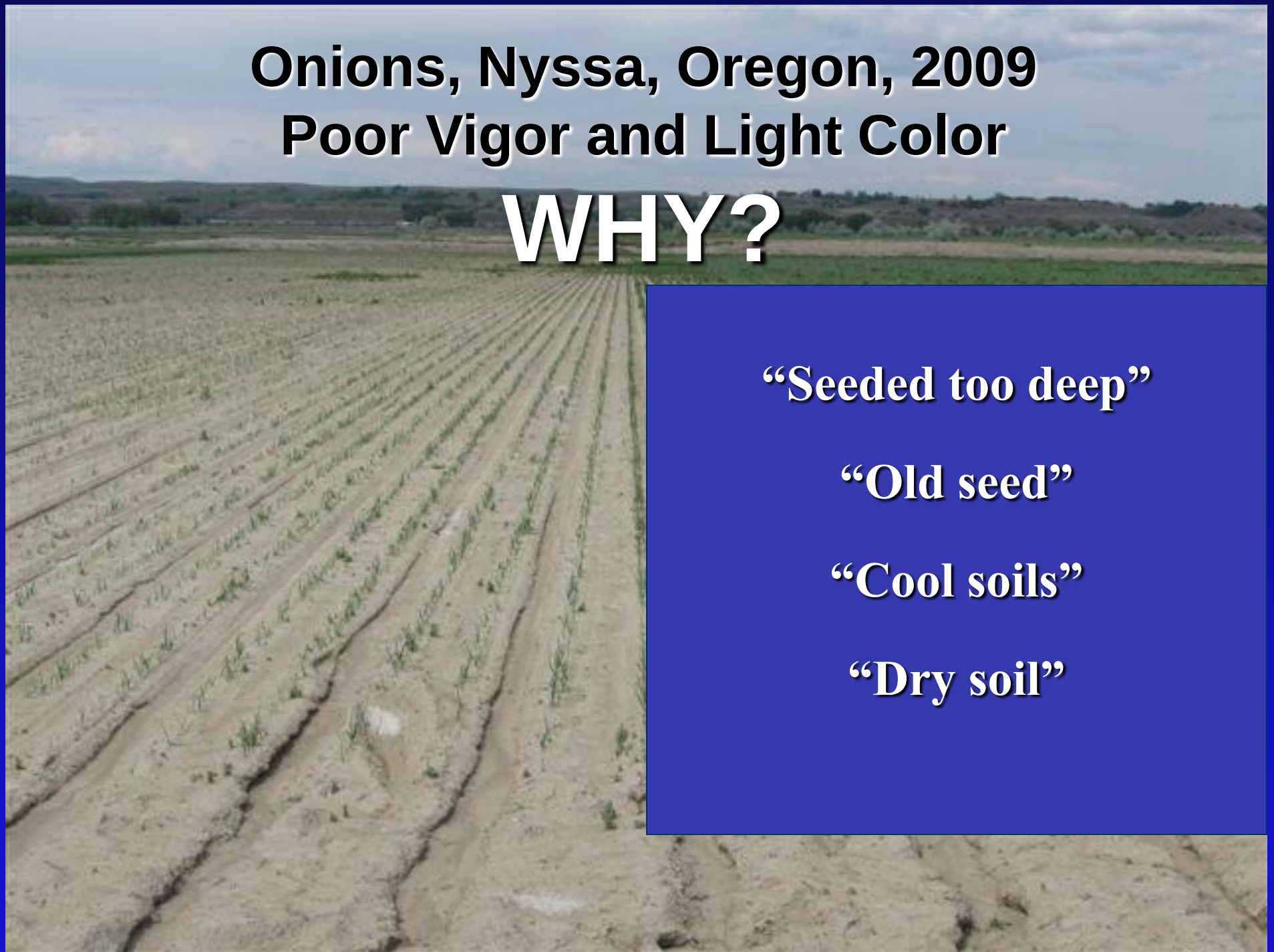
Severe Verticillium wilt after 1 year of RR corn (left) Idaho, 2009

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, corn	91 ppm
Wheat, corn, soybean	79 ppm



Onions, Nyssa, Oregon, 2009
Poor Vigor and Light Color

WHY?

"Seeded too deep"

"Old seed"

"Cool soils"

"Dry soil"

Winter Wheat ‘not as good as it used to be’

Poor vigor, Slow growth, ‘Anemic,’ Spotty, Take-all

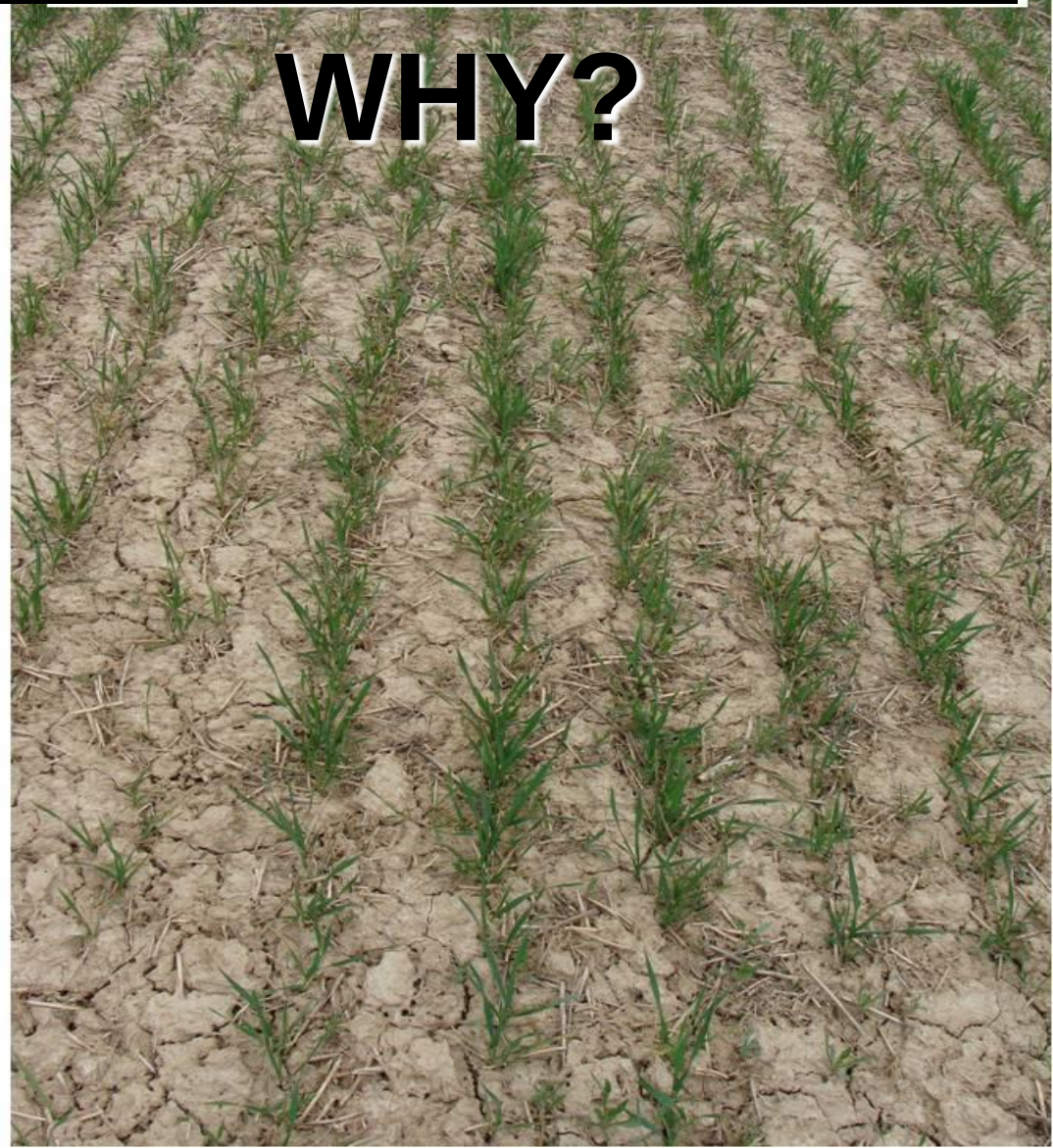
“Planted too deep”

“Too much residue”

“Old seed”

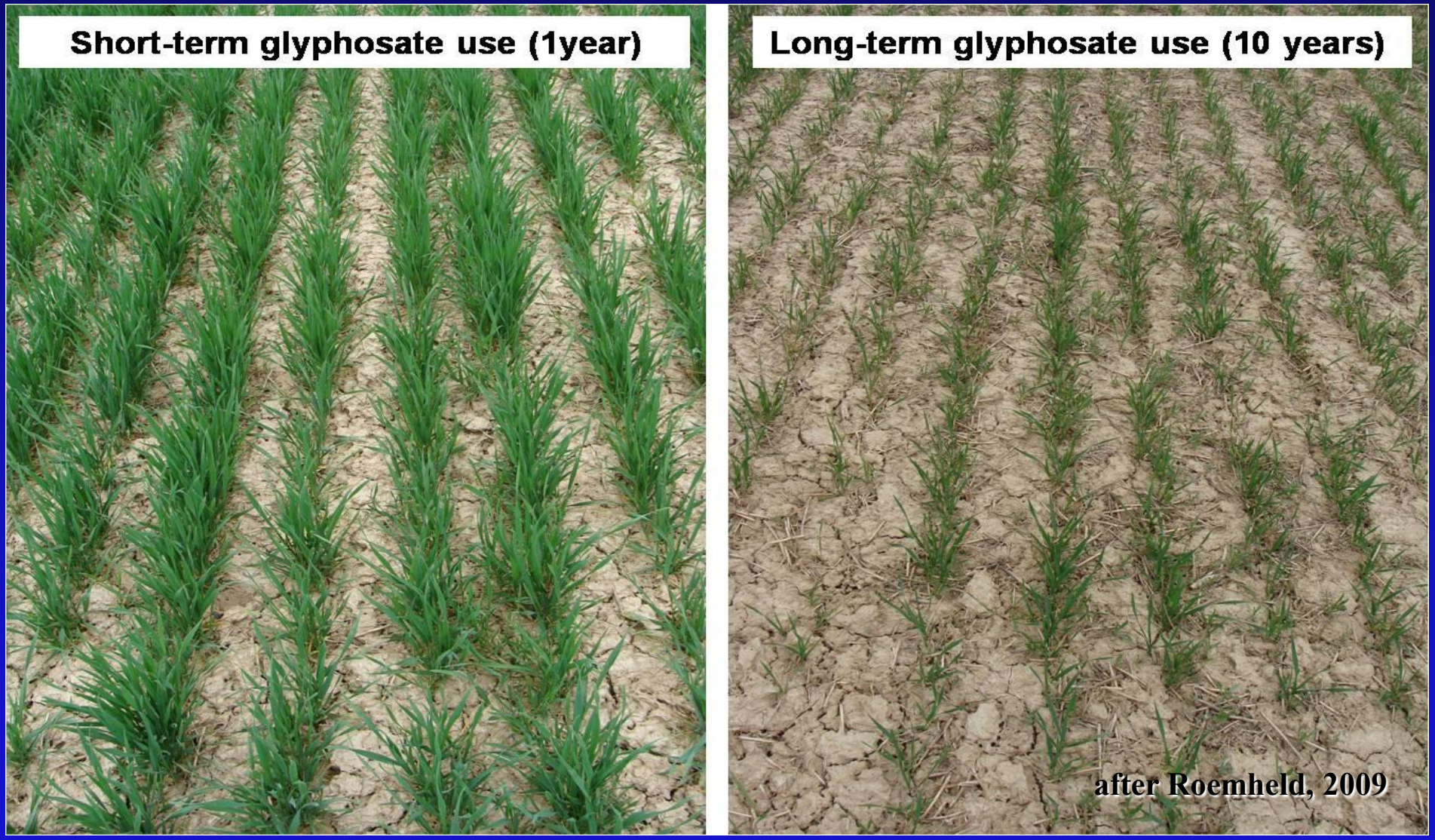
“Dry seed bed”

“Poor fertility”



Long-term effect of glyphosate application

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



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

Tissue:	Mn	Zn
Isoline	%	%
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!

After Zobiole et al., 2009

Frequency of Glyphosate and Severity of Fusarium Head Scab - Wheat & Barley

Number of glyphosate applications in the previous three years	FHB index (%)
None	4.2
1 to 2	6.4 ***
3 to 6	12.4 ***

Average % increase in Fusarium Head Scab by glyphosate	
All crops	75 %
Minimum tilled crops	122 %
Crops after RR canola	Highest!

Fernandez et al. 2005, *Crop Sci. 45: 1908-1916*;
Fernandez et al. 2007, *Crop Sci. 47: 1574-1584*)

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!