Relationship Between Mineral Nutrition of Plants and Disease Incidence

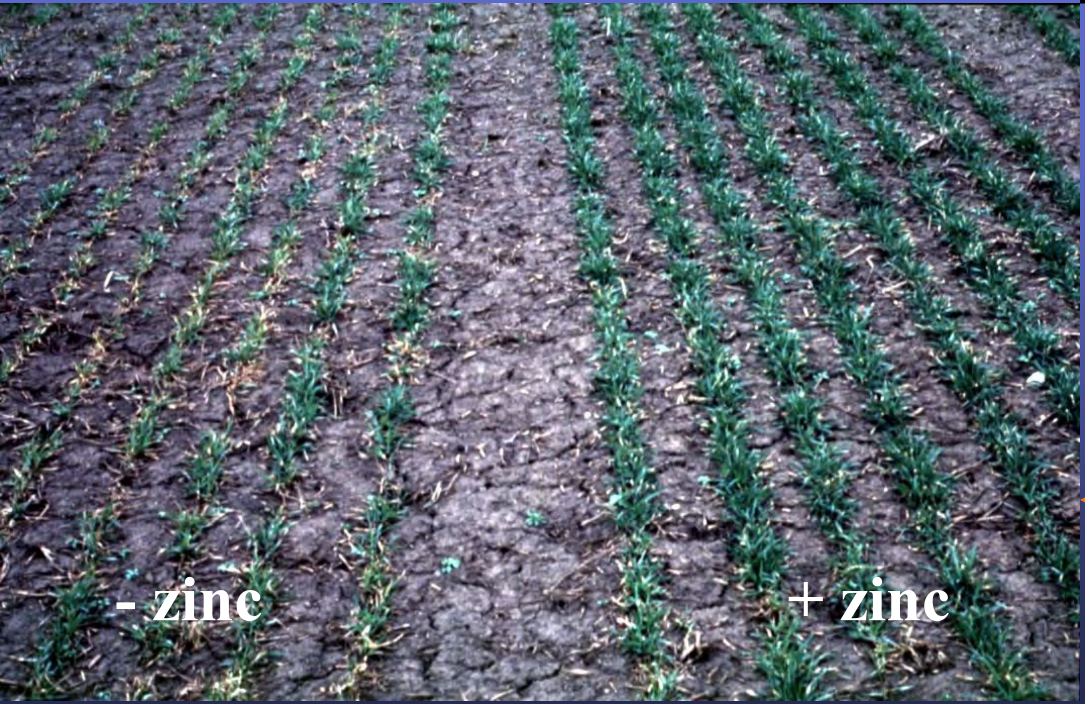
Don M. Huber

Botany & Plant Pathology Department
Purdue University, West Lafayette, IN USA
E-mail: huber@btny.purdue.edu

Disease can alter plant nutrition

- Availability
- Impaired utilization
- Mobilization

Frenching of Tobacco caused by Bacillus cereus (Mn toxicity)



Nutrition can alter Disease severity

Effect of Zn sufficiency on Rhizoctonia winter-kill of wheat

Effects of Disease on Plant Nutrition

Disease Type	Effect on Plant Nutrition
• Root rots, damping-off, insects, nematodes	Immobilization, absorption and distribution
• “Maceration” (rot) diseases	Distribution (“sinks”), depletion, change metabolism
• Vascular wilts, leaf spots	Translocation, distribution, efficiency
• Galls, brooms, over-growth	Distribution (“sinks”) metabolic efficiency
• Viruses	“Sinks”, depletion, metabolic efficiency
• Fruit & storage rots	“Sinks”, distribution, nutrient reserves

Reports of Vegetable Diseases Influenced by Nutrients

Disease	Effect on Diseases: Increase	Effect on Diseases: Reduce	Total
Bacterial	22	34	56
Fungal	79	191	270
Virus	19	19	38
Nematode	10	12	22
Total	130	256	386*

*About 4% are reported to both increase or decrease depending on the situation

Reported* Effects of Nutrients on Disease

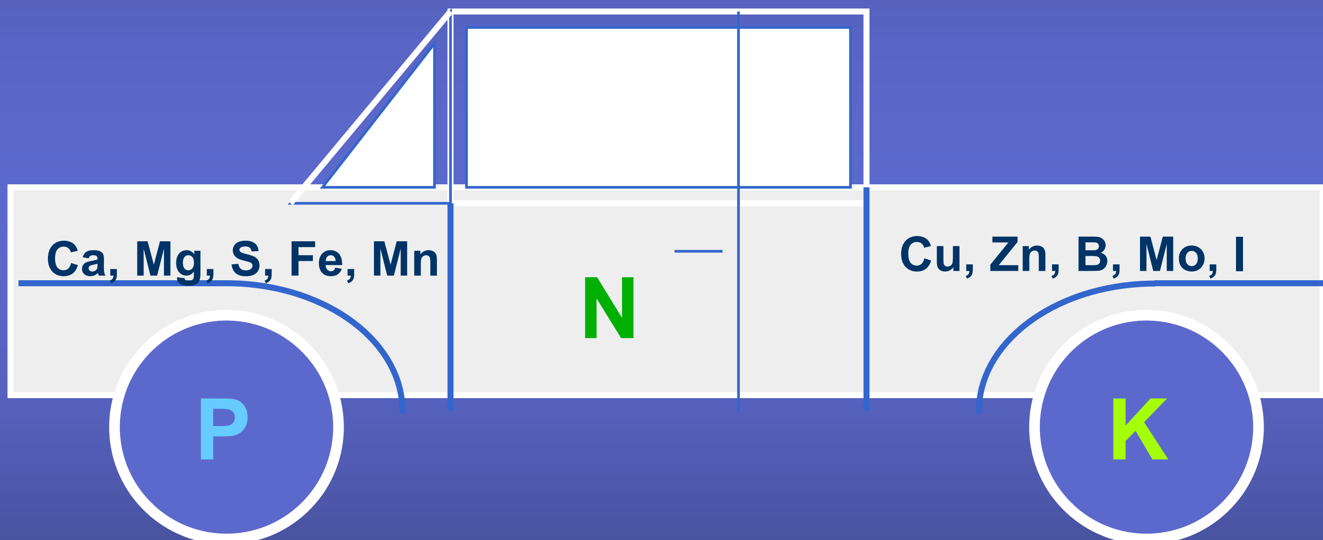
Mineral element	Disease is: Decreased	Increased	Variable
Nitrogen ($N/NH_4/NO_3$)	168	233	17
Phosphorus (P)	82	42	2
Potassium (K)	144	52	12
Calcium (Ca)	66	17	4
Magnesium (Mg)	18	12	2
Manganese (Mn)	68	13	2
Copper (Cu)	49	3	0
Zinc (Zn)	23	10	3
Boron (B)	25	4	0
Iron (Fe)	17	7	0
Sulfer (S)	11	3	0
Other (Si, Cl, etc.)	71	6	8

*Based on 1,200 reports in the literature.

Effect of the form of Nitrogen on Potato Diseases

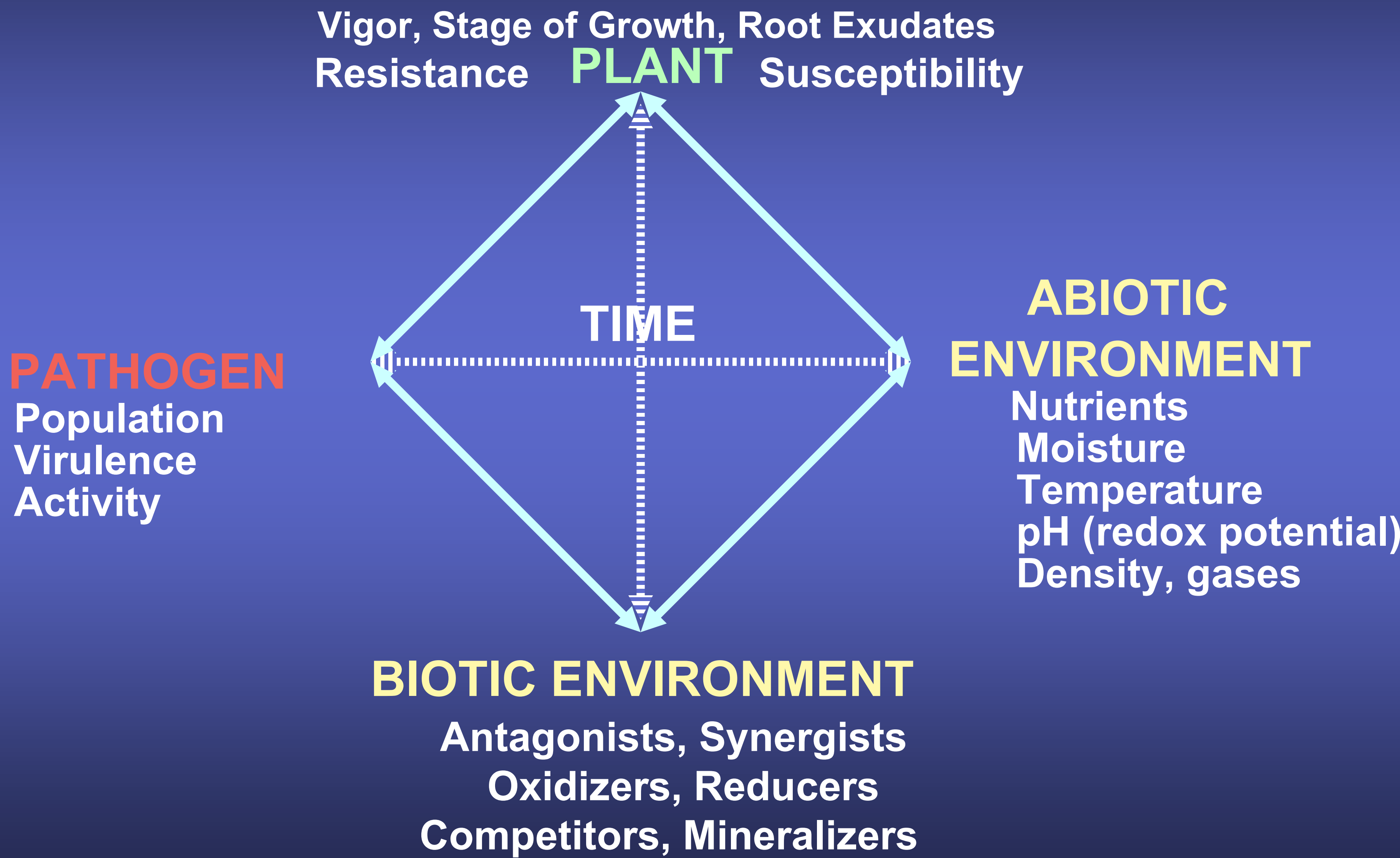
Source of N	Disease: *Rhizoctonia* Canker	*Verticillium* Wilt	Yield (kg/ha)	Percent No. 1
$(NH_4)_2SO_4$	6.2 a	3.9 b	32,670	69 a
$Ca\ (NO_3)_2$	4.8 b	9.4 a	21,340	57 b

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



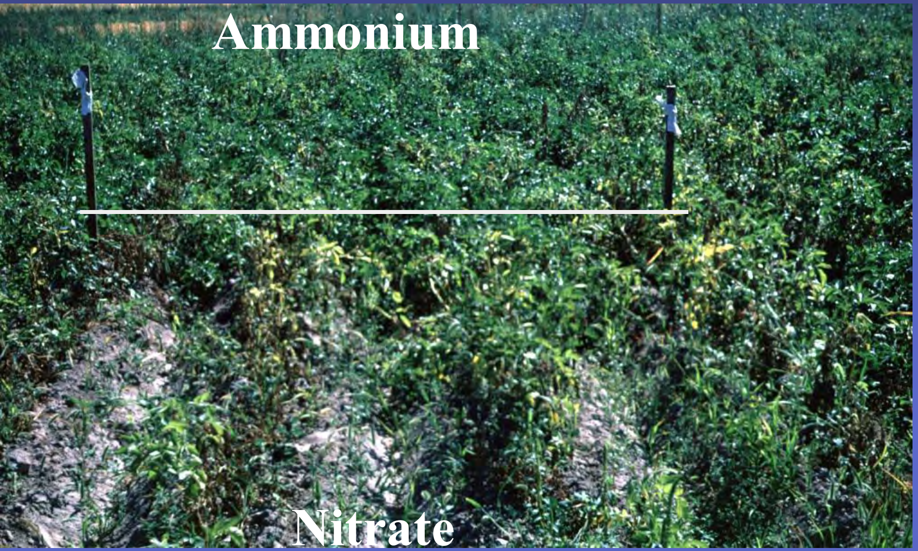
Nutrient Balance is Important

INTERACTING FACTORS DETERMINING DISEASE SEVERITY



Implications of Nutrition in Disease

Verticillium wilt of potato



Rhizoctonia winter-kill of wheat

- Observed effects of mineral amendment on disease severity
- Comparison of plant tissue levels of resistant and susceptible plants
- Comparison of plant tissue levels of diseased and non-diseased plants
- Association of conditions affecting a specific nutrient with differences in disease
- A combination of the above

EFFECT OF MINOR ELEMENTS ON YIELD OF TAKE-ALL INFECTED WINTER WHEAT

Minor Element	Wheat Variety: AUBURN	Wheat Variety: BEAU
	---------kg/ha--------	
None	2,950	2,750
Cu	2,750	2,880
Fe	2,950	2,880
Mg	3,250	2,880
Mn	3,750	3,350
Zn	2,950	2,880

Minor elements co-injected with NH_3 + nitrapyrin; sandy loam soil

Correlation of Tissue Zn with *Rhizoctonia* "winter-kill"*

Condition	Tissue Zinc Without	Tissue Zinc With(in)	% Plant Kill Without	% Plant Kill With(in)
Barnyard Manure	20	41	80	15
Sediment Area	17	27	100	45
Tree Leaf-drop Area	19	34	65	20

Sufficiency Level: 20 -150 mg/kg

*Caused by *Rhizoctonia cerealis*

EFFECT OF AN OAT PRECROP

CROP SEQUENCE	Tissue Mn	Disease Index*	Yield (kg/ha)
Wheat-Wheat-Wheat	20	4.2	1,450
Wheat-Oats-Wheat	55	1.8	3,900
Oats-Oats-Wheat	76	1.0	4,160

*Take-all root & crown rot: 0 = no infection, 5 = dead (white heads)

Factors Affecting Mn Availability and Severity of Some Diseases*

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

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

EFFECT OF SOME CULTURAL PRACTICES ON TISSUE Mn & TAKE-ALL

CULTURAL CONDITION	Mn*	Take-all**
Loose Seedbed	11.2	3.5
Firm Seedbed	19.3	2.8
Wheat Precrop	21.0	4.3
Oat Precrop	45.0	1.8
Nitrification	8.9	3.5
Inhibiting Nitrification	17.2	2.4

*Mn Sufficiency Range is 20-150 µg/g
**Disease index: 1 = no infection; 5 = dead (white-head)

ENVIRONMENTAL GROUPINGS

- **LOW-HIGH pH**
  - High pH Diseases - Increased by Oxidizing Conditions
  - Low pH Diseases - Increased by Reducing Conditions
- **FORM OF NITROGEN**
  - Diseases Favored by Nitrate - Increased by Oxidizing
  - Diseases Favored by Ammonium - Increased by Reducing
- **MICRONUTRIENT**
  - Diseases Reduced by Mn, Fe, S - Increased by Oxidizing
  - Diseases Reduced by Ca, Zn, Mg - Increased by Reducing

Relationship of Nutrition with Disease

1. Genetics of the Plant
2. Nutrient Form or Availability
3. Rate Applied or Available
4. Method and Time Applied
5. Source of Element & Associated Ions
6. Integration with other practices

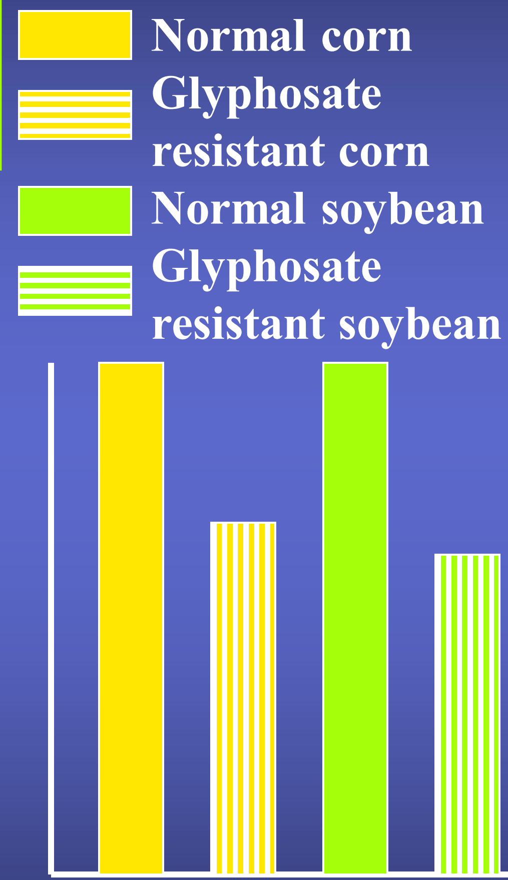
Relationship of Nutrition with Disease

1. Genetics of the Plant

Immunity<-->Resistance<-->Tolerance<-->Susceptibility
[Nutrient uptake efficiency, nutrient availability]

Difference in Mn Uptake efficiency: Rye is more efficient than wheat

Take-all of: Wheat after wheat (front) versus Wheat after oats (back)



Effect of the glyphosate resistance gene on Mn uptake efficiency

NUTRIENT UPTAKE EFFICIENCY

- Root Uptake Kinetics
- Root Morphology
- Siderophore Production
- Microbial Activity in rhizosphere

Transcient foliage chlorosis of soybeans after applying glyphosate on a low Mn soil [banded to show effect]

Relationship of Nutrition with Disease

2. Nutrient Form or Availability

Oxidized <--> Reduced, Soluble <--> Non-soluble

Inhibition of Nitrification

Organic Nitrogen → Ammonium

Urea → Ammonium

Ammonium → ~~→~~ Nitrite → Nitrate

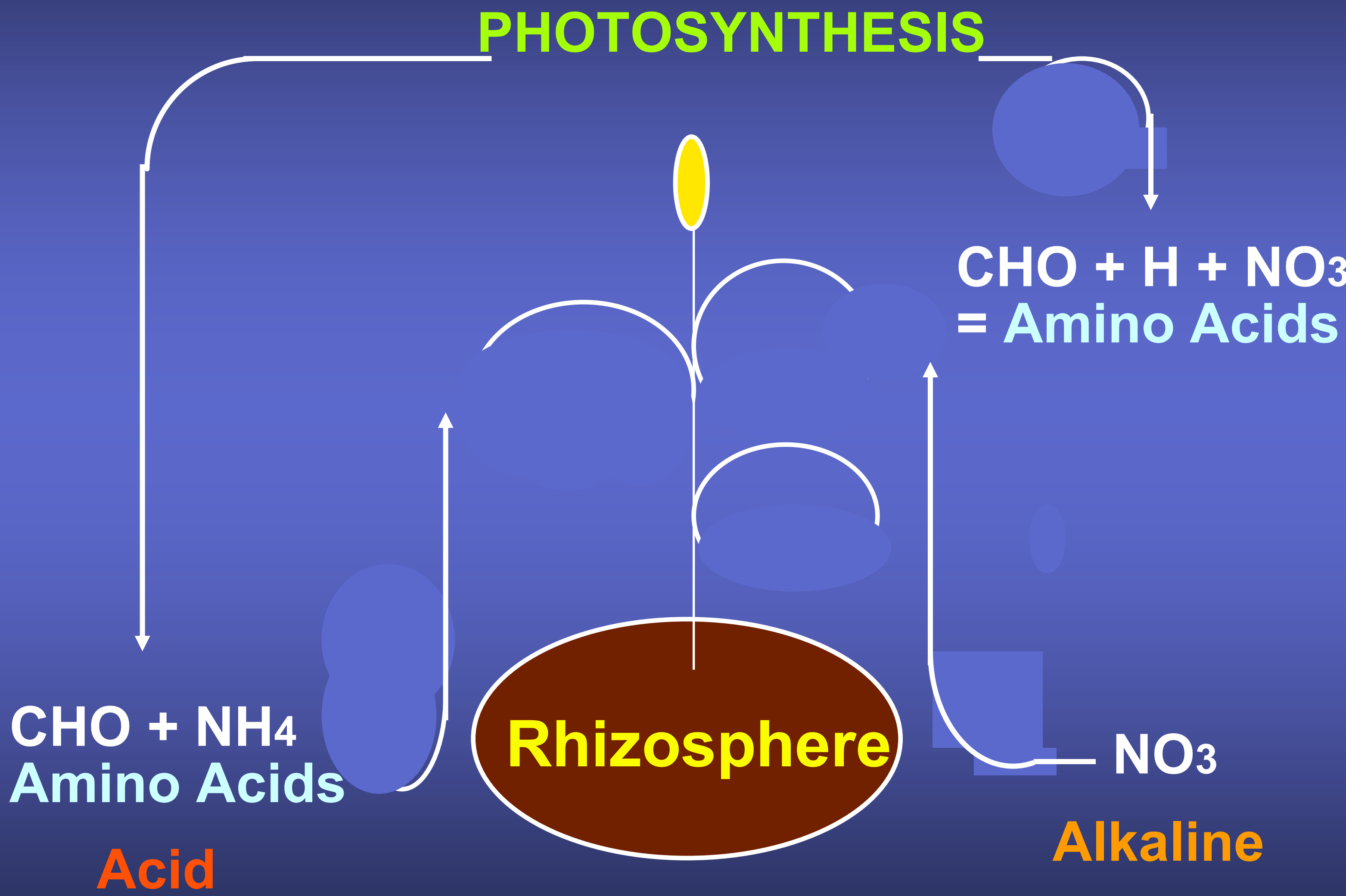
Nitrate → Nitrous oxides Denitrification

Nitrite → Leaching

Nitrate → Leaching

Nitrogen, Iron, Manganese, Sulfur

INFLUENCE OF THE FORM OF NITROGEN



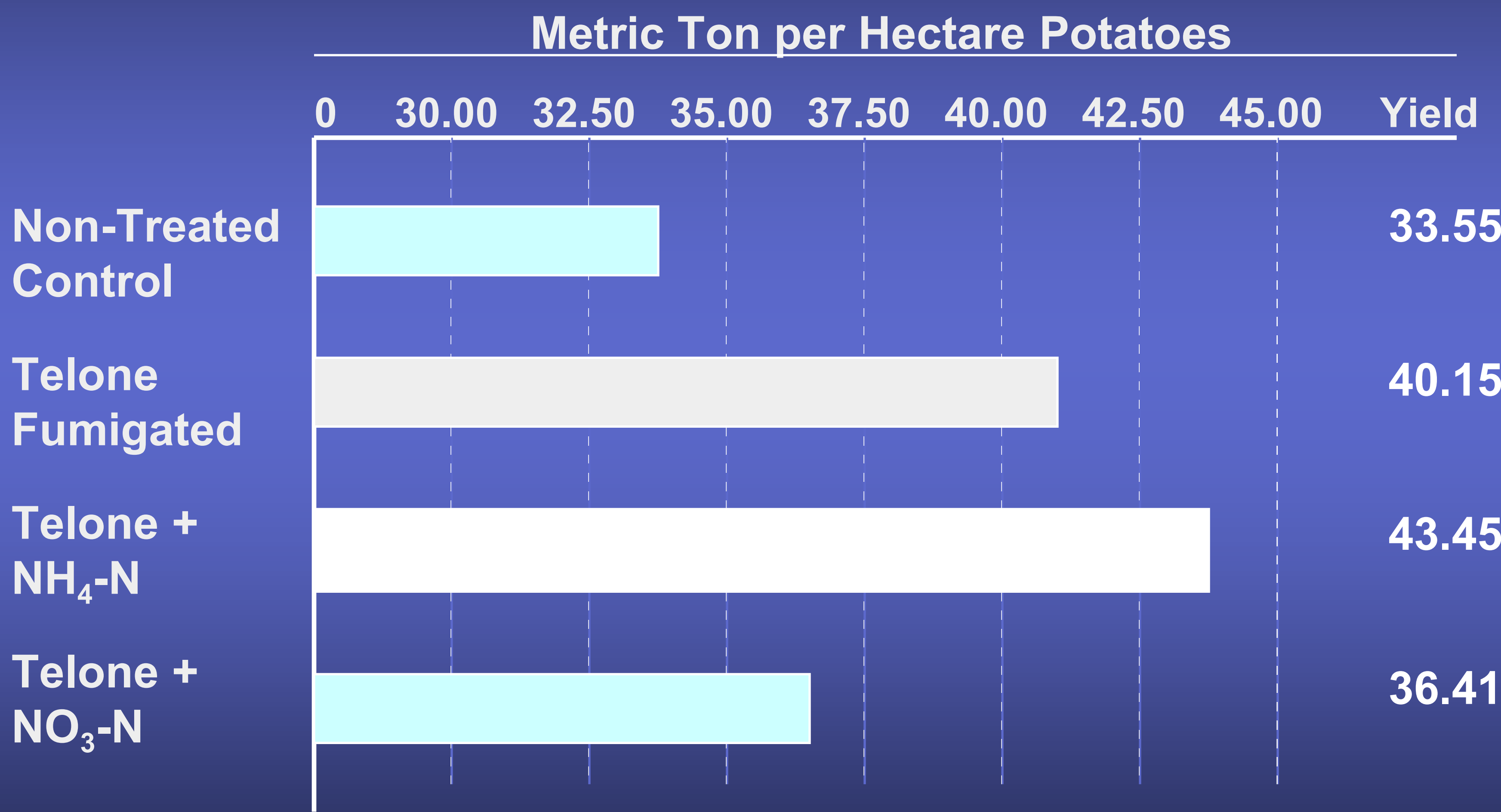
Some Diseases Reduced by N0$_3$, High pH

Crop	Disease	Pathogen
Asparagus	Wilt	*Fusarium*
Bean	Chocolate Spot	*Botrytis*
	Root Rot	*Fusarium*
	Root Rot	*Rhizoctonia*
Beet	Damping Off	*Pythium*
Cabbage	Club Root	*Plasmodiophora*
	Yellows	*Fusarium*
Celery	Yellows	*Fusarium*
Corn	Ear rot	*F. moniliforme*
Cucumber	Wilt	*Fusarium*
Pea	Damping-Off	*Rhizoctonia*
Pepper	Wilt	*Fusarium*
Potato	Stem Canker	*Rhizoctonia*
Tomato	Gray Mold	*Botrytis*
	White Mold	*Sclerotinia*
	S. Blight	*Sclerotium*
	Wilt	*Fusarium*

Diseases Reduced by NH_4, Low pH

Crop	Disease	Pathogen
Bean	Root Rot	*Thielaviopsis*
	Root Knot	*Meloidogyne*
Carrot	Root Rot	*Sclerotium*
Corn	Stalk rot	*Gibberella*
Egg Plant	Wilt	*Verticillium*
Many	Root rot	*Phymatotrichum*
Onion	White Rot	*Sclerotium*
Pea	Root Rot	*Pythium*
Potato	Scab	*Streptomyces*
	Wilt	*Verticillium*
	Virus	*Potato Virus X*
Rice	Blast	*Magnaporthe*
Tomato	S. Wilt	*Pseudomonas*
	Anthracnose	*Colletotrichum*
	Wilt	*Verticillium*
	Virus	*Potato Virus X*
Wheat	Take-all	*Gaeumannomyces*

Effect of N Form on Yield of *Verticillium* Infected Potato



90 kg/ha N applied

90 kg/ha N + a nitrification Inhibitor applied

Effect of inhibiting nitrification of ammonia on take-all of wheat

Ammonium N with a nitrification inhibitor

Ammonium N without inhibiting nitrification

Nitrate nitrogen

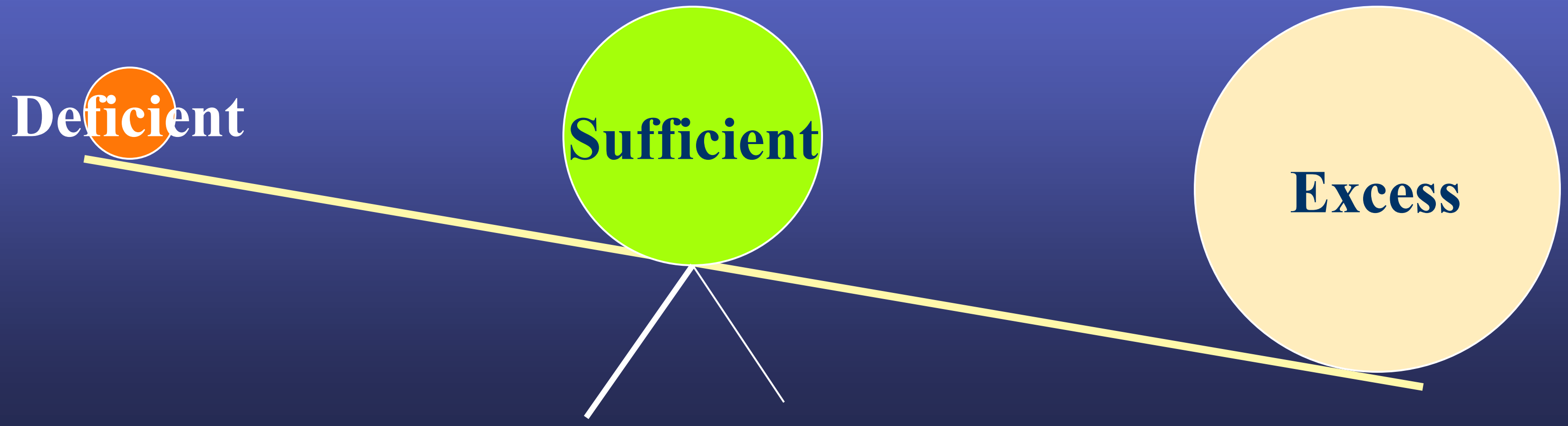
Effect of Inhibiting Nitrification on Scab of Potato

Disease scale: 0 = no surface scab, 2 = 10% surface scab, 6 = 30% scab.

Relationship of Nutrition with Disease

3. Rate Applied or Available

- Amount available
  - Deficiency to sufficiency versus
  - Sufficiency to excess for the particular plant
- Time available
- Nutrient balance



Effect of Nitrogen Rate on Take-all Root and Crown Rot of Wheat

	Soil Type			
	Sand		Sandy Loam	
N rate	Yield	%White heads	Yield	% White heads
None	1,270	30	938	50
45	1,540	26	2,350	23
90	1,680	18	3,150	19
135	2,550	12	3,220	20

Relationship of Nutrition with Disease

4. Method and Time Applied

Soil <--> Seed <--> Foliage, Side-dress <--> Band <--> Broadcast

Spring <--> Fall <--> Split

Susceptibility of Plant, Favorable Environment, Virulence of Pathogen

Effect of nitrogen source on *Rhizoctonia* "winter-kill" of winter wheat

Nitrogen Treatment	Time	Percent Kill
NH_3 + N-Serve	September	14
Urea Granuals	February	40
28% N Solution	February	60
Urea	April	14

Effect of Time of Nitrogen Application on Rhizoctonia Winter-Kill of Wheat

Effect of Application Method on Mn Availability & Take-all of Wheat

Method	Availability	Take-all effect
Broadcast	Poor (Rapidly oxidized & immobilized)	None
Band	Fair (Limited to the Band)	Positive
Foliar	Good (Not translocated downward)	Secondary
Seed	Good (but available only for seedling)	Positive

Relationship of Nutrition with Disease

5. Source and Associated Ions

Gas <--> Liquid <--> Granule, Anion <--> Cation (K_2SO_4/KCl)

EFFECT OF NITROGEN SOURCE ON *RHIZOCTONIA* OF WINTER WHEAT

Nitrogen Treatment	Time	Percent Kill
NH_3 + N-Serve	September	14
Urea Granuals	February	40
28% N Solution	February	60
Urea	April	14

Relationship of Nutrition with Disease

6. Integration with other practices

Rotation, Tillage, Seed rate, Herbicide, pH, Moisture

Severe take-all of wheat following glyphosate on soybeans (left), the non-treated control is right.

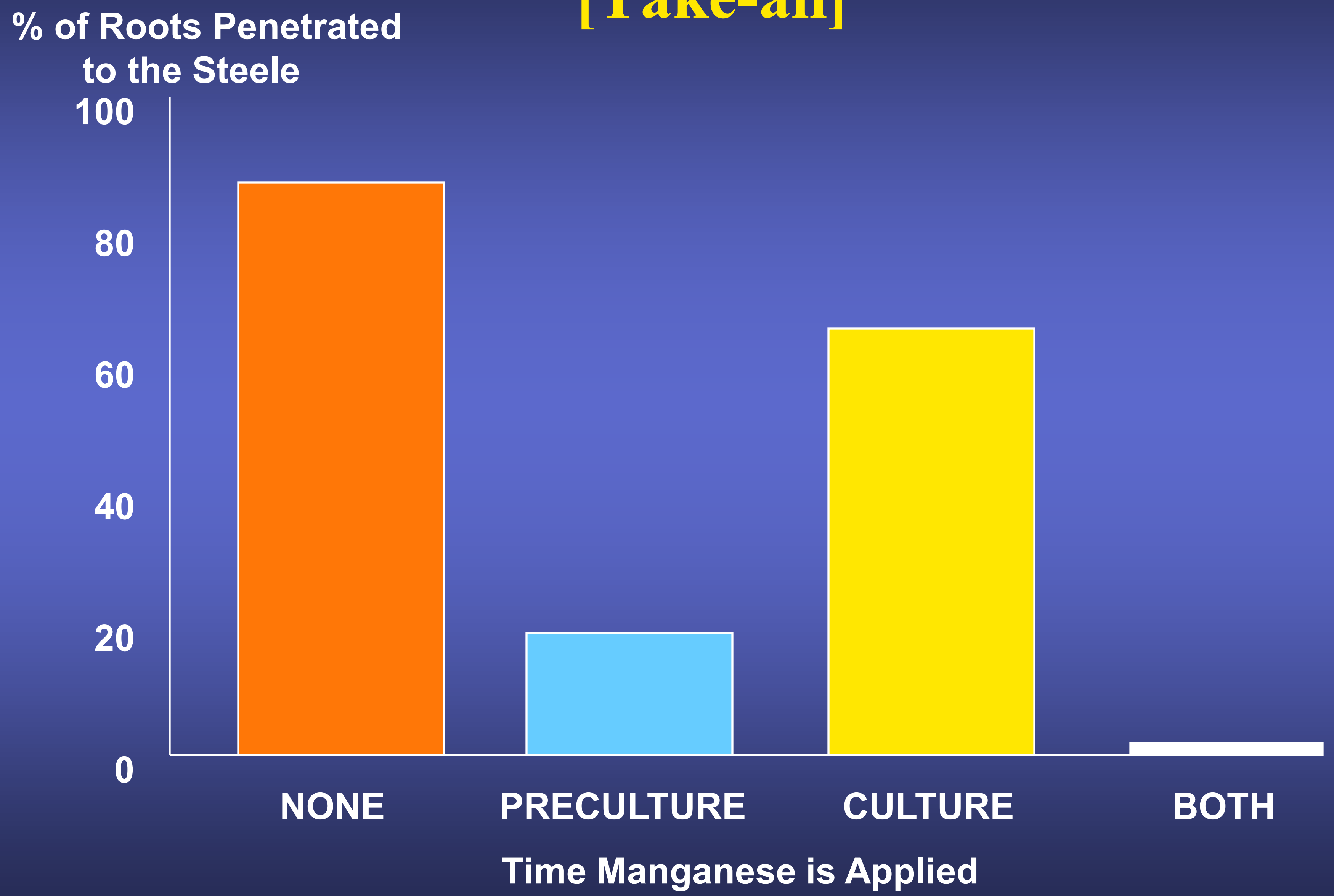
Less take-all of wheat in a firm (right) than loose seed-bed (left)

Mechanisms by which Nutrients Reduce Disease

- **Increased Plant Resistance**
  - Physiology - phytoalexin, CHO, phenolic production
  - Defense- callus, lignituber, cicatrix formation
- **Disease Escape**
  - Increased growth - roots, leaves
  - Shortened Susceptible stage
- **Increased Plant Tolerance**
  - Nutrient sufficiency
  - Compensation
- **Inhibited Pathogen Activity**
  - Reduced virulence
  - Survival, multiplication
  - Biological control

Effect of Mn on Root Penetration

[Take-all]



VIRULENCE FACTORS OF PATHOGENS

- Immobilization/mobilization of nutrients
  - Blast, take-all, frenching
- Physical wounding
  - Fungi and nematodes
- Maceration - necrosis
  - Bacterial and fungal enzymes
- Vascular plugging
  - Bacterial gums and Fungal enzymes
- Stimulation of physiology & excess growth
  - Hormones, genetic transformation
- “Toxins”
  - Pyricularin, alpha picolinic acid, etc.
- Combination

EFFECT OF NITROGEN FORM ON ENZYMES OF *RHIZOCTONIA SOLANI*

Enzyme(s)	Nitrogen Form NH_4	Nitrogen Form NO_3
Cellulase*	+	--
Polygalacturonase**	.3230	.0088
Pectin transeliminase**	.0817	.0083

*Cellulose membrane decomposition

**Viscosity reduction (V.R./µg protein)

RHIZOSPHERE INTERACTIONS

- **Population of Oxidizers or Reducers**
  - **Tolerant vrs Susceptible Wheat to Take-all**
  - **Tolerant vrs Susceptible Tobacco to Frenching**
  - **Tolerant vrs Susceptible Plants to Crown Gall**
  - **Biological Control - Plant Growth Promotion**
  - **Oats Resistant to Take-all**
    - **Glycocyanide Root Exudates toxic to Oxidizers**
- **Siderophore Production**
  - **Plant (Rye versus Wheat)(Melons vrs Wheat)**
  - **Fe, Mn, etc. Immobilization or Solubilization**
- **Configuration of Root System**
  - **Susceptible vrs Tolerant Cotton**
  - **Tap Root vrs heighly branched**

MECHANISM OF ACTION

- **PREDISPOSITION**
  - **Nutrient Stress**
  - **Physiological Regulation**
- **VIRULENCE**
  - **Over come plant defenses**
  - **Production of extra-cellular enzymes**
- **PATHOGENESIS**
  - **Compromise plant defenses**
  - **Membrane permeability**
  - **Physiologic regulation**

USING NUTRIENTS FOR DISEASE CONTROL

- **Modify Availability**
  - **Fertilizing (amending)**
  - **Changing the environment**

    pH, tillage, seed bed, crop rotation, etc.
  - **Microbial enrichment (PGPR)**
- **Modify Uptake**
  - **Improve cultivar efficiency**

    Root morphology

    Siderophore production

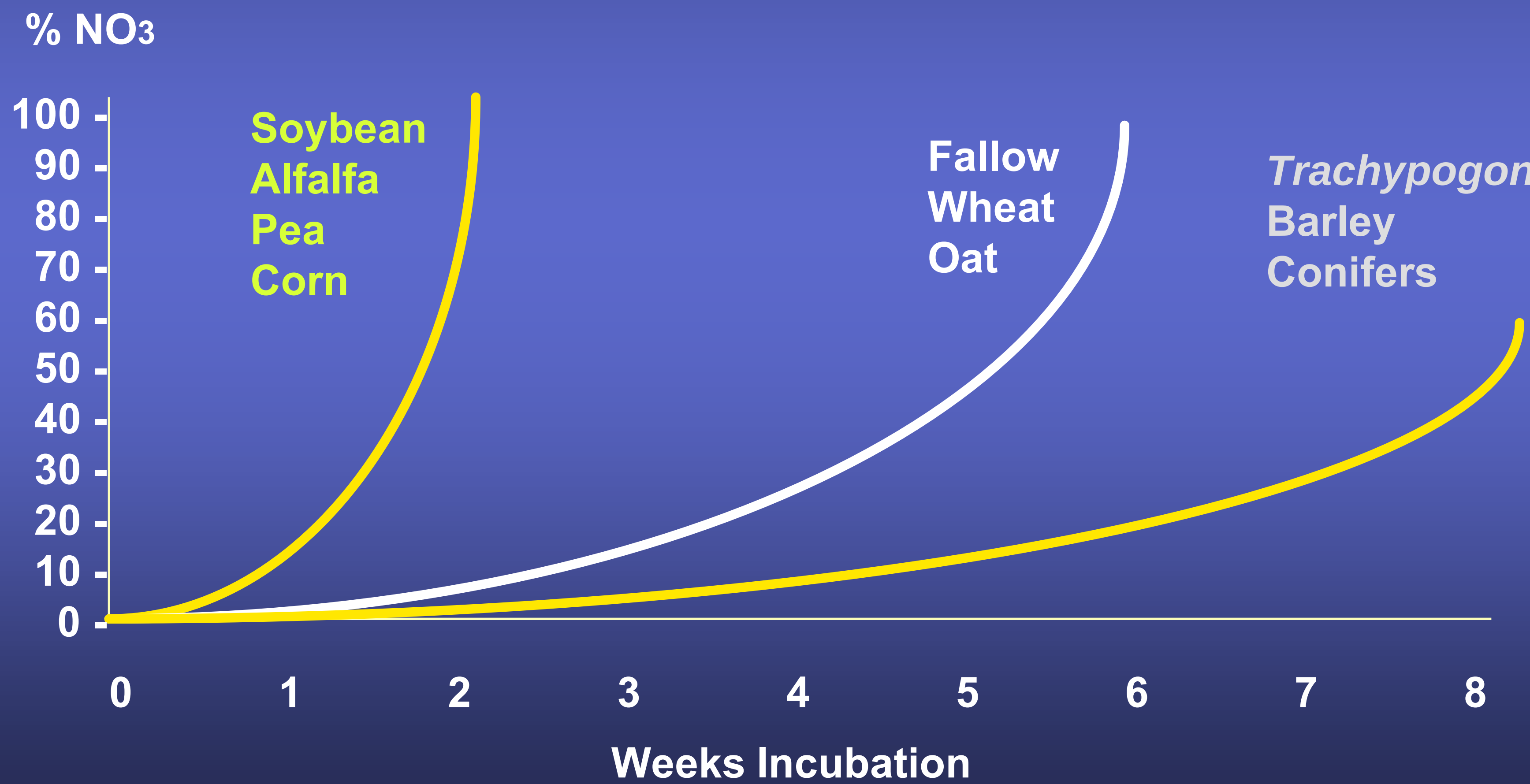
    Rhizosphere influence
  - **Improve Cultivar Tolerance**

CHANGING REACTIONS

- **Modify the Environment**
  - Organic amendments (manure)
  - Crop sequence
  - Inorganic amendments (Liming vrs Sulfur)
  - Fertilization
  - Moisture control (Flood falowing, etc.)
- **Modify the Plant**
  - "Insensitivity" to microbial metabolites
  - Siderophore production
  - Root exudates
- **Modify the Microflora**
  - "Biological control" - PGPR
  - Inhibit nitrification

Changing the Biological Environment

Effect of crop residues on nitrification



Factors Affecting Mn Availability and Severity of Potato Scab

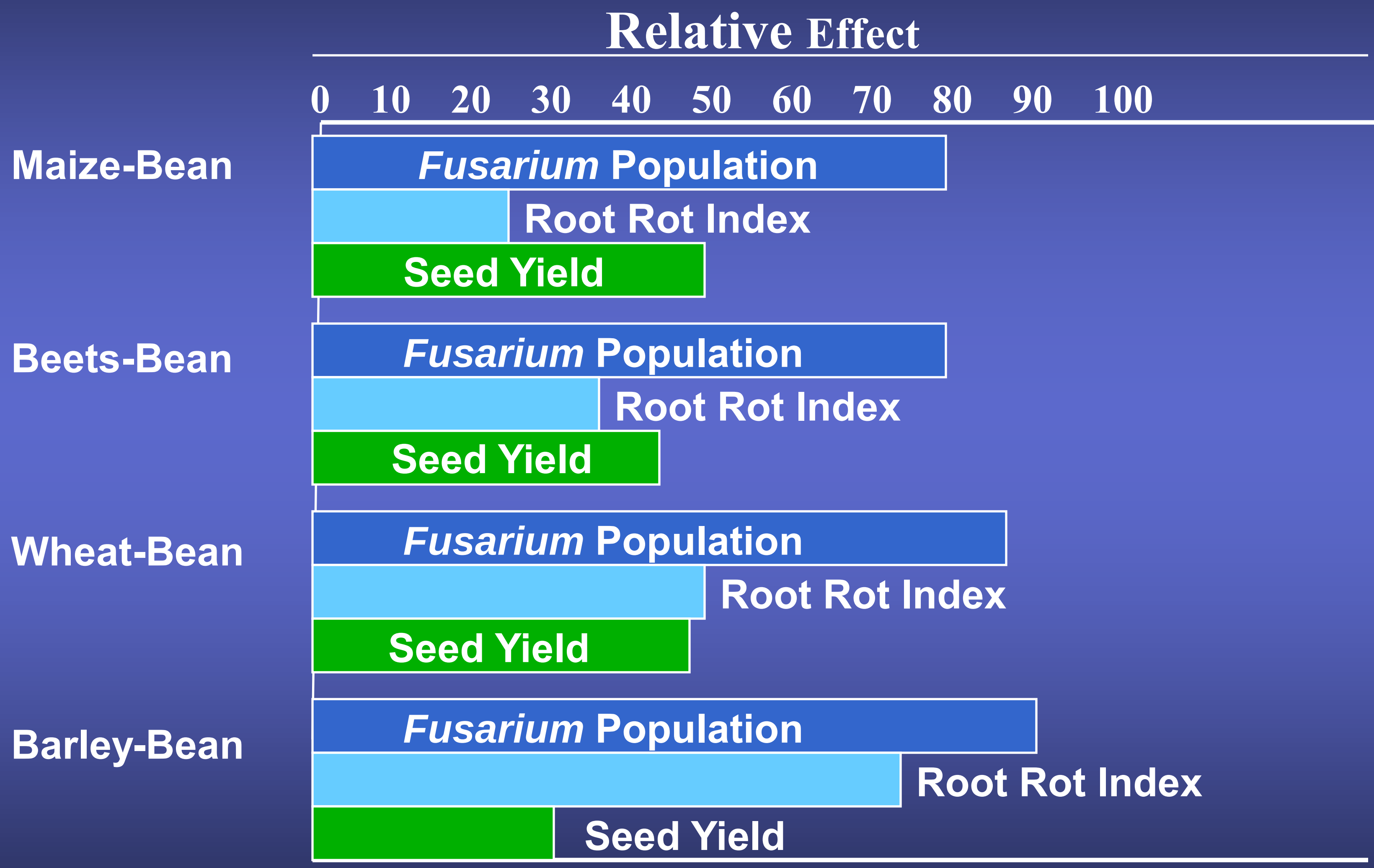
Soil Factor or Cultural Practice	Effect on: Mn Availability	Effect on: Scab Severity
Low Soil pH	Increase	Decrease
Green Manures	Increase	Decrease
Ammonium Fertilizers	Increase	Decrease
Irrigation	Increase	Decrease
Firm Seed bed	Increase	Decrease
Nitrification Inhibitors	Increase	Decrease
Soil Fumigation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

Fusarium Root Rot of Bean

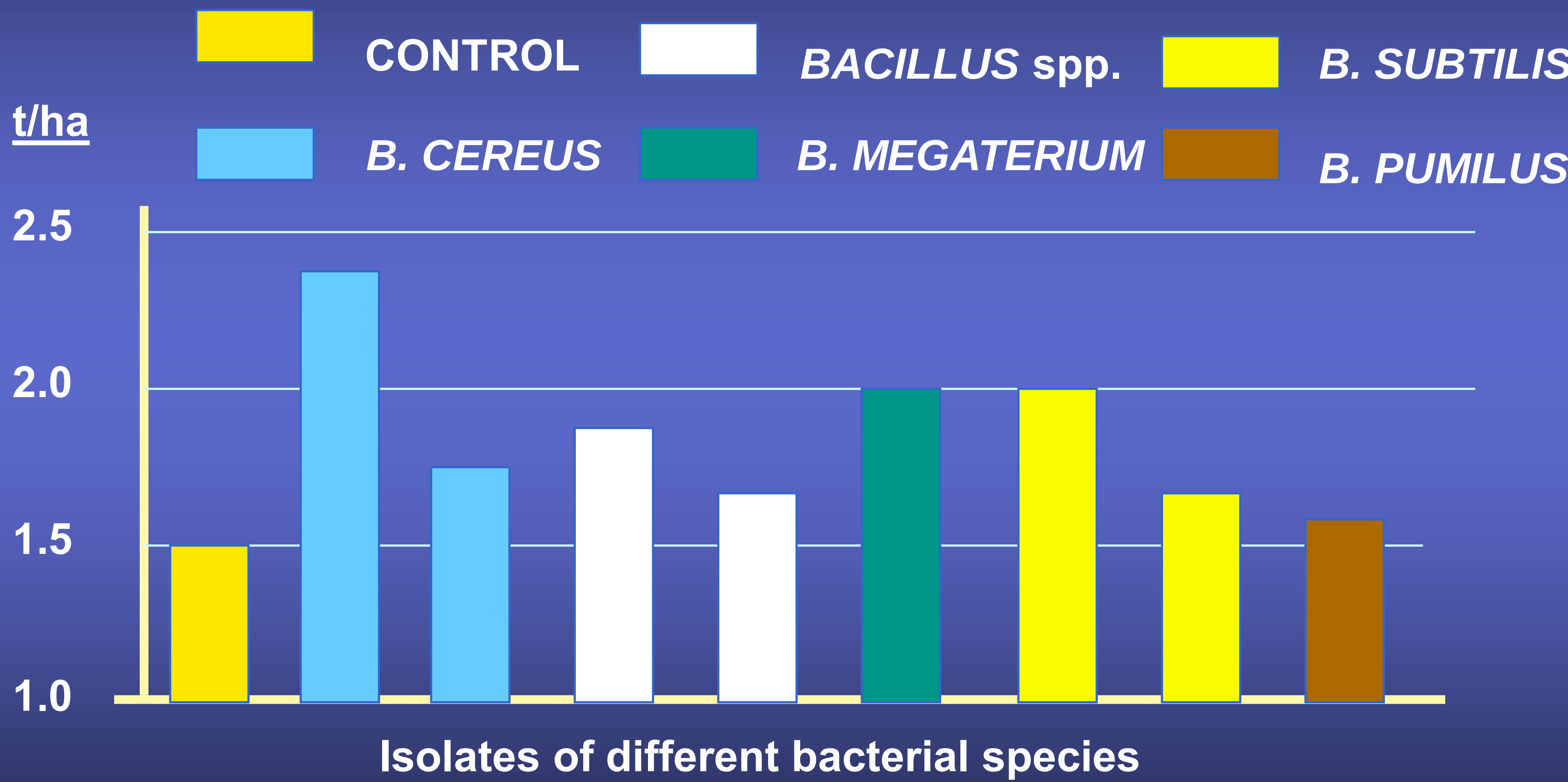
- Caused by *F. solani* fsp. *phaseoli*
- Loss from: Root and hypocotyl rot
- Control: Crop sequence

  Nitrate-N

CROP SEQUENCE, *FUSARIUM*, BEAN ROOT ROT & Yield



EFFECT OF SEED TREATMENT WITH VARIOUS SPECIES OF *BACILLUS* ON WHEAT YIELDS



After DB Scott, 1995

NUTRIENT MANAGEMENT must:

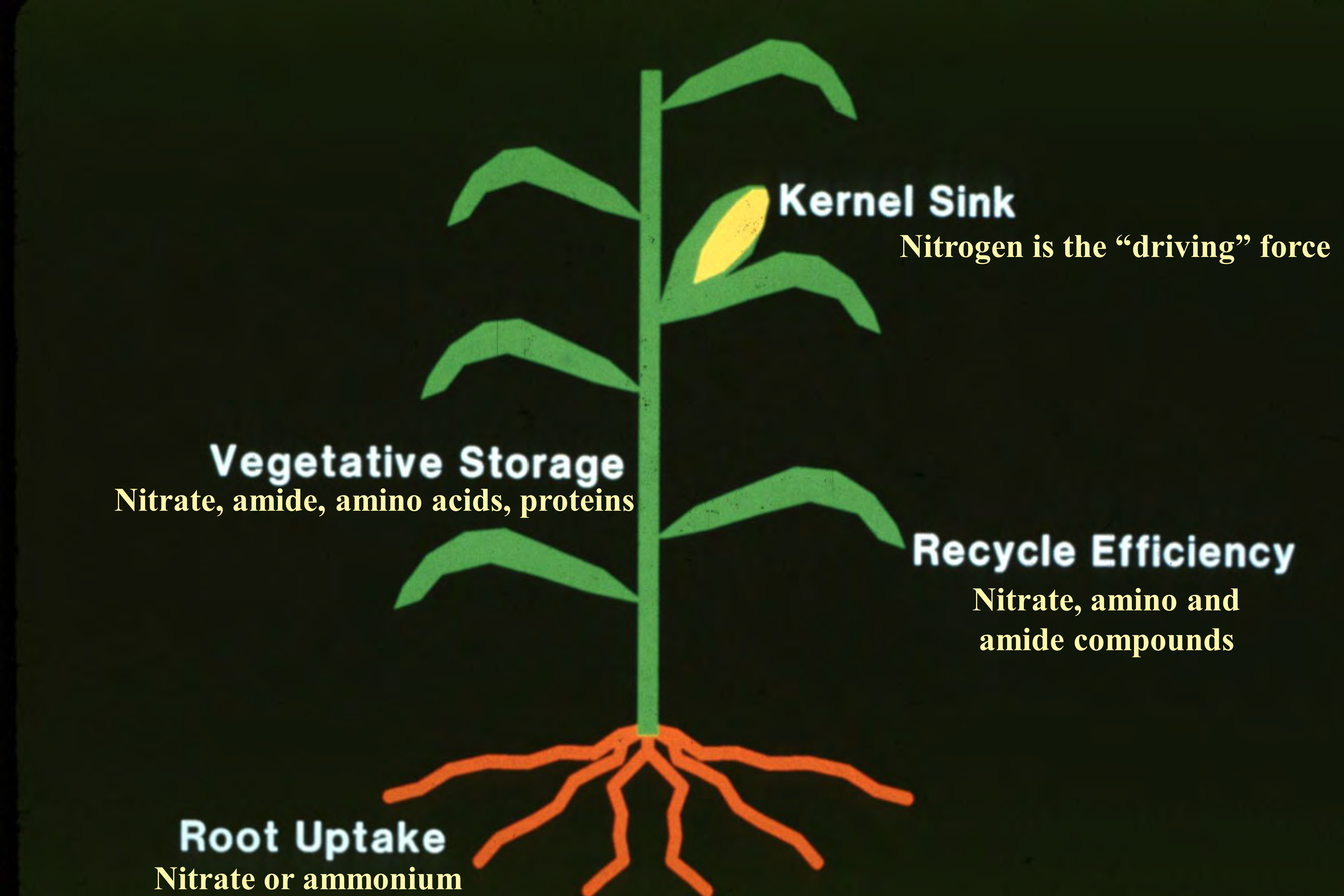
- Meet Potential Crop Needs
- Use Best Management Practices
  - Rate and form of application
  - Time of application
- Be Economically Feasible
- Include Essential Pest Control
- Be Environmentally Sound

Corn Stalk Rot, caused by *Gibberella zeae* and other fungi
Cost farmers $ 8-10 billion a year

Stalk rot is one of the most important soilborne diseases of corn

Losses Occur Through

- Reduced yield
- Lower grain quality
- Increased harvest costs
- Reduced production efficiency


Kernel Sink
Nitrogen is the “driving” force
Vegetative Storage
Nitrate, amide, amino acids, proteins
Recycle Efficiency
Nitrate, amino and
amide compounds
Root Uptake
Nitrate or ammonium

EFFECT OF NITROGEN STRESS

During grain-fill plants cannibalize:

1. **Storage nitrogen**
   (Recycle)

2. **Physiological nitrogen (enzymes)**
   Rubisco
   Pep Carboxylase

3. **Structural proteins**
   Glycoprotein (hydroxyproline) in cell walls

EFFECTS of NITROGEN on STALK ROT

- **Nitrogen Rate:**

  Reduces stalk rot up to full sufficiency
  Excess nitrogen increase stalk rot

- **Nitrogen Form:**

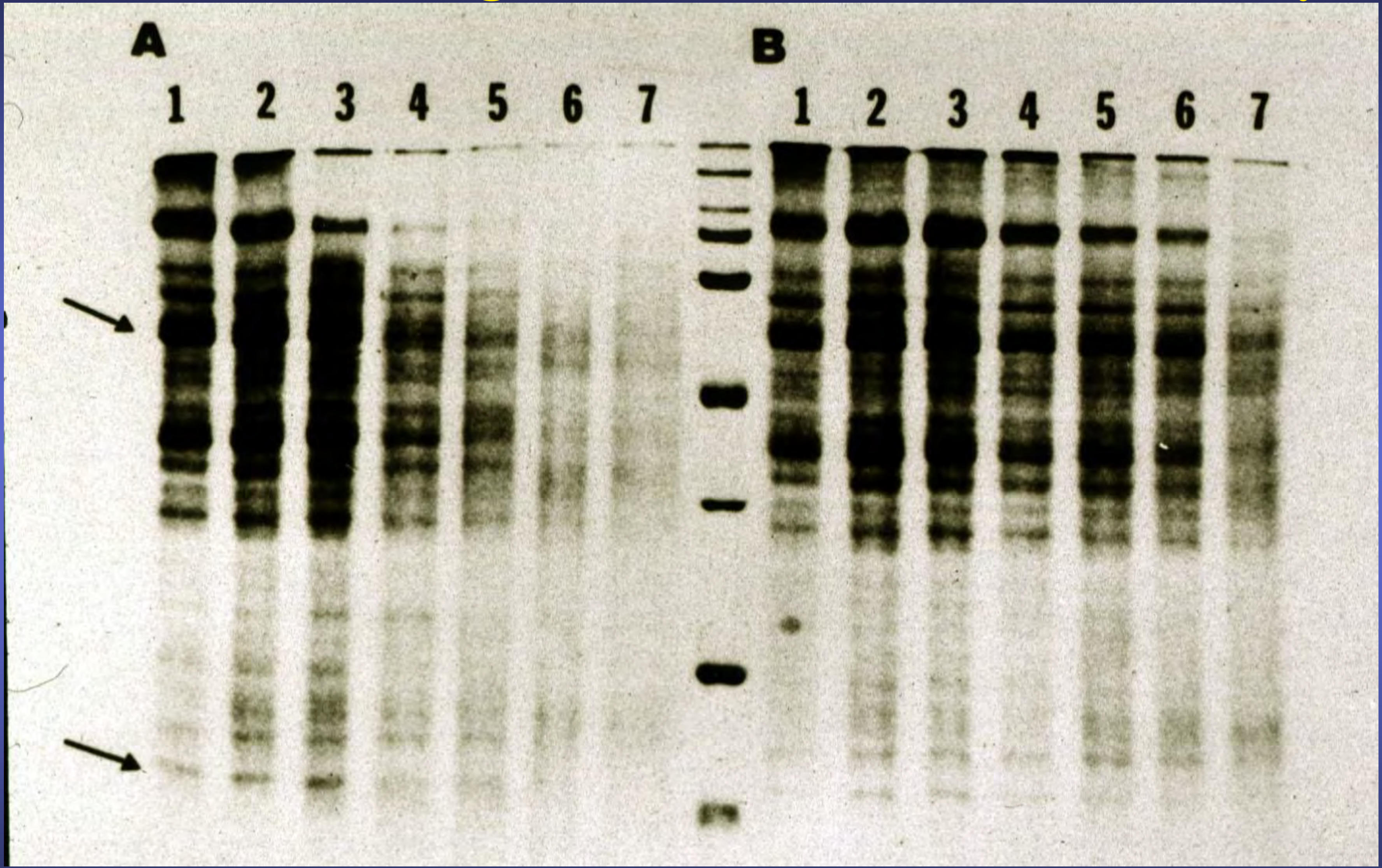
  Ammonium reduces stalk rot through
  - **Nitrogen efficiency**
  - **Physiological interactions**

PREDISPOSITION TO STALK ROT: A CARBON OR NITROGEN DEFICIENCY

- **CARBON:**
  Senescence when photosynthesis stops
  Low carbohydrate reserves increase

- **NITROGEN:**
  Rate response up to sufficiency
  (Maintains photosynthesis)
  Excess increases
  Ammonium reduces (form effect)
  "Stay green" hybrids are more tolerant

Effect of Inhibiting Nitrification on Rubisco Activity



120 # N/acre

120 # N/acre + Nitrapyron

30 Days Post Pollination

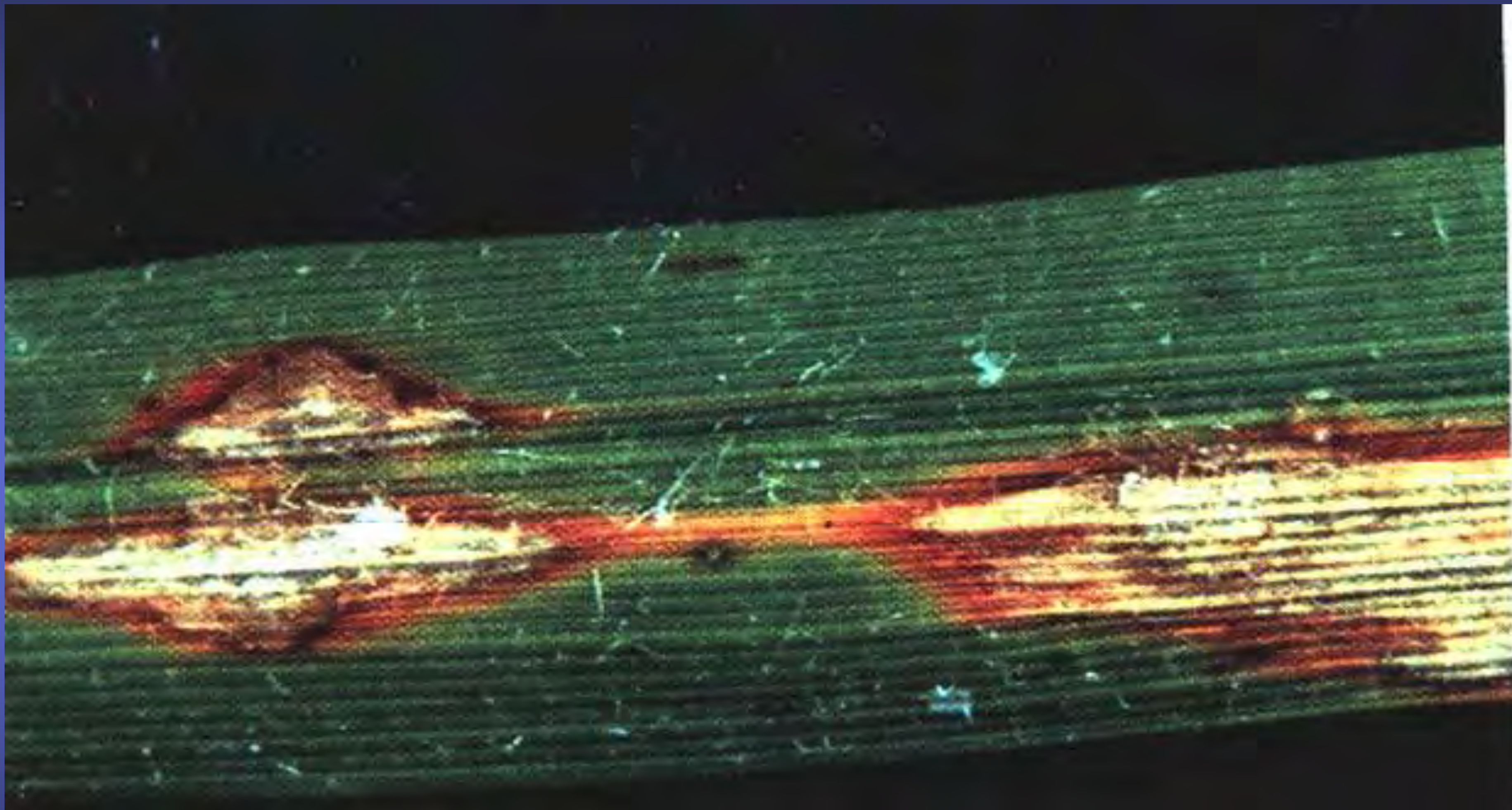
Hybrid: B73xMo17

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

Costs farmers $ 5 billion a year

Blast is one of the most important diseases worldwide because rice is a major source of food for 60% of the world's population

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

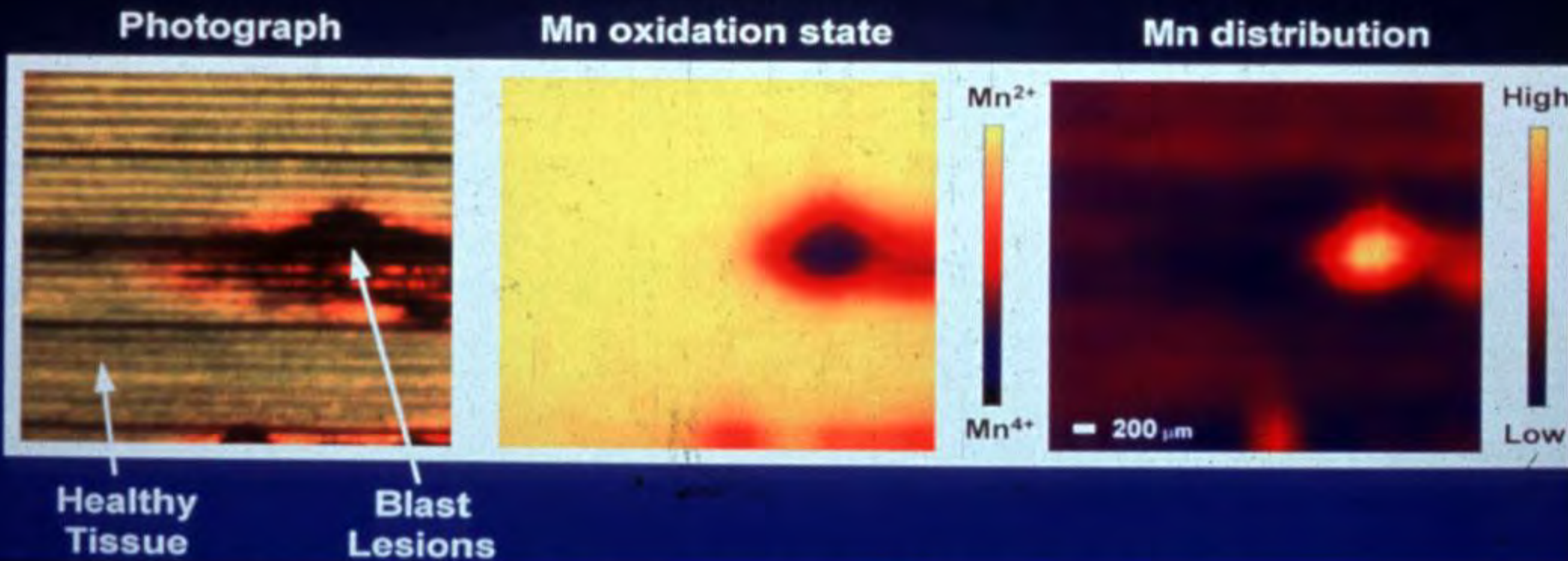


Effects of Cultural Conditions on Mn Availability & Blast

Condition	Manganese availability	Blast severity
Upland rice culture	Decrease	Increase
Alkaline soils	Decrease	Increase
Nitrate nitrogen	Decrease	Increase
Aerobic or dry soils	Decrease	Increase
“Low” temperatures	Decrease (uptake)	Increase
Sandy soil	Decrease	Increase
Manure	Decrease	Increase
High plant populations	Decrease	Increase
Paddy rice culture	Increase	Decrease
Acid soils	Increase	Decrease
Ammonium nitrogen	Increase	Decrease
Inhibiting nitrification	Increase	Decrease
Anaerobic soils	Increase	Decrease
“High” temperatures	Increase	Decrease
Silicon fertilization	Increase	Decrease
Clay & loam soils	Increase	Decrease

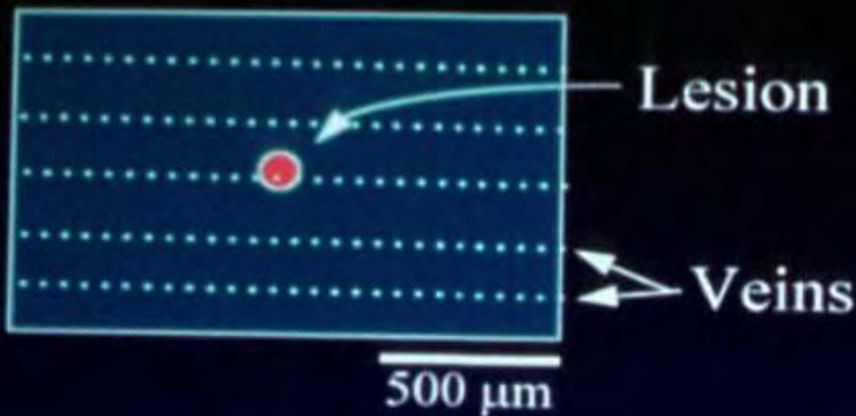
Manganese in Rice Blast Lesions

Rice leaves infected with *P. grisea*

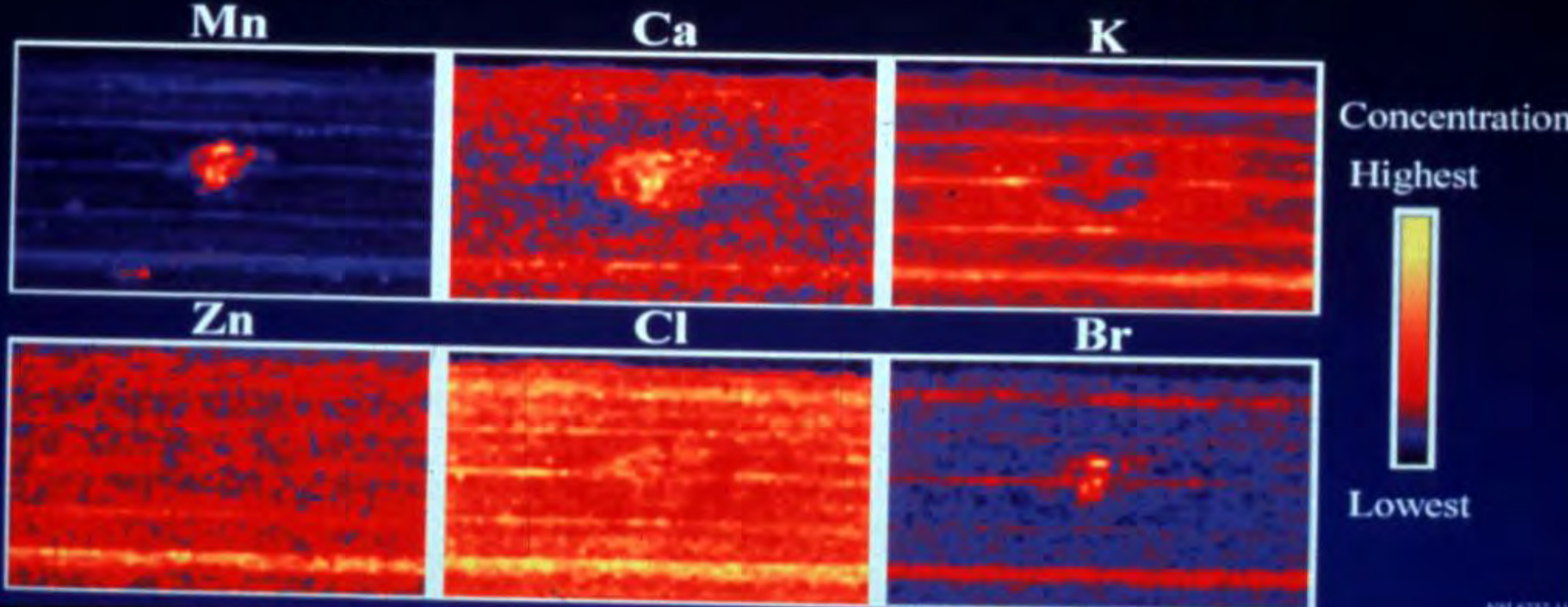


Pathogen induced Mn deficiency in the infection court

Elemental Distributions in Rice Blast Lesions

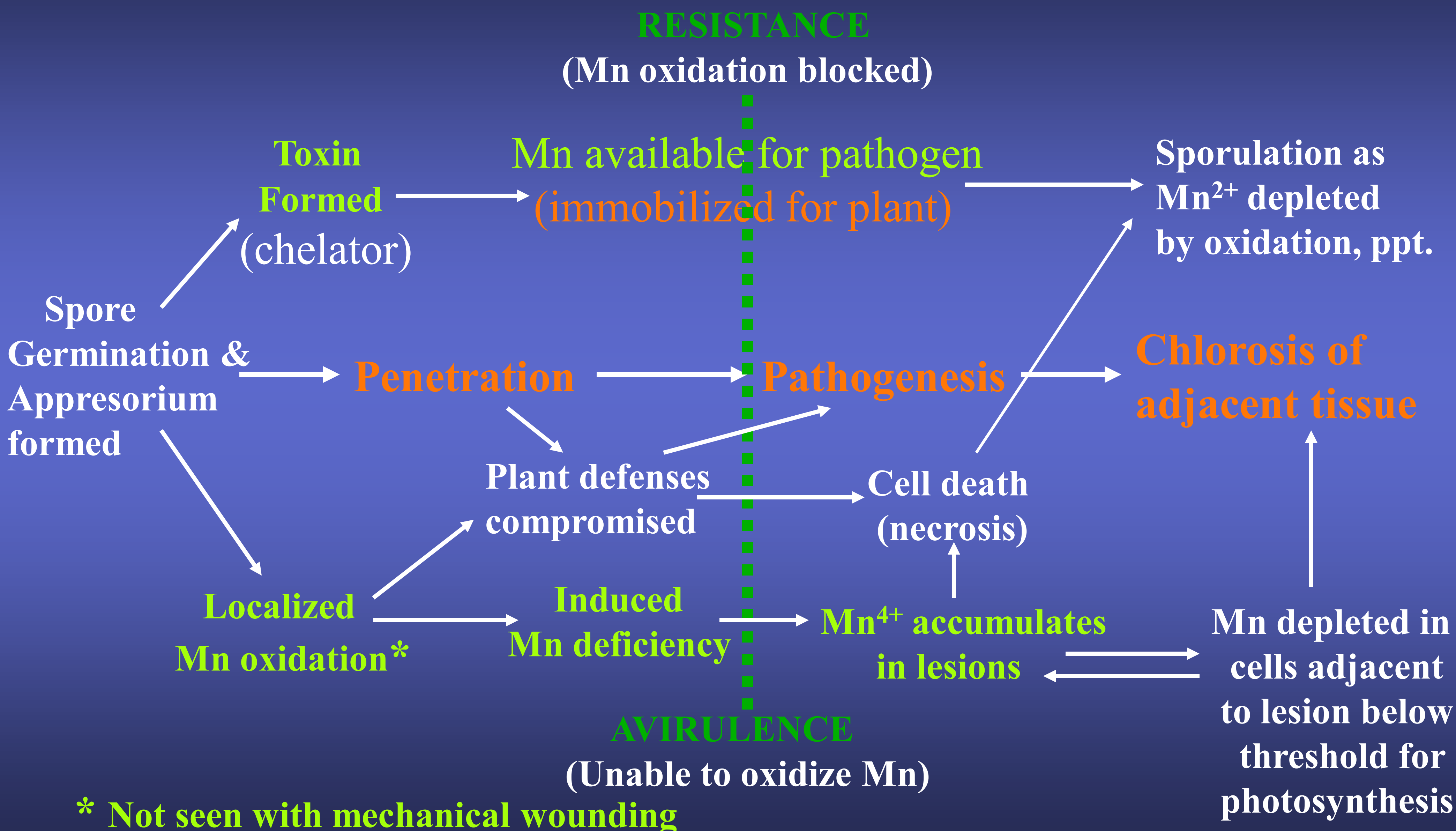


91L7, IL-1



Only Mn, Ca, (and Br) accumulate at the infection site

A PROPOSED ROLE OF Mn IN BLAST PATHOGENESIS



“Take-all” Root, Crown, and Stem Rot of Cereals

Caused by *Gaeumannomyces graminis* var *tritici*

MANGANESE AVAILABILITY AND MICROBIAL ACTIVITY

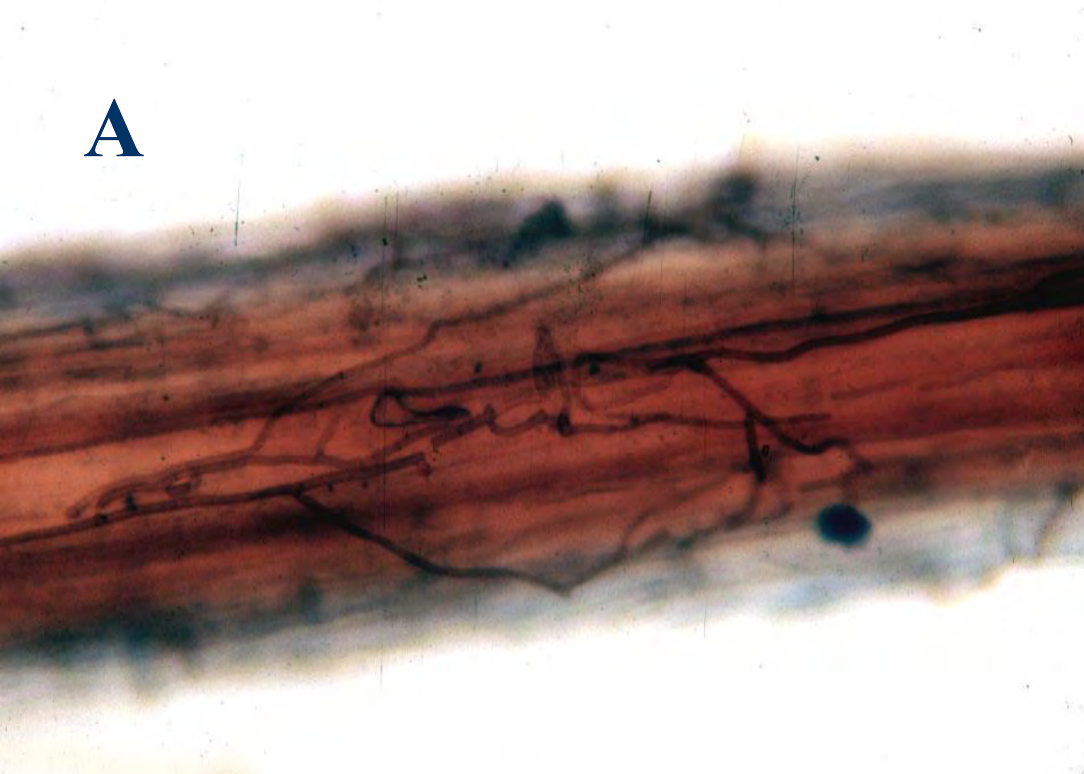
pH:	Acid < 5.5	Biological	> 7.8 Alkaline
Mn Form:	Mn^{++}	Activity	Mn^{++++}
Availability:	Available		Not Available

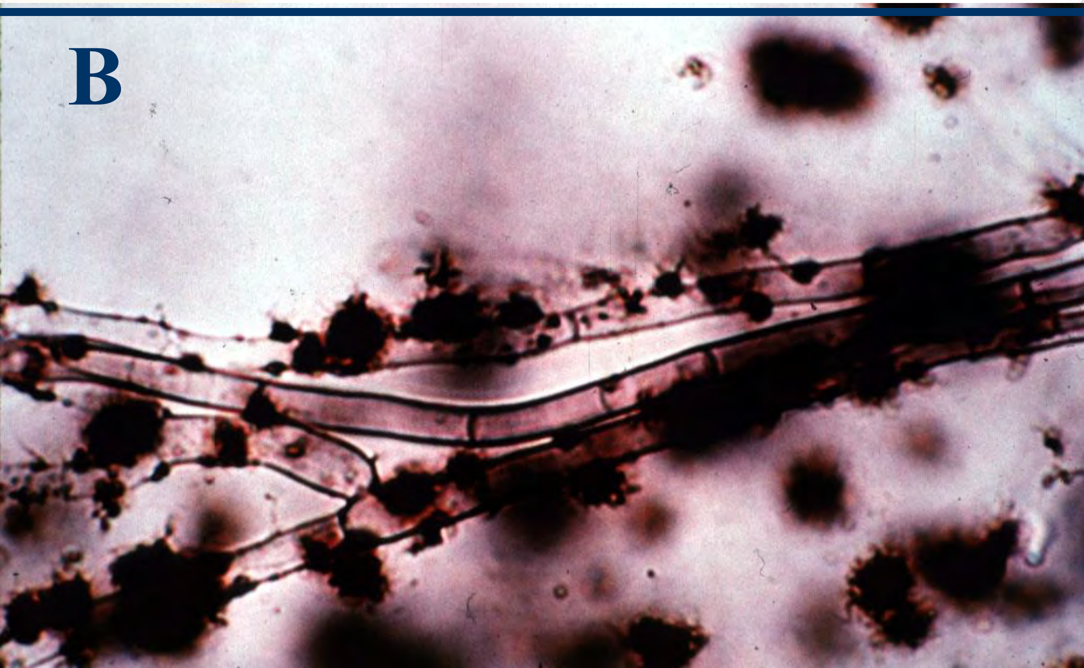
Gaeumannomyces graminis

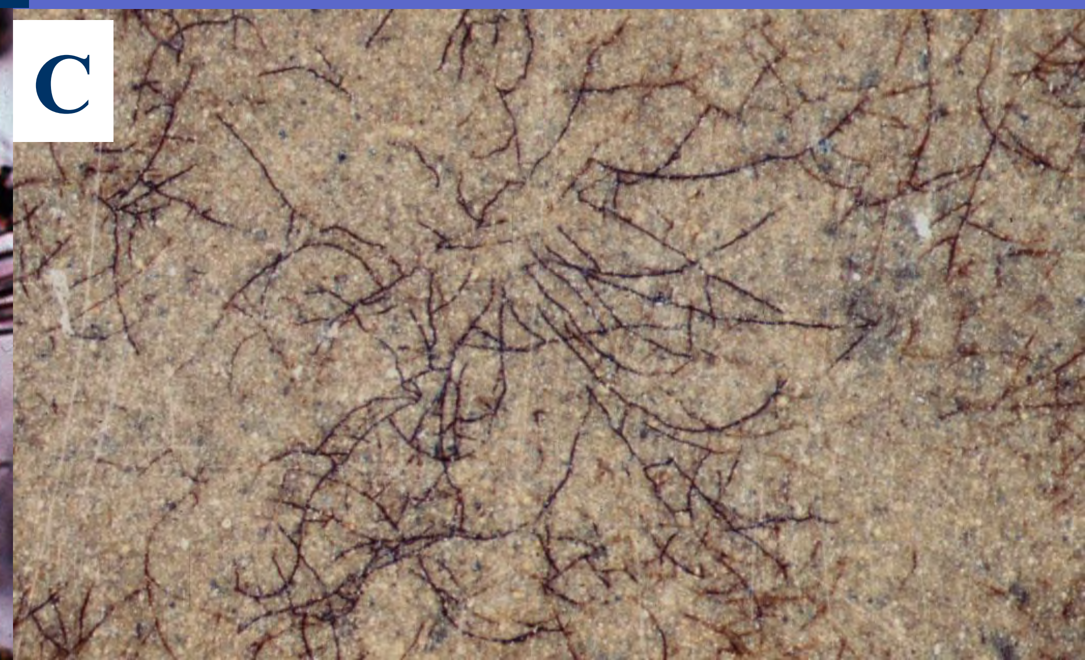
A. Runner hyphae on wheat root

B. Oxidation of Mn in media

C. Oxidation of Mn in soil

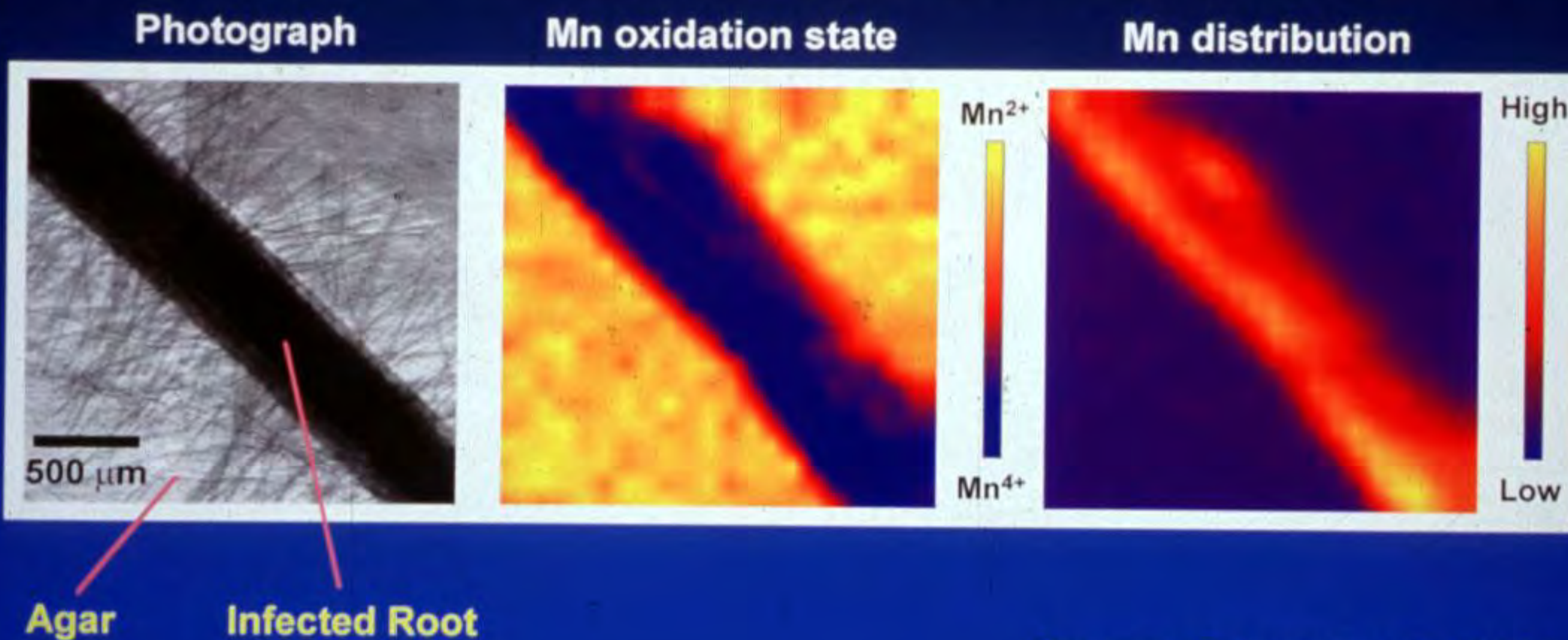






Manganese in Wheat Take-all Disease

Seedlings in agar with 50 mg L^{-1} Mn^{2+} and infested with *G. graminis*



Source: Schulze et al. (1995)

Effect of an Oat Precrop on Take-all

Crop Sequence	Tissue Mn	Disease Index	Yield (kg/ha)
Wheat-wheat-wheat	20	4.2	1,450
Wheat-oats-wheat	55	1.8	3,900
Oats-oats-wheat	76	1.0	4,160

APPROACHES TO IMPROVE DISEASE CONTROL

Mn Seed Content
Mn Uptake Efficiency
Root Exudate Effects

Plant

MICROBES

Mn Reducers
Inhibit Nitrifiers

SOIL

Mn Amendment
Mn Seed Treatment
pH Adjustment
Cultural Modification
Nutrient Balance

Fusarium Wilt/Yellows Disease

- **Disease of fruit, vegetable, fiber and ornamental crops**
- **Increased with ammonium-N**
- **Severe in low (acid) pH soils**
- **Control: Adequate liming PLUS nitrate-N**
- **(Decreases Mn and Fe availability)**

Wilt/Yellows Diseases Caused by *Fusarium oxysporum*

Plant	Disease	Pathogen
Asparagus	Wilt	*F. oxysporum f. sp. asparagi*
Bean	Yellows	*F. oxysporum f. sp. phaseoli*
Beet	Yellows	*F. oxysporum f. sp.betae*
Broccoli, Cauliflower, Cabbage,Collard	Yellows	*F. oxysporum f. sp. conglutinans*
Celery	Yellows	*F. oxysporum f. sp. apii*
Muskmelon	Wilt	*F. oxysporum f. sp. melonis*
Pea	Wilt	*F. oxysporum f. sp. pisi (race 1)*
Pea	Near Wilt	*F. oxysporum f. sp. pisi (race 2)*
Radish	Yellows	*F. oxysporum f. sp. raphani*
Spinach	Wilt	*F. oxysporum f. sp. spinaciae*
Tomato	Wilt	*F. oxysporum f. sp. lycopersici*
Watermelon	Wilt	*F. oxysporum f. sp. niveum*

SUMMARY

- The purpose of nutrition and disease control is to increase crop production efficiency.
- Plant fertility is an important part of an IPM program.
- Many cultural practices which reduce disease work by influencing nutrient uptake.
- Nutrition is most effective with “tolerant” varieties.
- Nutrient stressed plants may be more susceptible to disease.

SUMMARY (Continued)

- Any single element may reduce severity of one disease, but increase another.
- No nutrient controls all diseases - each disease and environment should be considered within the production system.
- The form of a nutrient may be as important as the rate.
- It is important to maintain a balanced nutrition.