# Impacts of Mineral Nutrition on Growth of Crop Plants


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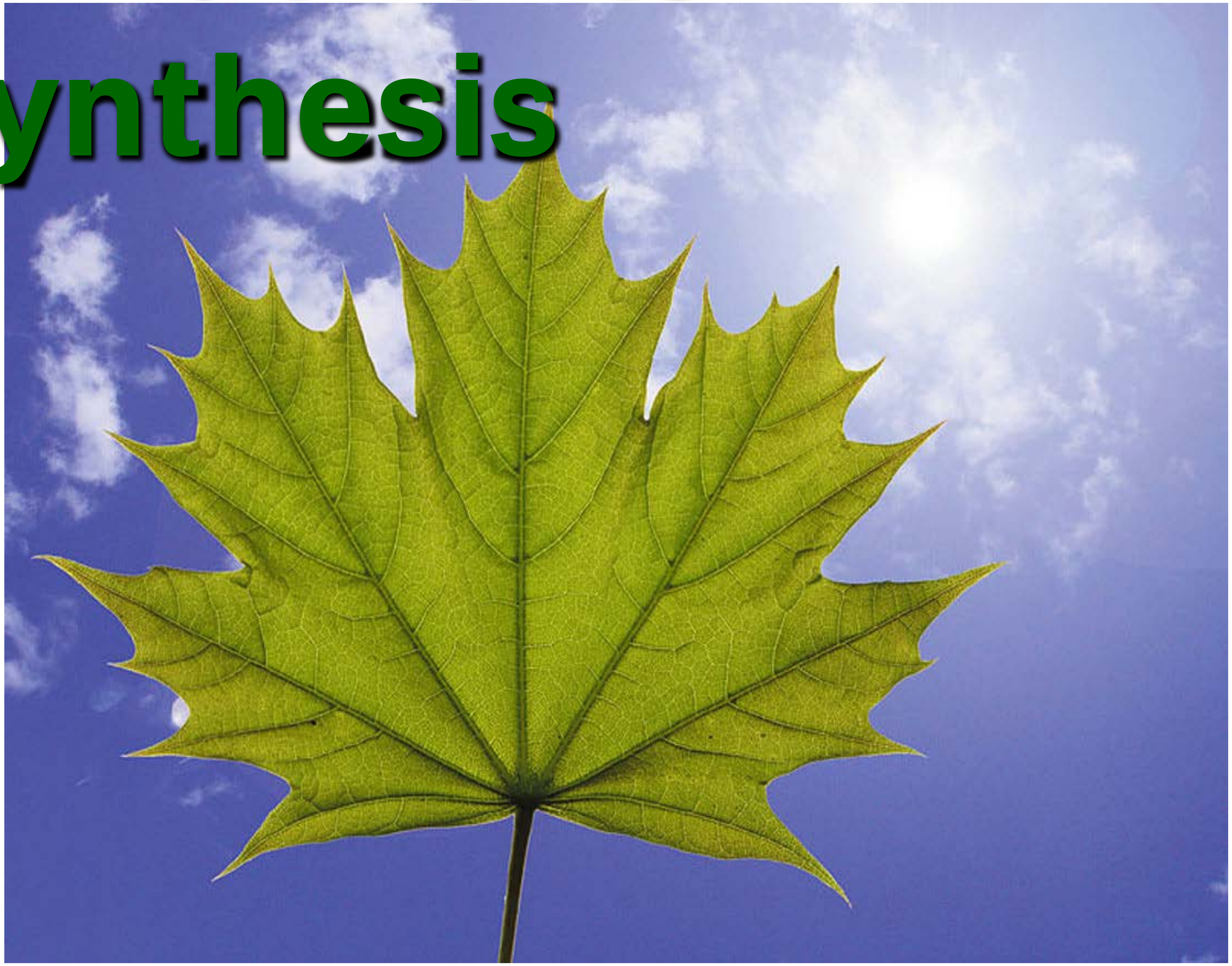
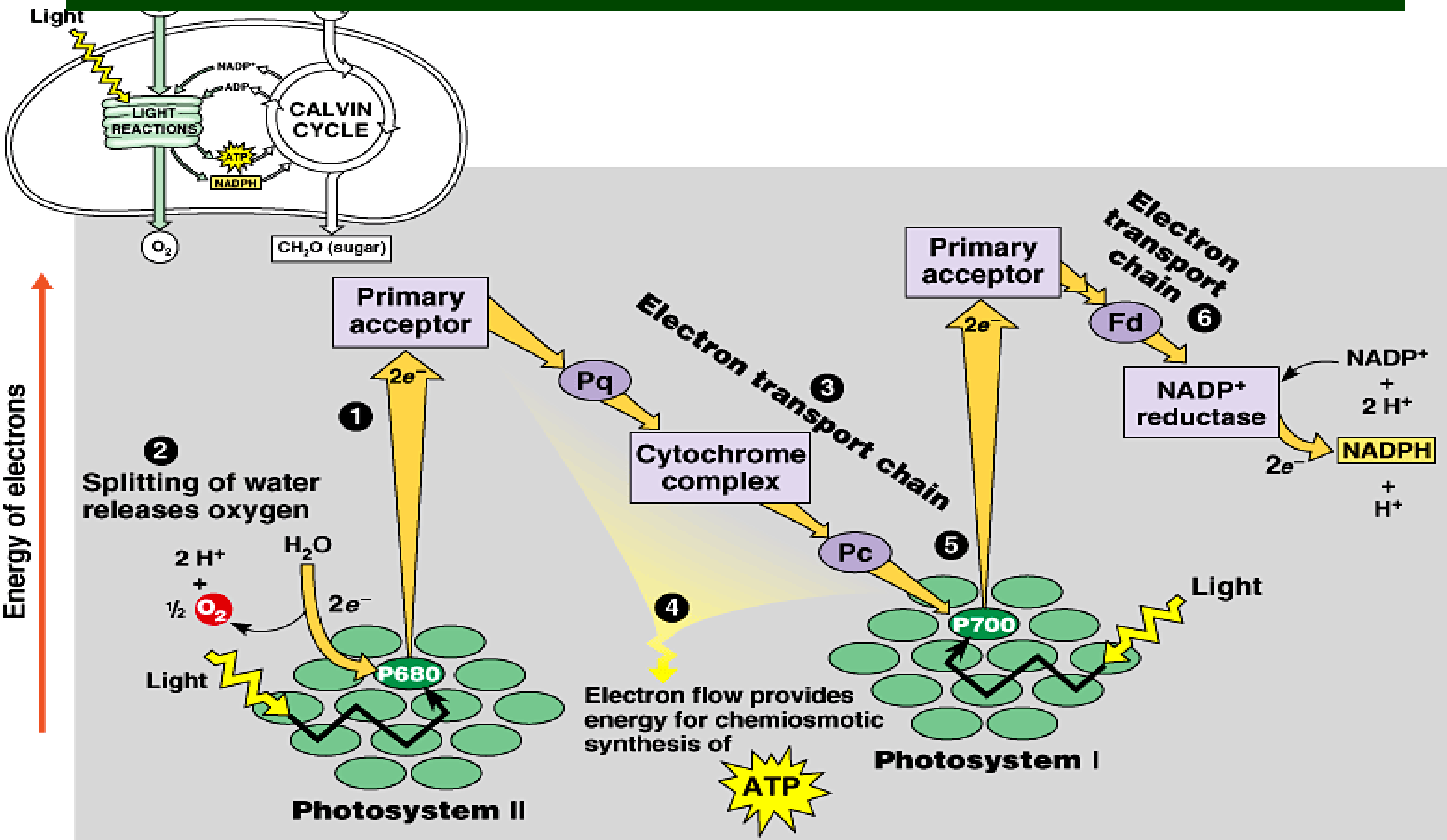
# TOPICS

- Mineral Nutrients in Photosynthesis
- Mineral Nutrients in Translocation of Photoassimilates (Yield Formation-Root Growth)
- Effect of Mineral Nutrition on Photooxidative Damage of Leaves
- Particular Roles of Micronutrients in Crop Production (e.g., pollination, diseases tolerance...)
- Role of Seed Nutrients in Seedling Vigour
- Impairments of Nutritional Status of Plants by Glyphosate
- Micronutrient Deficiencies in Human Populations

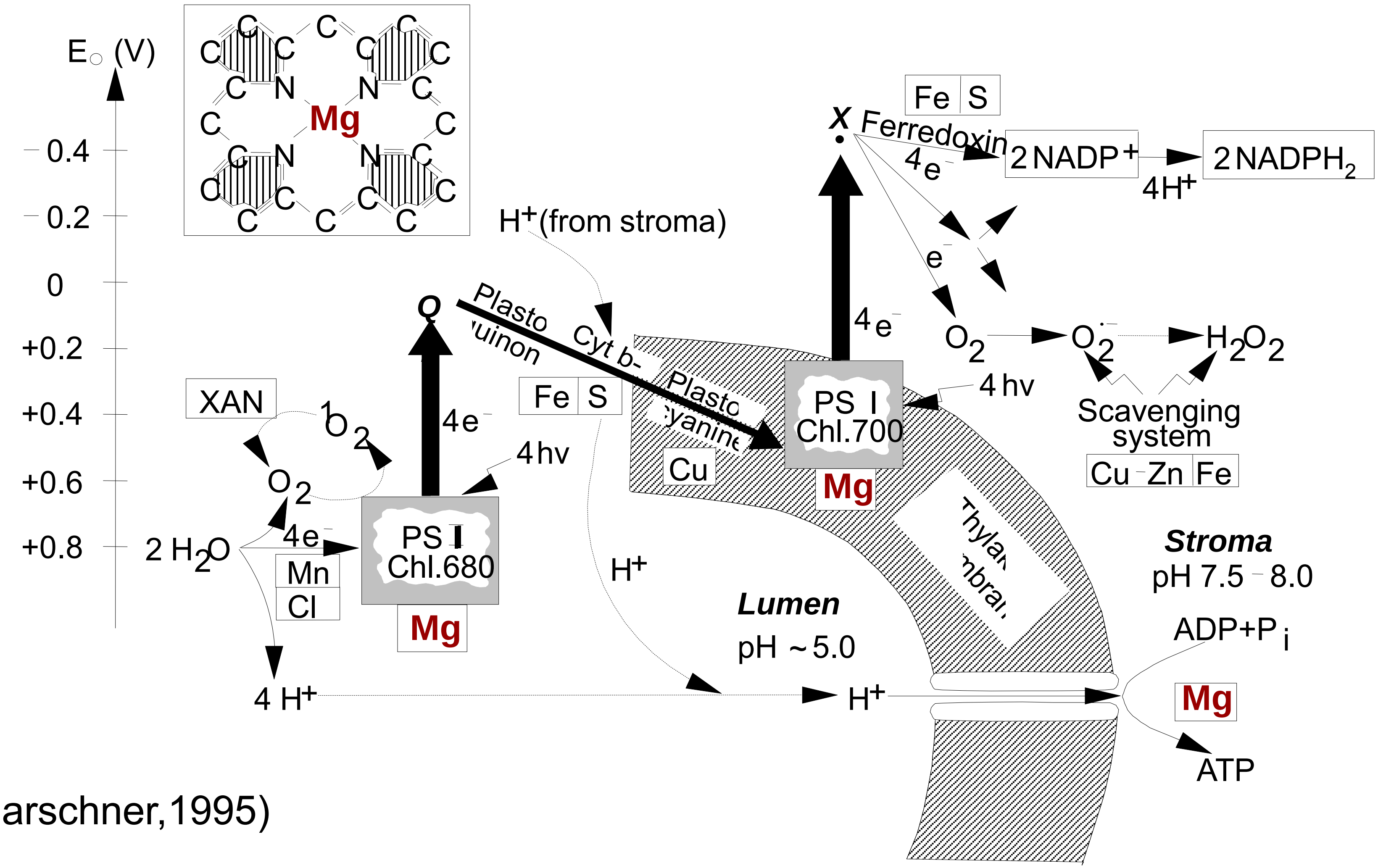
# Mineral Nutrients in Photosynthesis



# **Mineral Nutrients** required for photosynthetic electron transport and for ATP formation



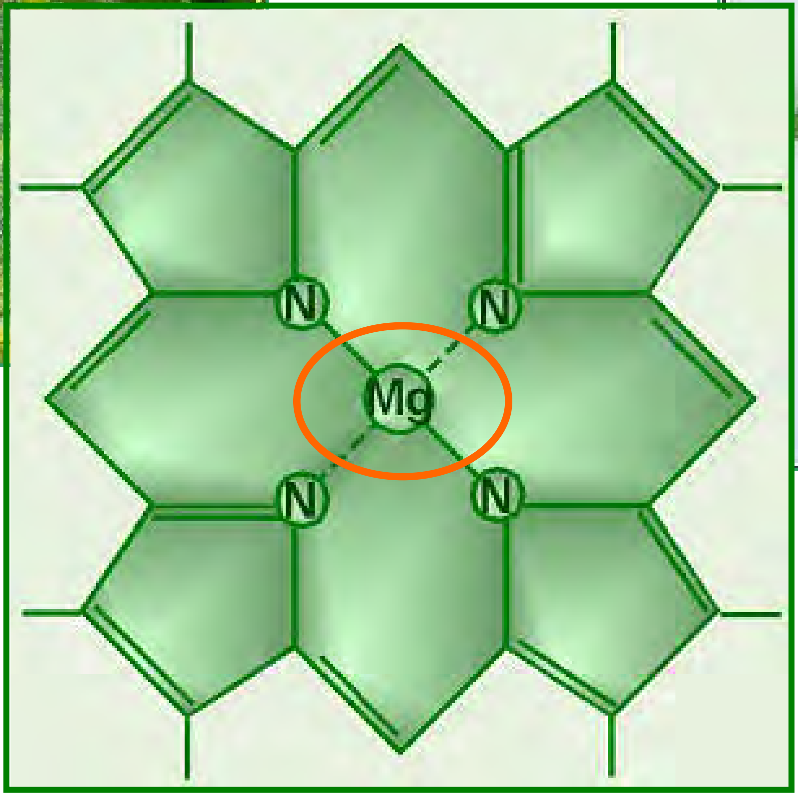
# **Mineral Nutrients** required for photosynthetic electron transport as well as for ATP formation



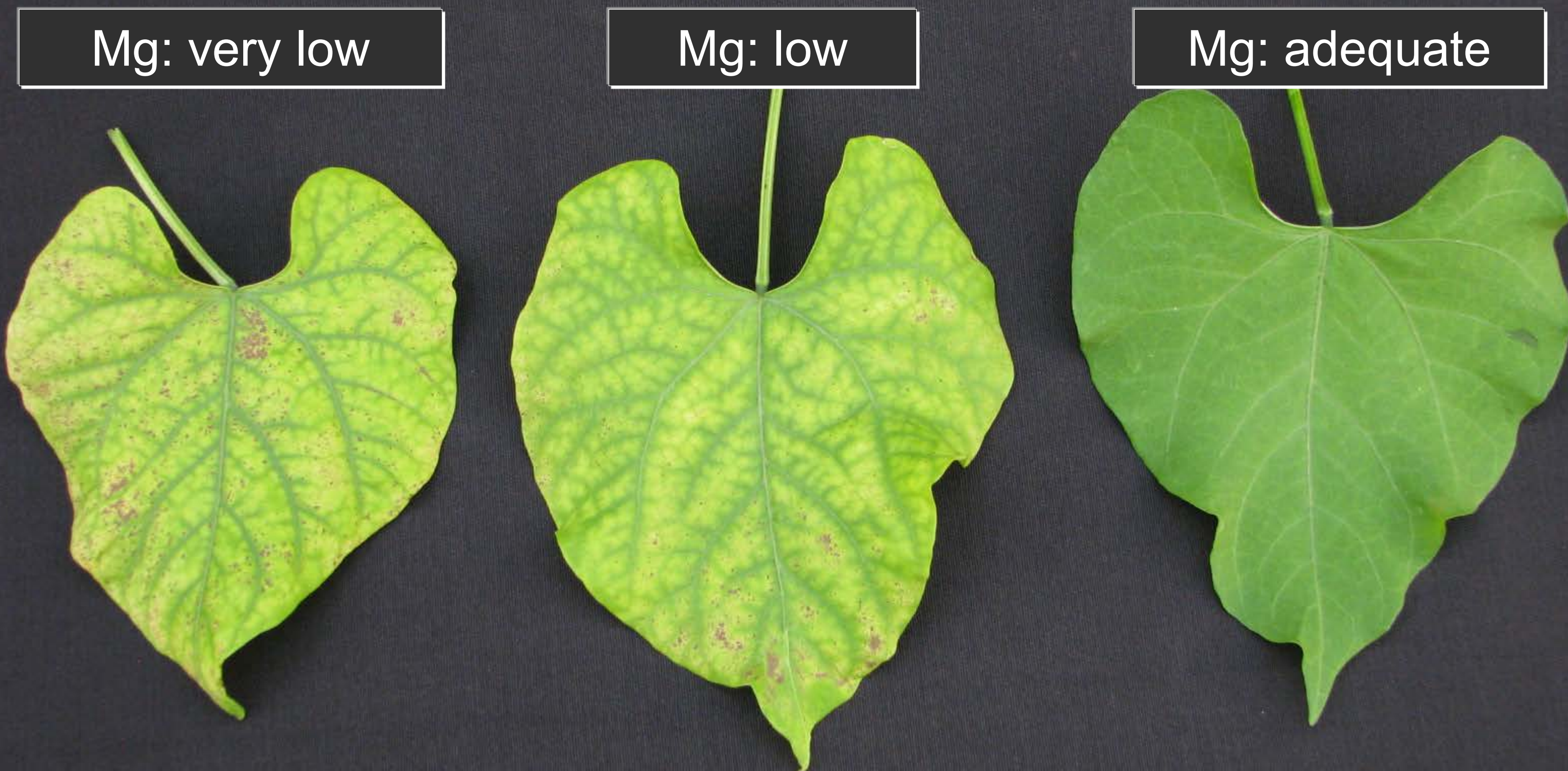

(Marschner,1995)

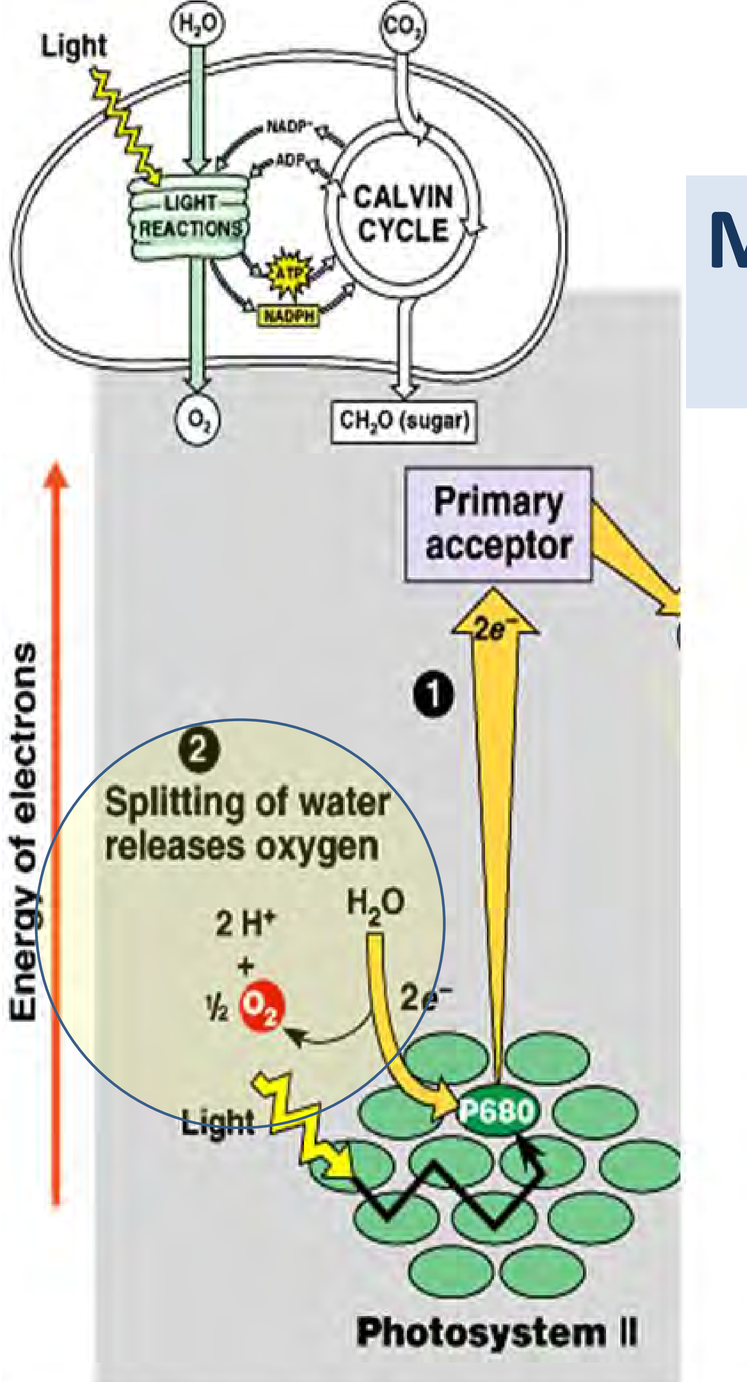
*Photosynthetic electron transport chain with photosystem II and I photophosphorylation;*

# Magnesium is the central ion of chlorophyll. Its deficiency causes chlorosis




# Magnesium  Deficiency in Bean





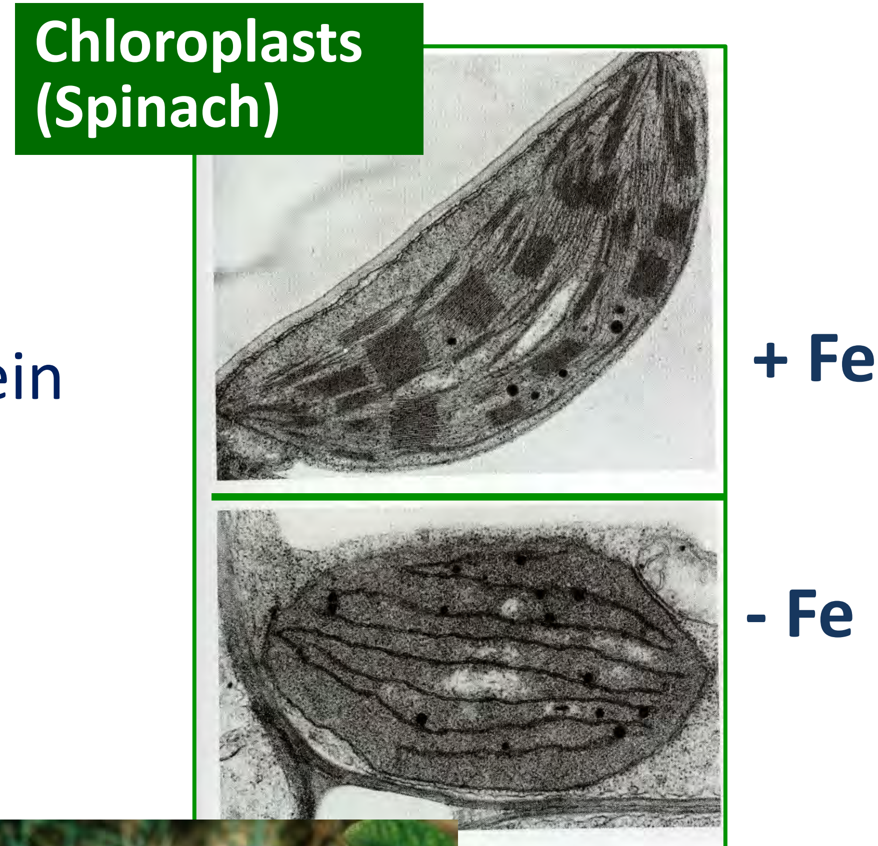


# Major function of manganese in photosynthesis

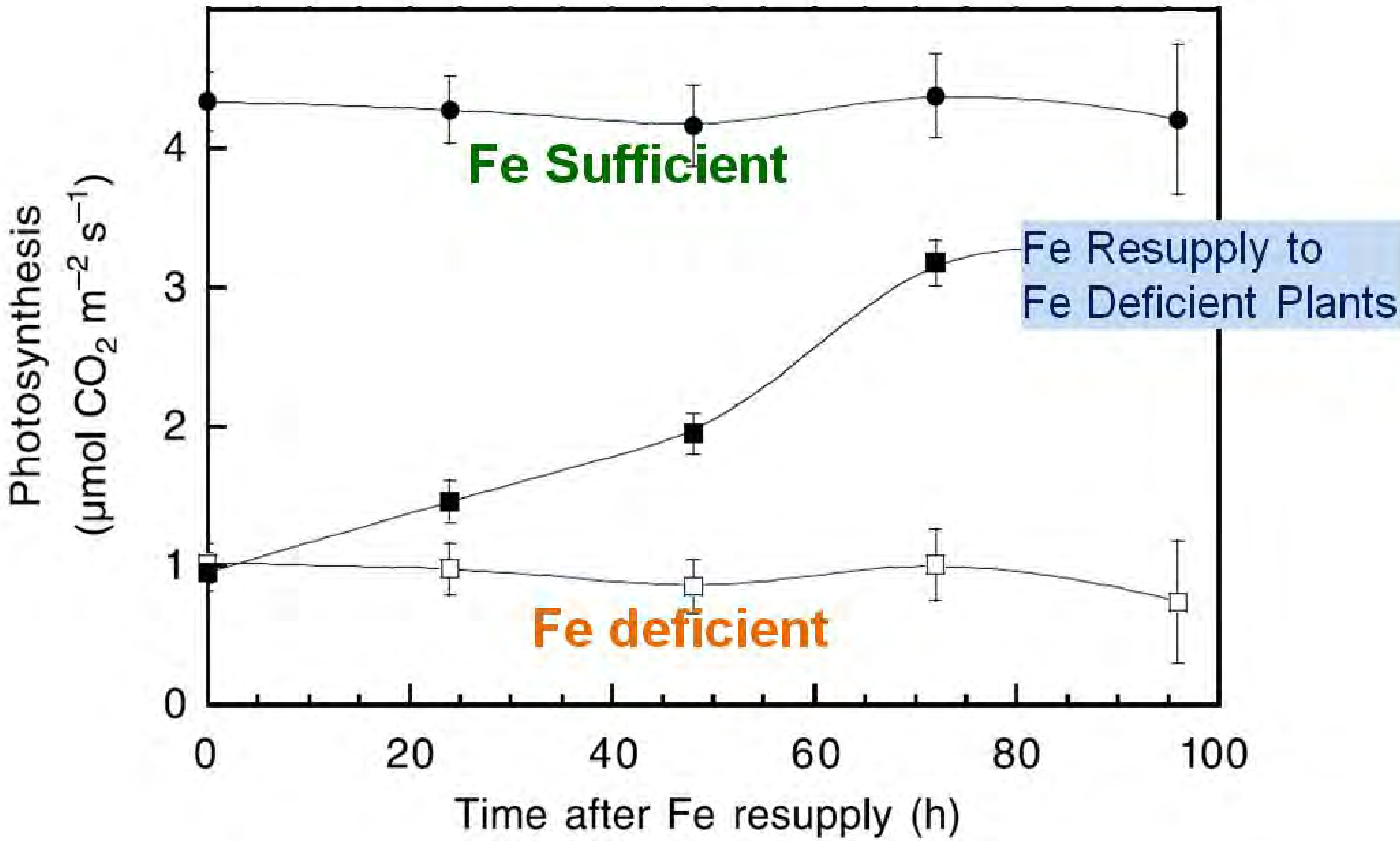
- Mn is constituent of the **water splitting enzyme** (Hill reaction) within the electron transport chain for photosynthesis.
  ($2\ H_2O \rightarrow 4H^+ + 4e + O_2$)

# Major functions of iron in Photosynthesis

- Biosynthesis of chlorophyll
- Formation of chloroplast protein
- Involvement in many redox processes

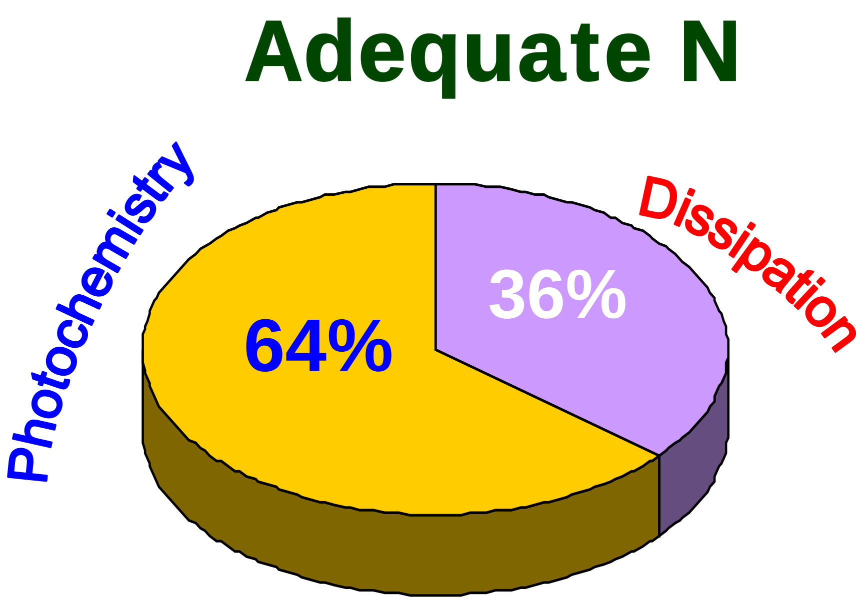


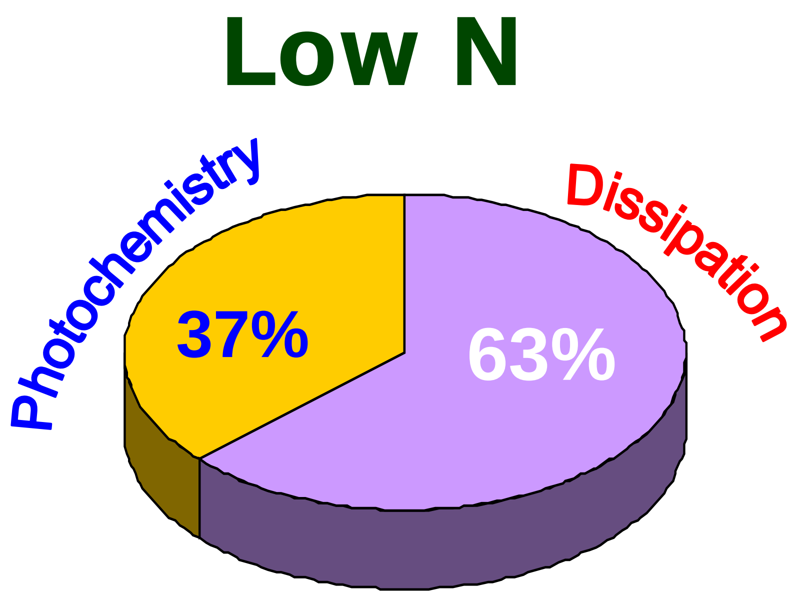

# Effect of Fe Supply on Photosynthesis in Sugarbeet




Larbi *et al. 2004*) *Photosynth. Res.* 89, 113-126

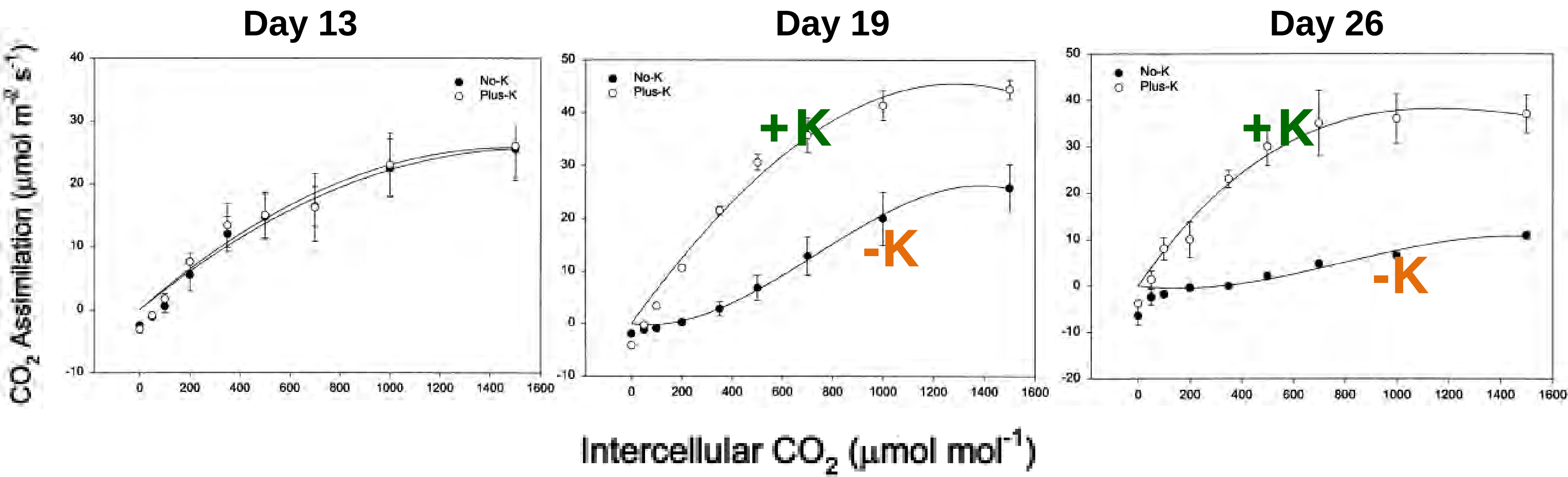
# Nitrogen is important for an effective use of absorbed light energy in photosynthesis




Verhoeben et al. Plant Physiol.
1997, 113: 817-824

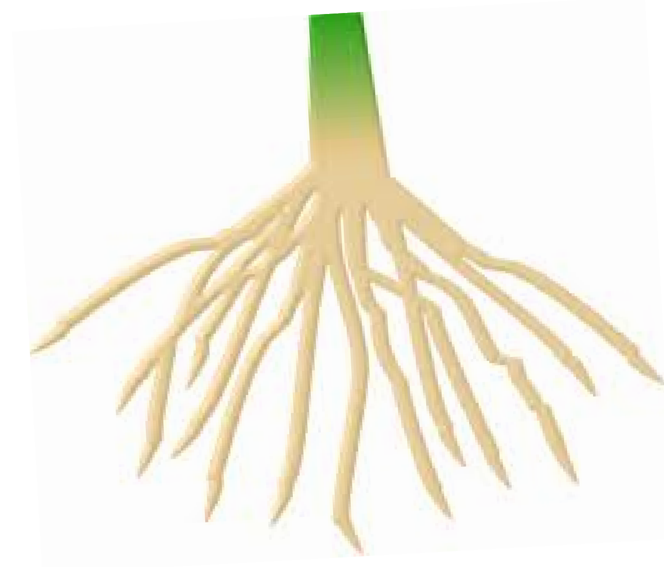
# Effect of Potassium on Photosynthesis in Cotton

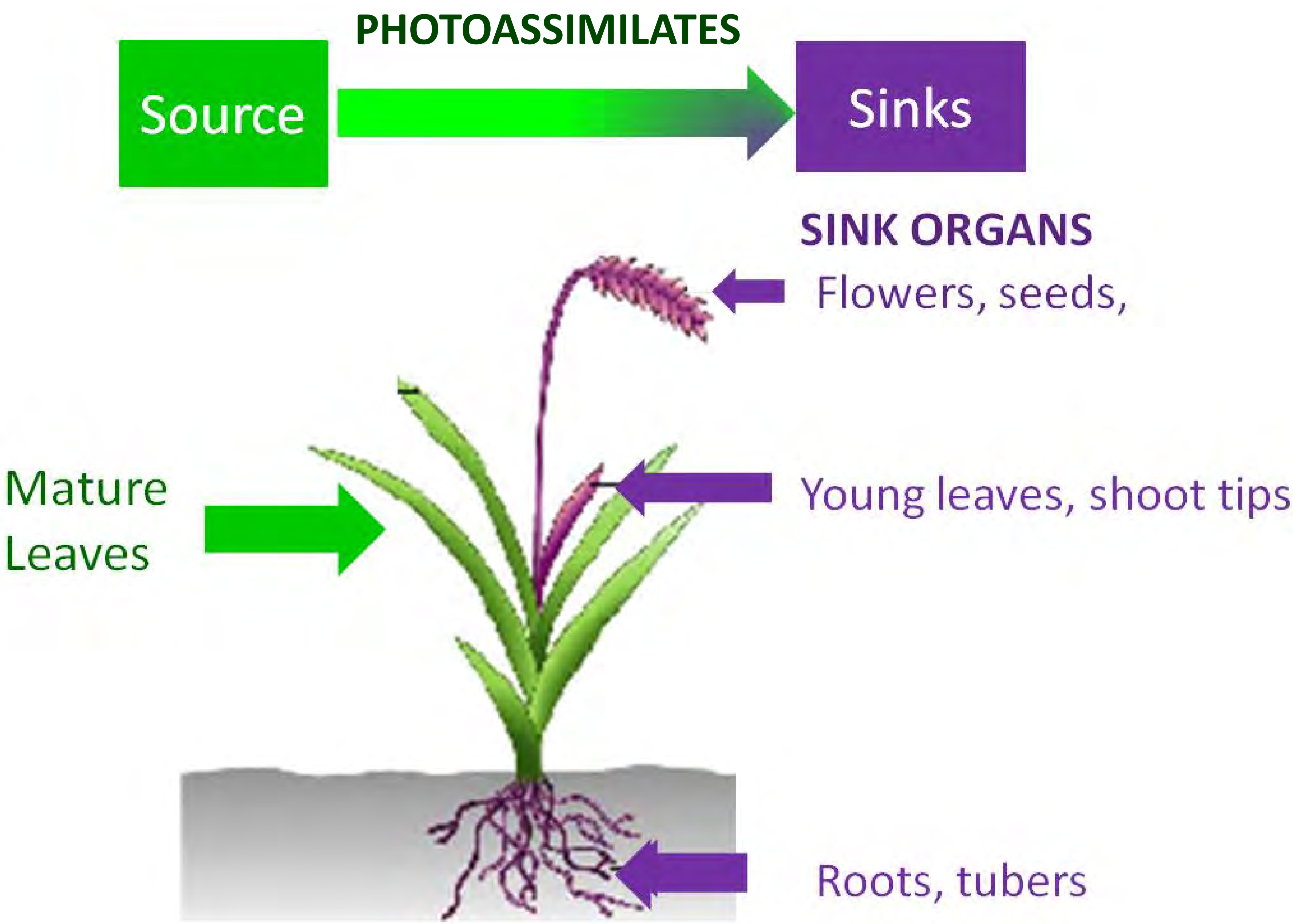



Severity of K deficiency

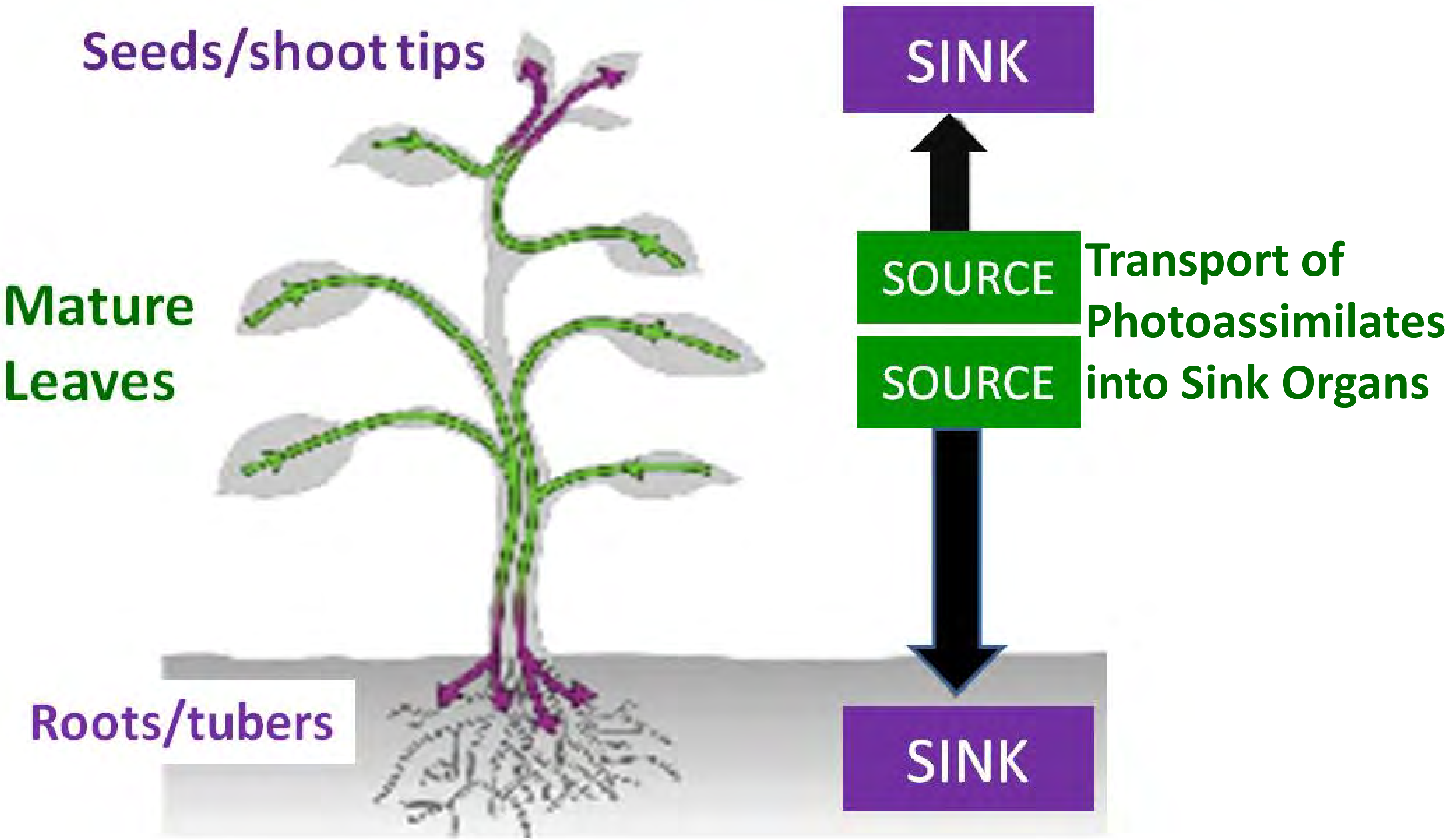
Bednarz, et al. 1998, Environ. Exp. Bot. 39: 131-139


# Translocation of Photoassimilates within Plants and Role of Mineral Nutrients

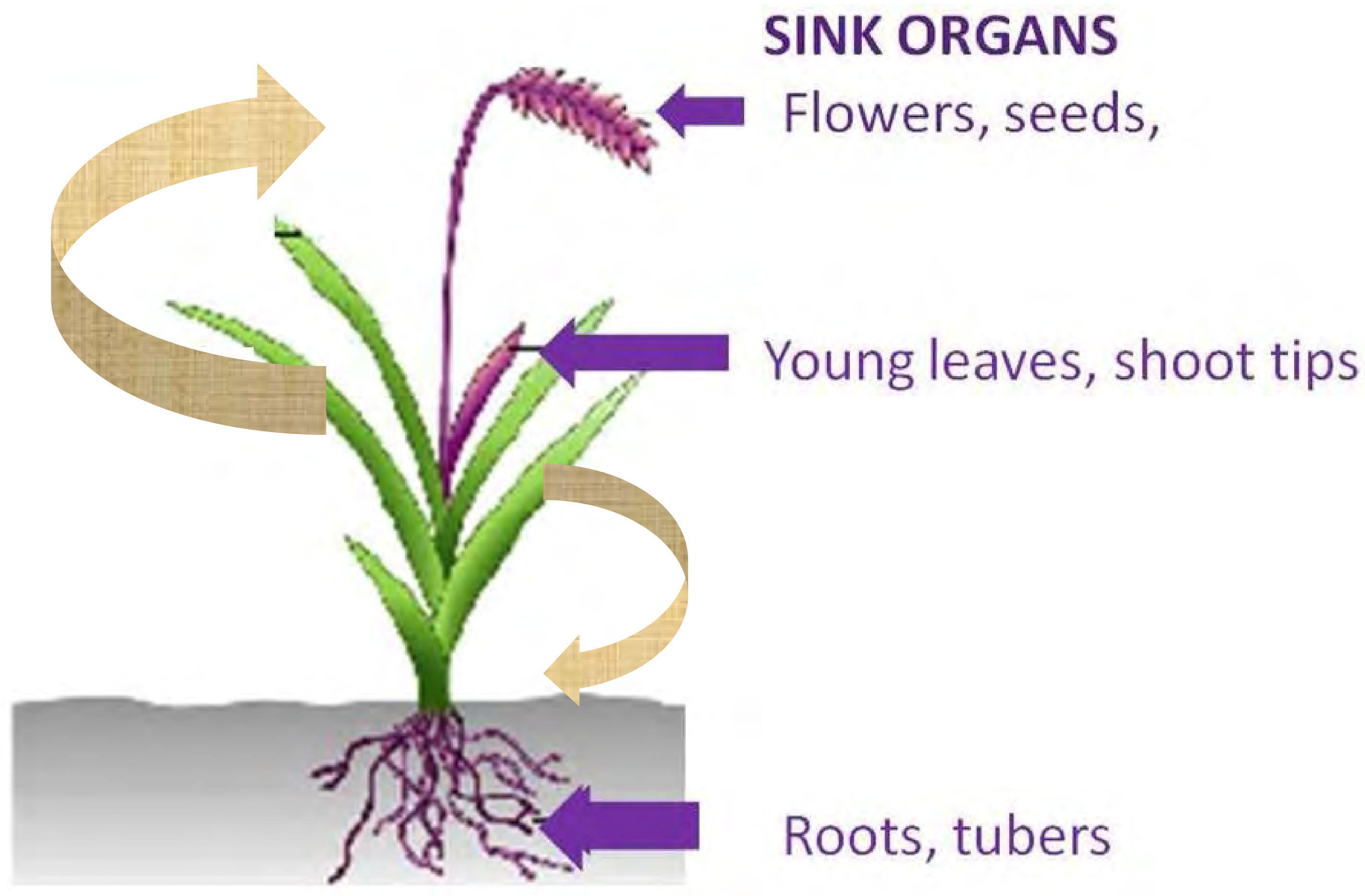



PHOTOASSIMILATES
Source
Sinks
SINK ORGANS
Flowers, seeds,
Mature
Leaves
Young leaves, shoot tips
Roots, tubers

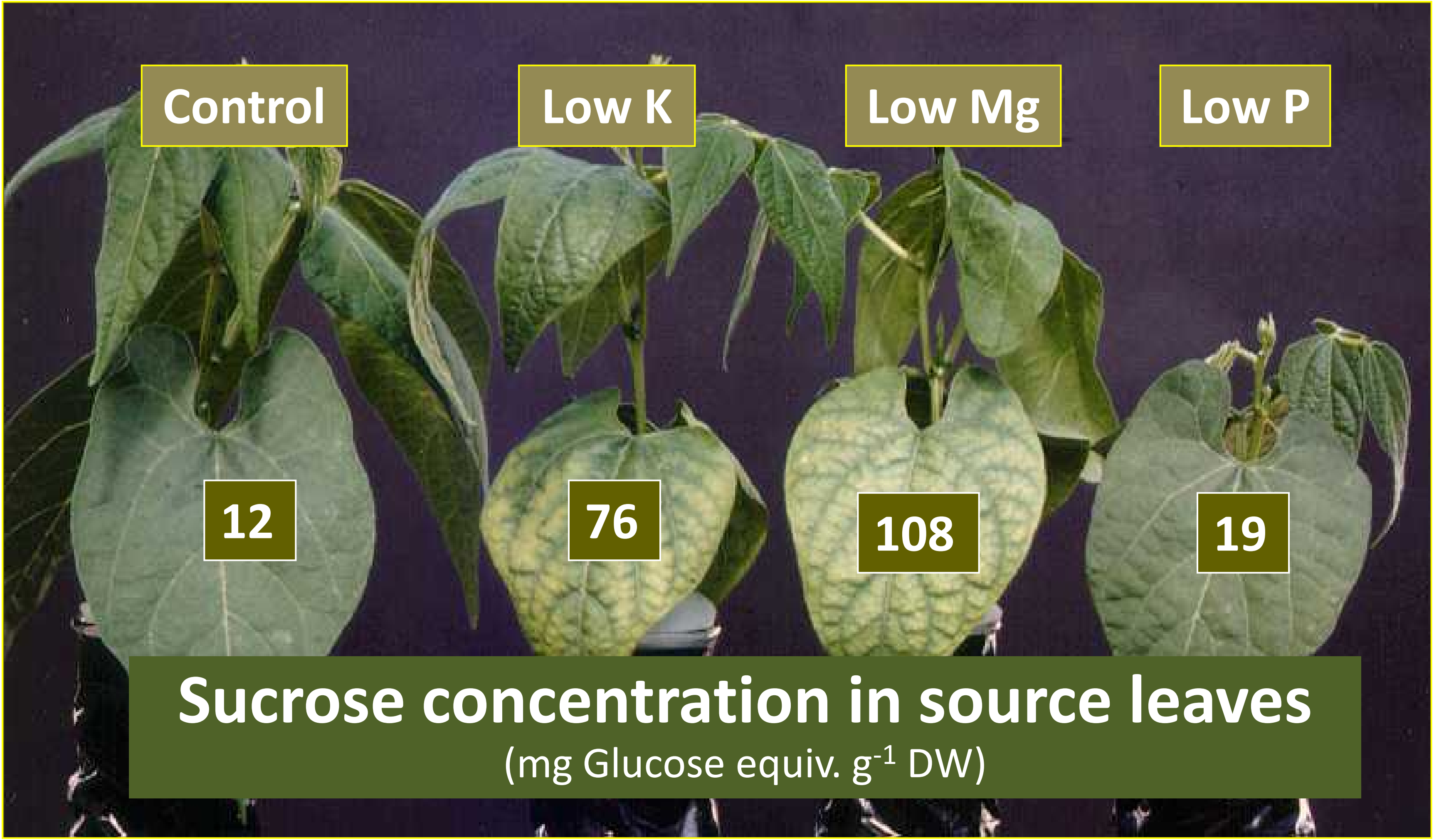
# Source leaves deliver sugar to tissues on the same end of the plant



# Transport of photoassimilates into sink organs (e.g., roots, seeds, tubers) show high dependency on adequate supply of potassium and magnesium



# Accumulation of Photoassimilates in Leaves of K and Mg Deficient Leaves



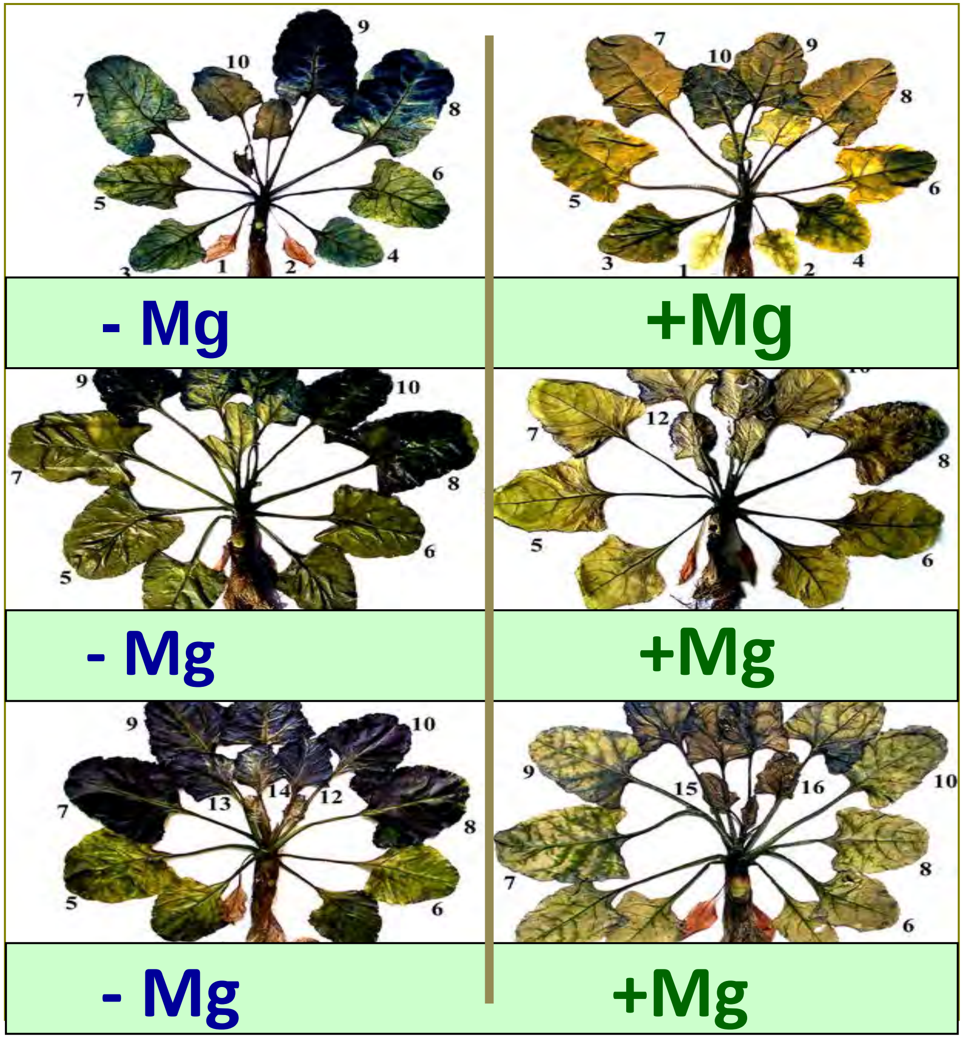

Cakmak et al., 1994b, J. Exp. Bot.


Relative distribution of total carbohydrates between shoot and roots (%)


Control | Low K | Low Mg | Low P

Cakmak et al., 1994a

# Effect of Mg deficiency on starch content in sugar beet leaves, as detected by lugol staining




Days 12

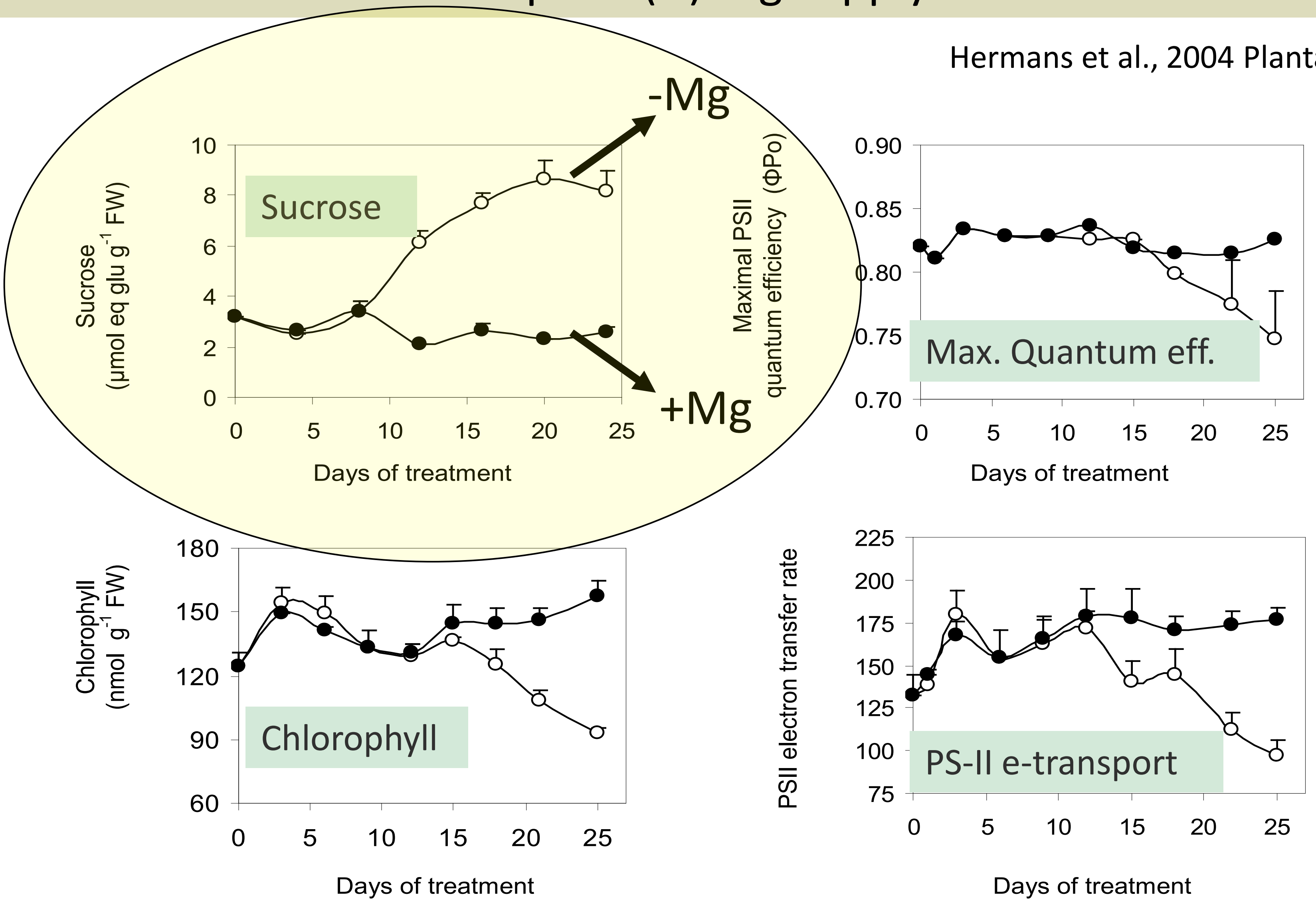
Days 16

Days 20

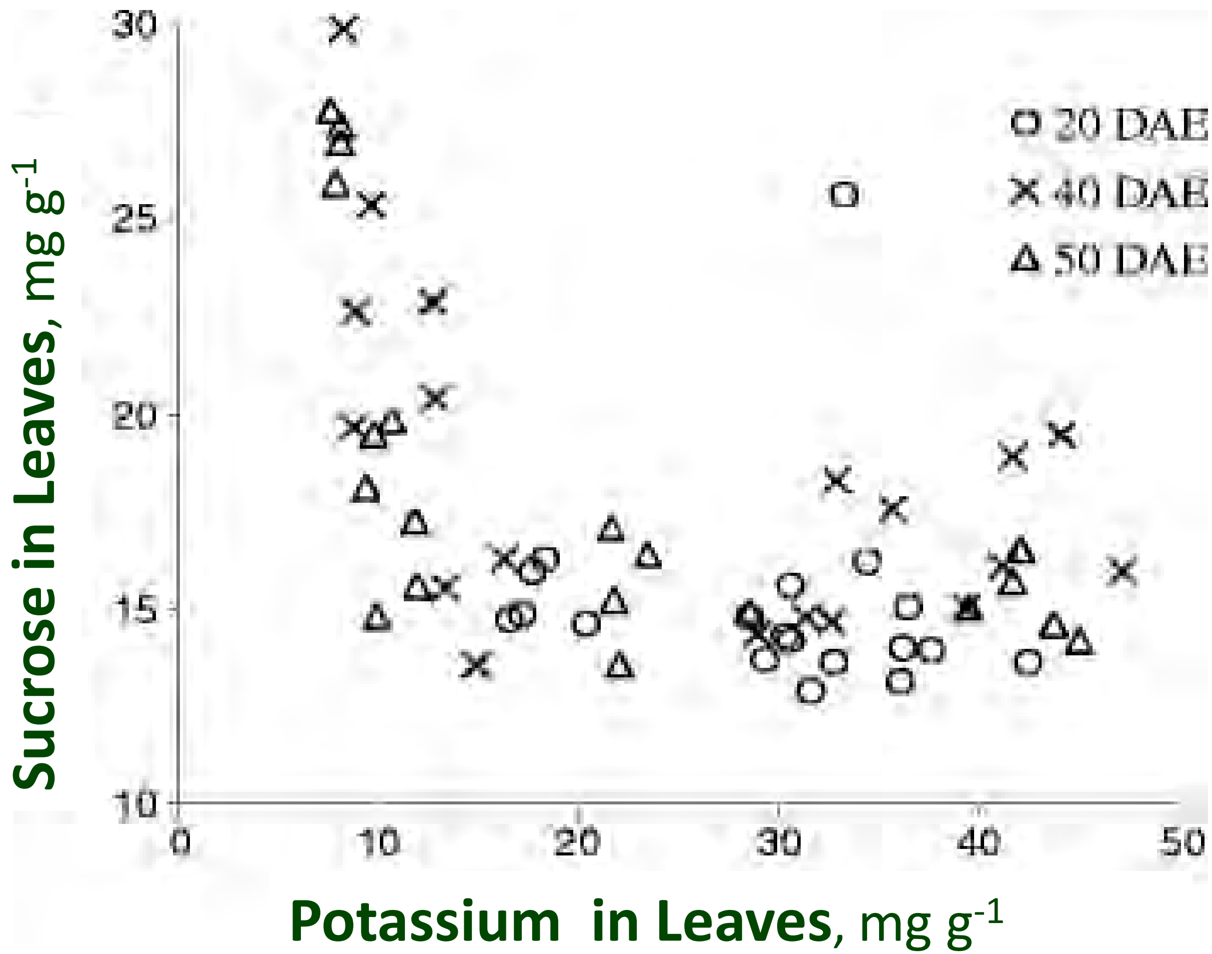
Hermans et al., 2005
Planta 220: 541-549

# Sucrose, chlorophyll and maximal quantum efficiency and electron transport rate of PSII in sugar beet plants with deficient (O) and adequate ( ) Mg supply.

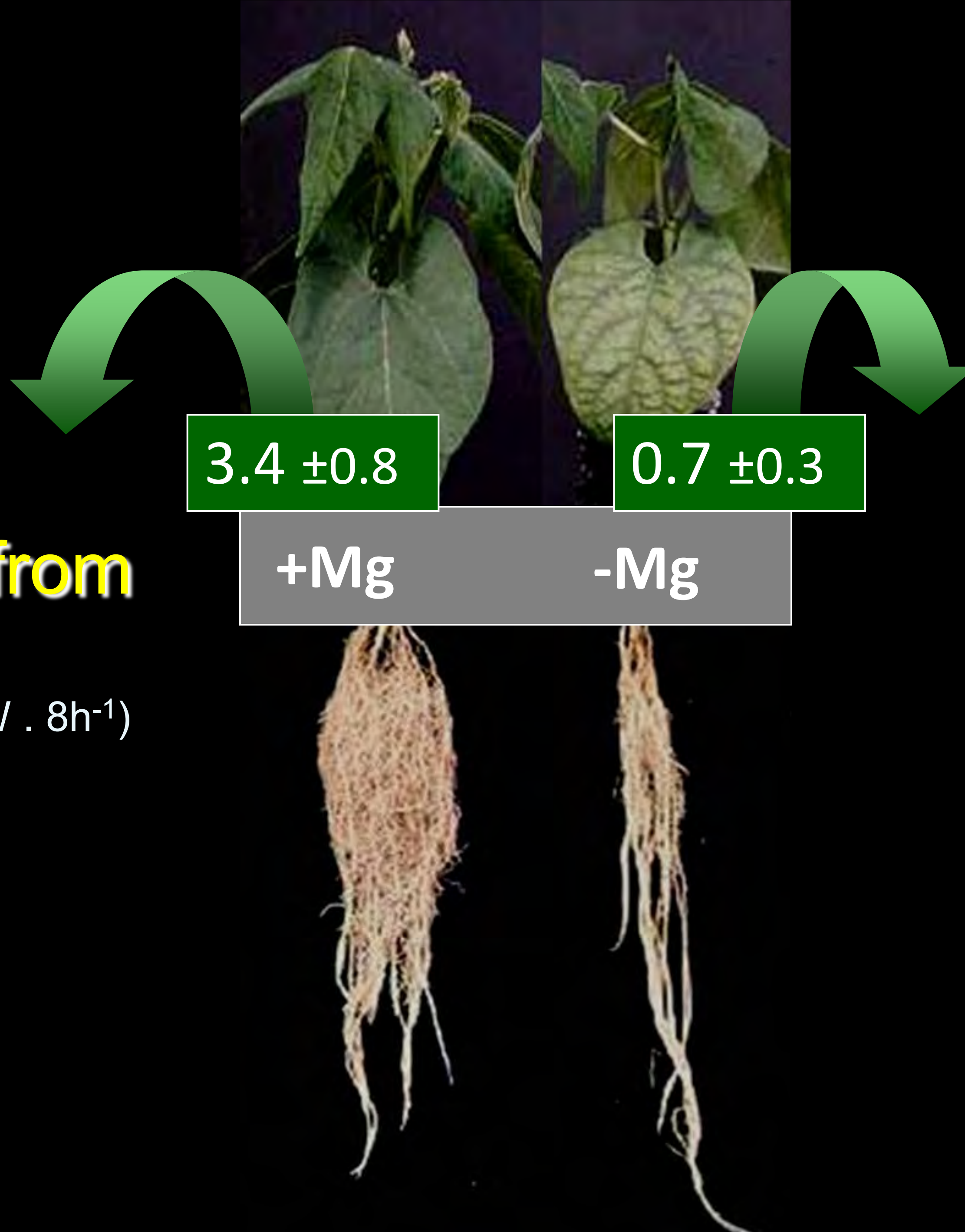
Hermans et al., 2004 Planta



# Relationship between sucrose and potassium concentrations in the first expanded leaves of cotton




Gerardeaux et al., 2009,
Plant Soil: 324, 329-343

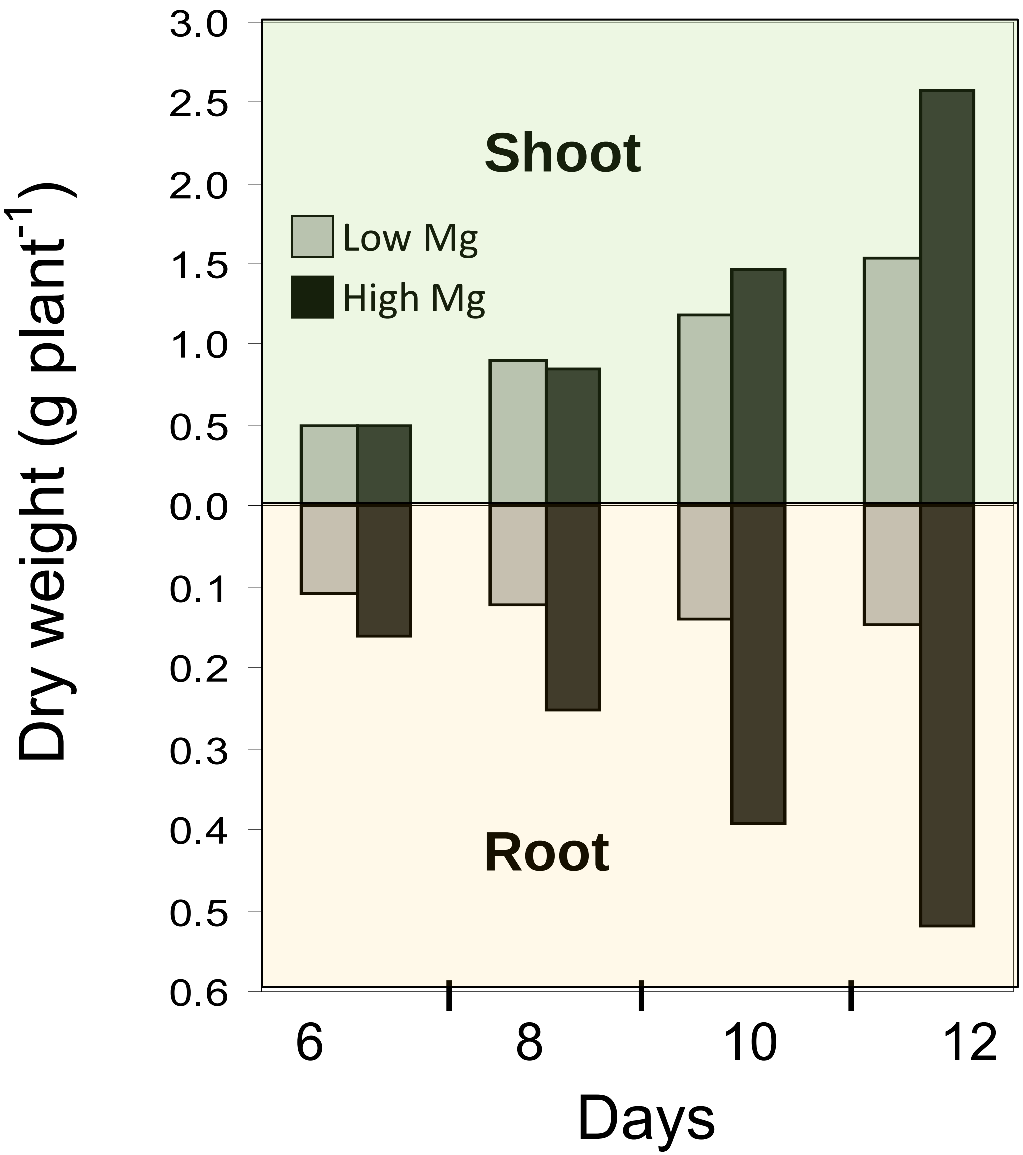



# Sucrose export from Leaves

(mg Glucose equiv . g-1 DW . $8h^{-1}$)

Cakmak et al., 1994b J. Exp Bot.

# Shoot and root dry weight of bean plants with deficient and adequate Mg supply




Before any visible change occurs in shoot, root growth is impaired under low Mg supply.

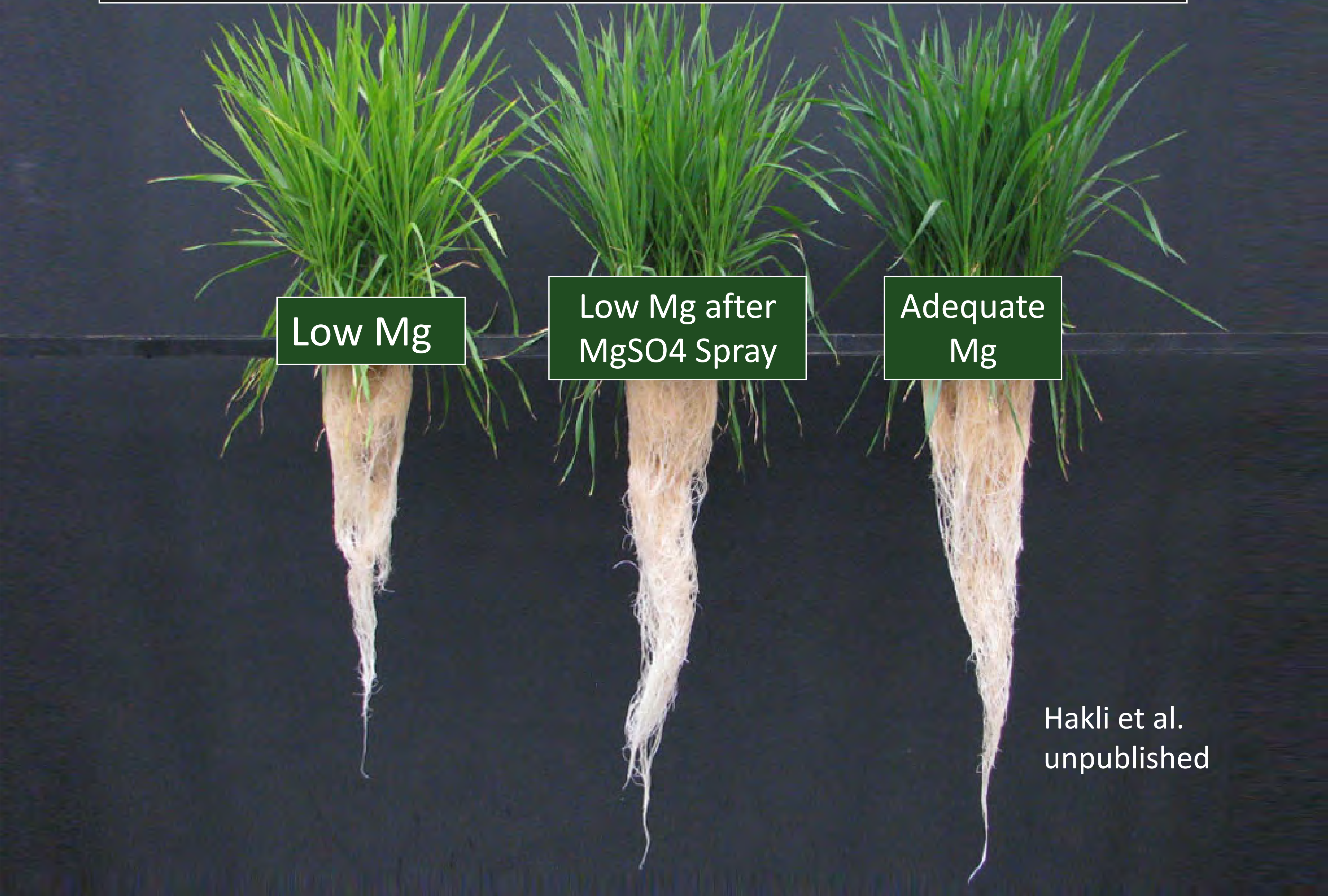
In field, impaired root growth under low Mg supply is not recognised !!

Cakmak et al., 1994a J. Exp Bot.

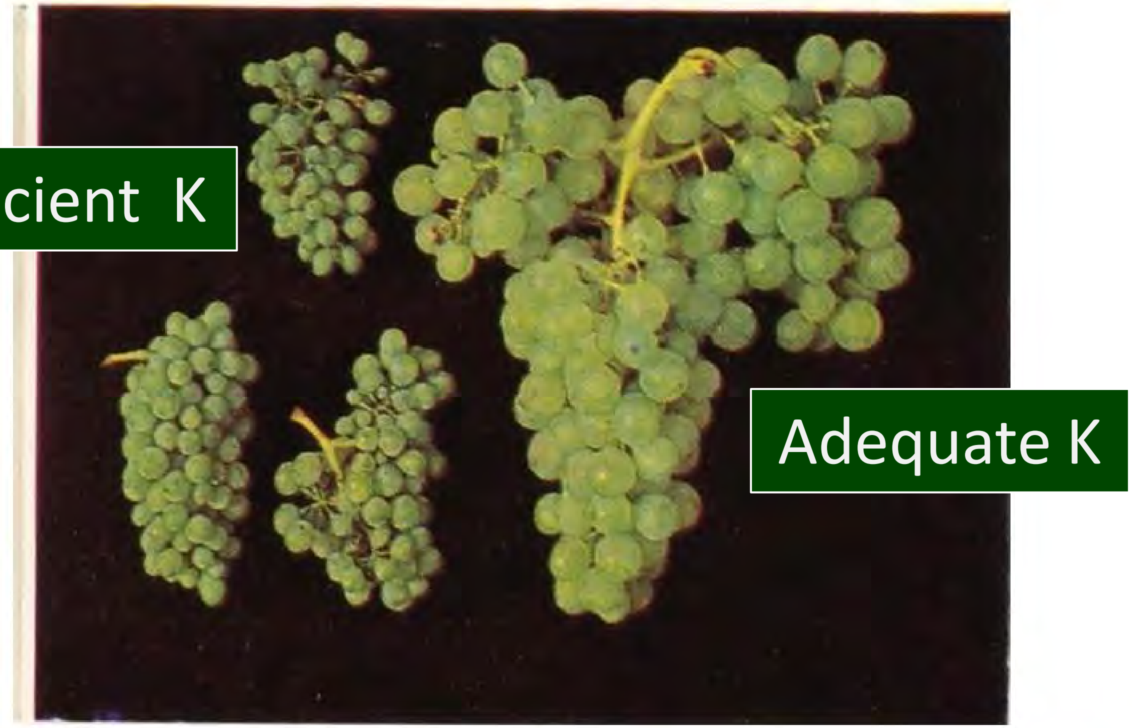
# Effect of Mg on Root and Shoot Growth in Wheat

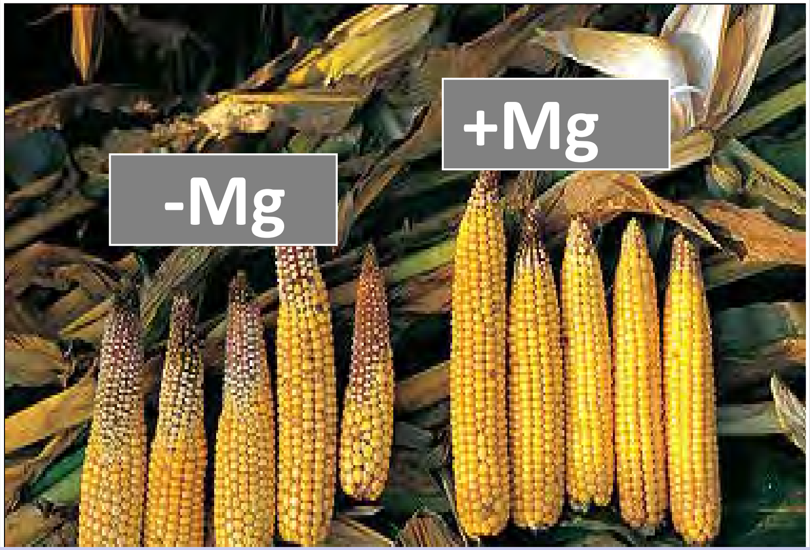

Hakli et al.
unpublished

# Effect of Mg on Root and Shoot Growth in Wheat

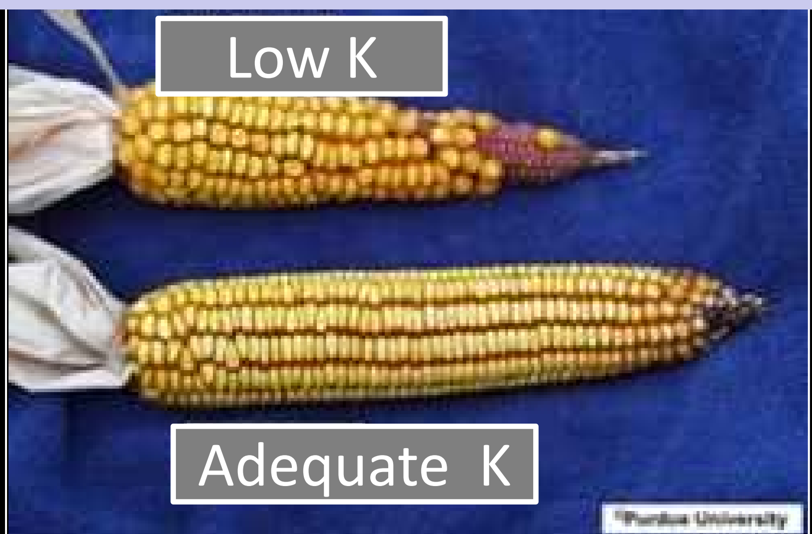


**Sink Organs are very sensitive to K and Mg deficiencies**




# Sink Organs are very sensitive to K and Mg deficiencies





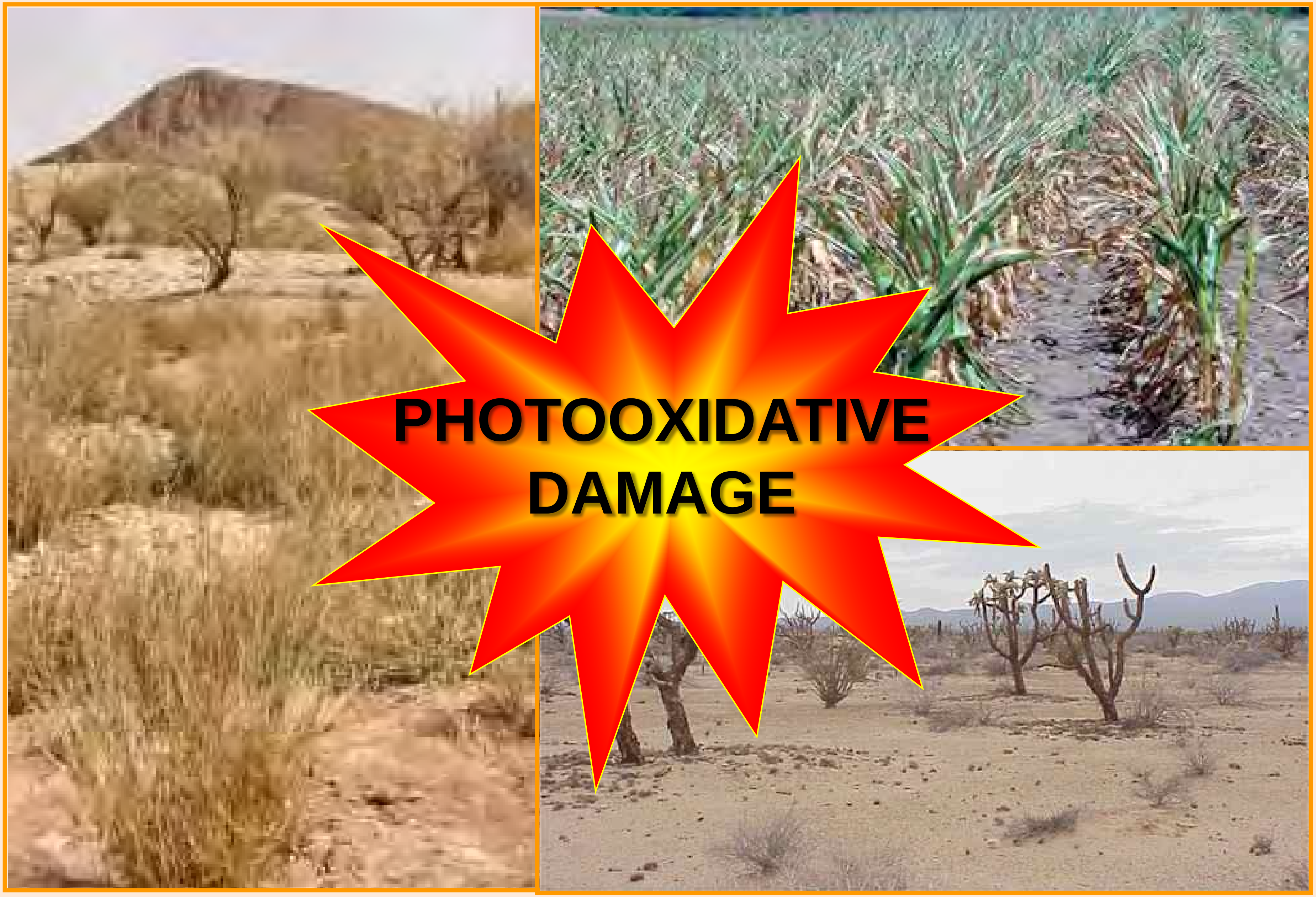
Cakmak and Kirkby, 2008, Physiol. Plant.

**Video Film**

Root growth with low and adequate Mg Suypply

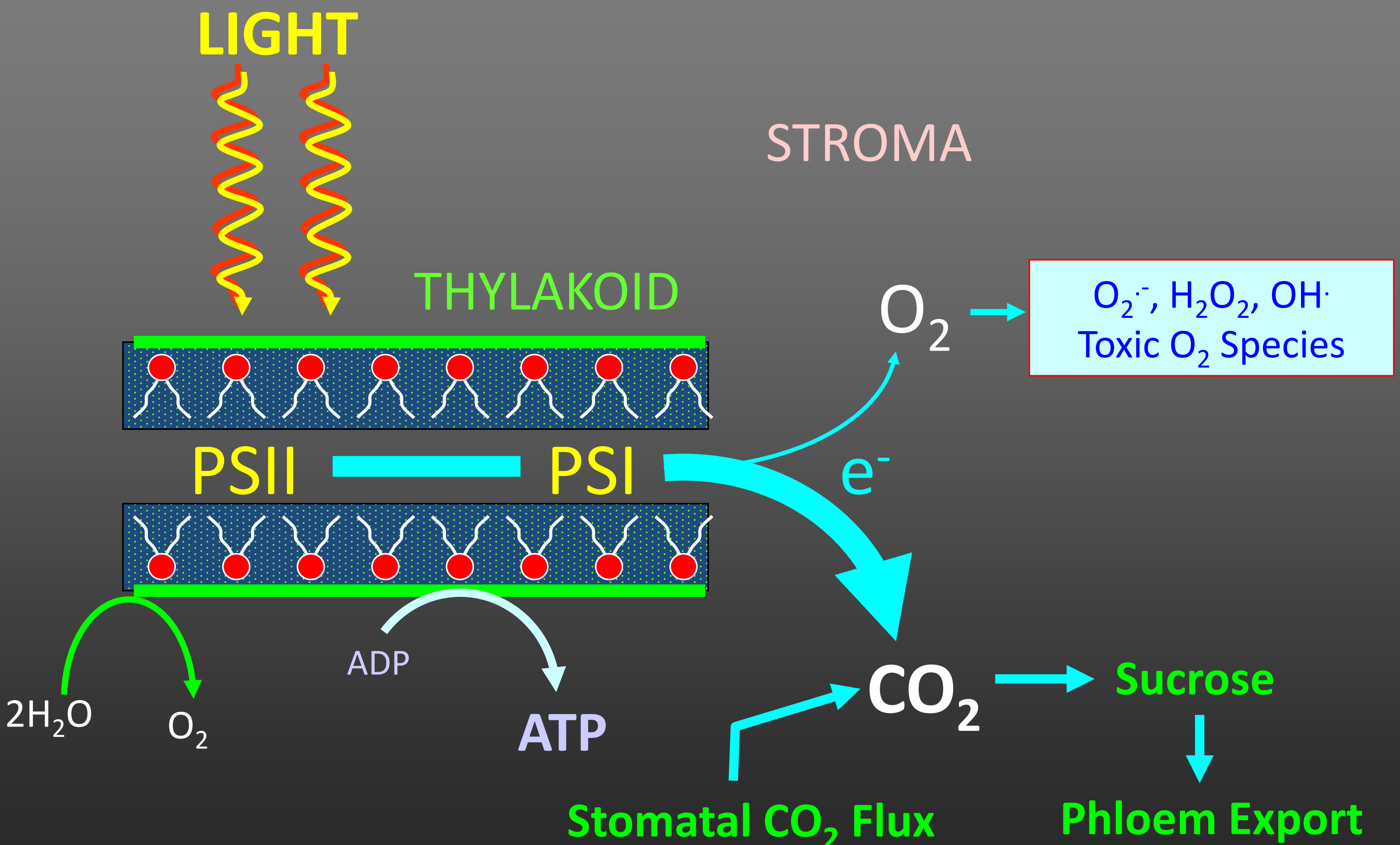
## Some Conclusions Regarding K and Mg Effect on Sugar Transport

- As a consequence of impaired carbohydrate translocation, roots of K and Mg deficient plants are much smaller. Reduced root growth under K or Mg deficiency will result in a limited nutrient and water uptake.
- A high K and Mg status of leaves is needed for adequate photo-assimilation and re-translocation of photoassimilates into seeds/roots. This is of particular relevance under conditions of inhibited root uptake of Mg (drought, high K supply, low pH soil).
- Late foliar application of Mg and also of K (during reproductive developing stage) will guarantee an efficient re-translocation of photo-assimilates into harvest products (e.g. grains, fruits, tubers), particularly under stress conditions with inhibited Mg or K uptake (e.g. drought, low pH)


PHOTOOXIDATIVE
DAMAGE

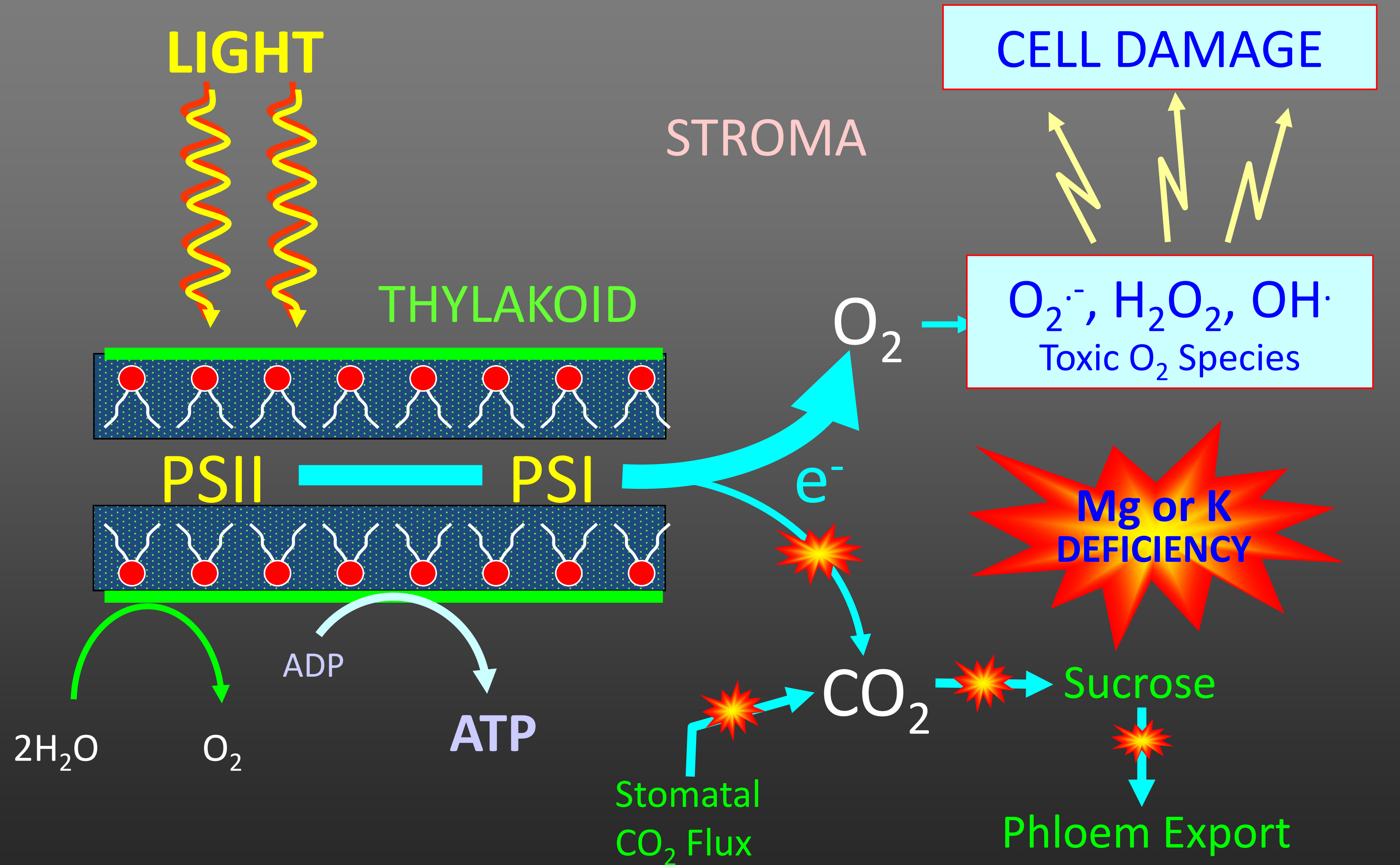
# PHOTOOXIDATIVE DAMAGE UNDER MINERAL NUTRIENT DEFICIENCY

# REMEMBER: Photosynthetic Electron Transport and Use of Light Energy in CO2 Fixation



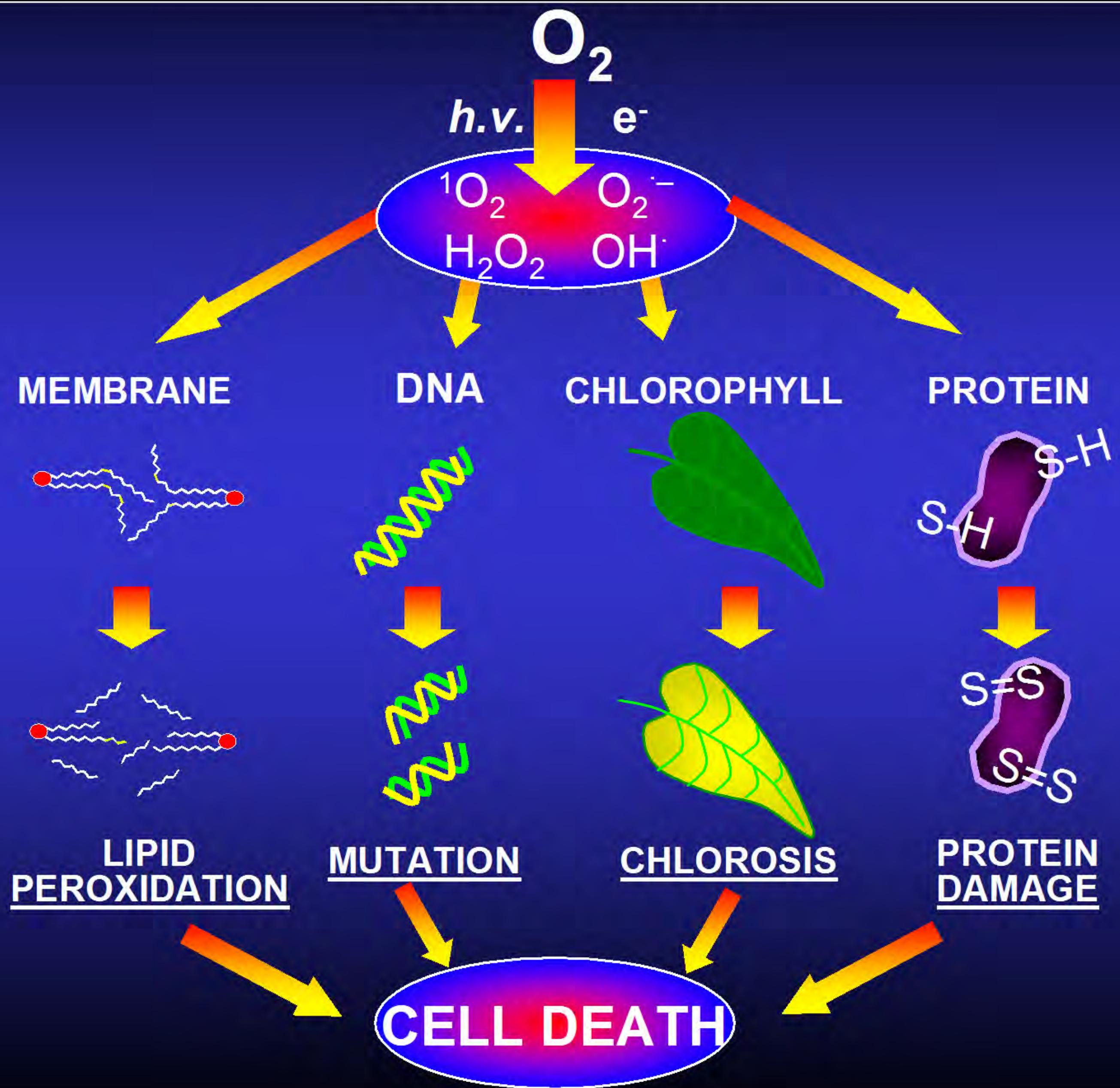

Cakmak, 2005; Soil Sci. Plant Nutr.

# Photosynthetic Electron Transport and Superoxide Radical Generation

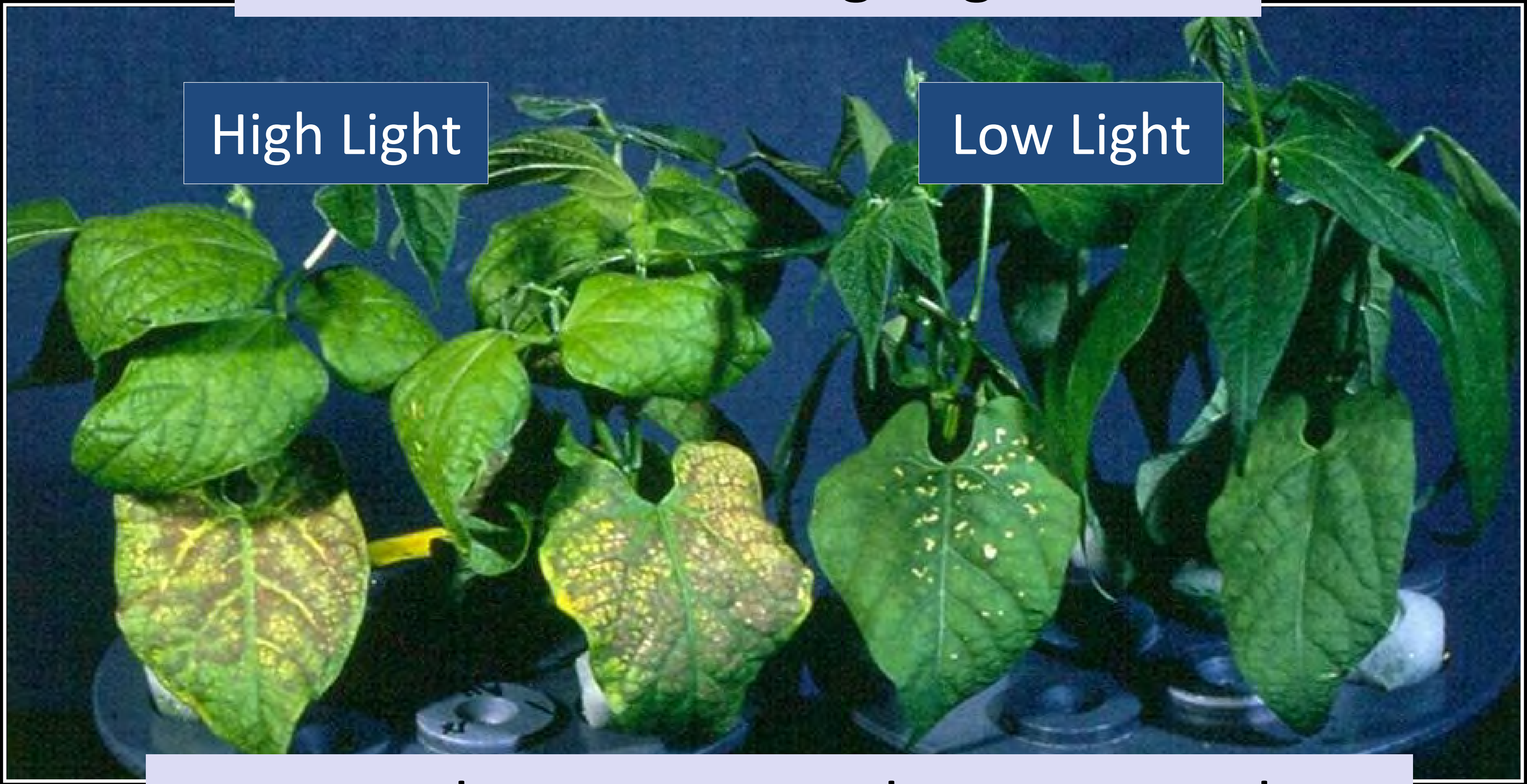



Cakmak and Kirkby, 2008 Physiol. Plant

# FREE RADICAL DAMAGE TO CRITICAL CELL CONSTITUENTS

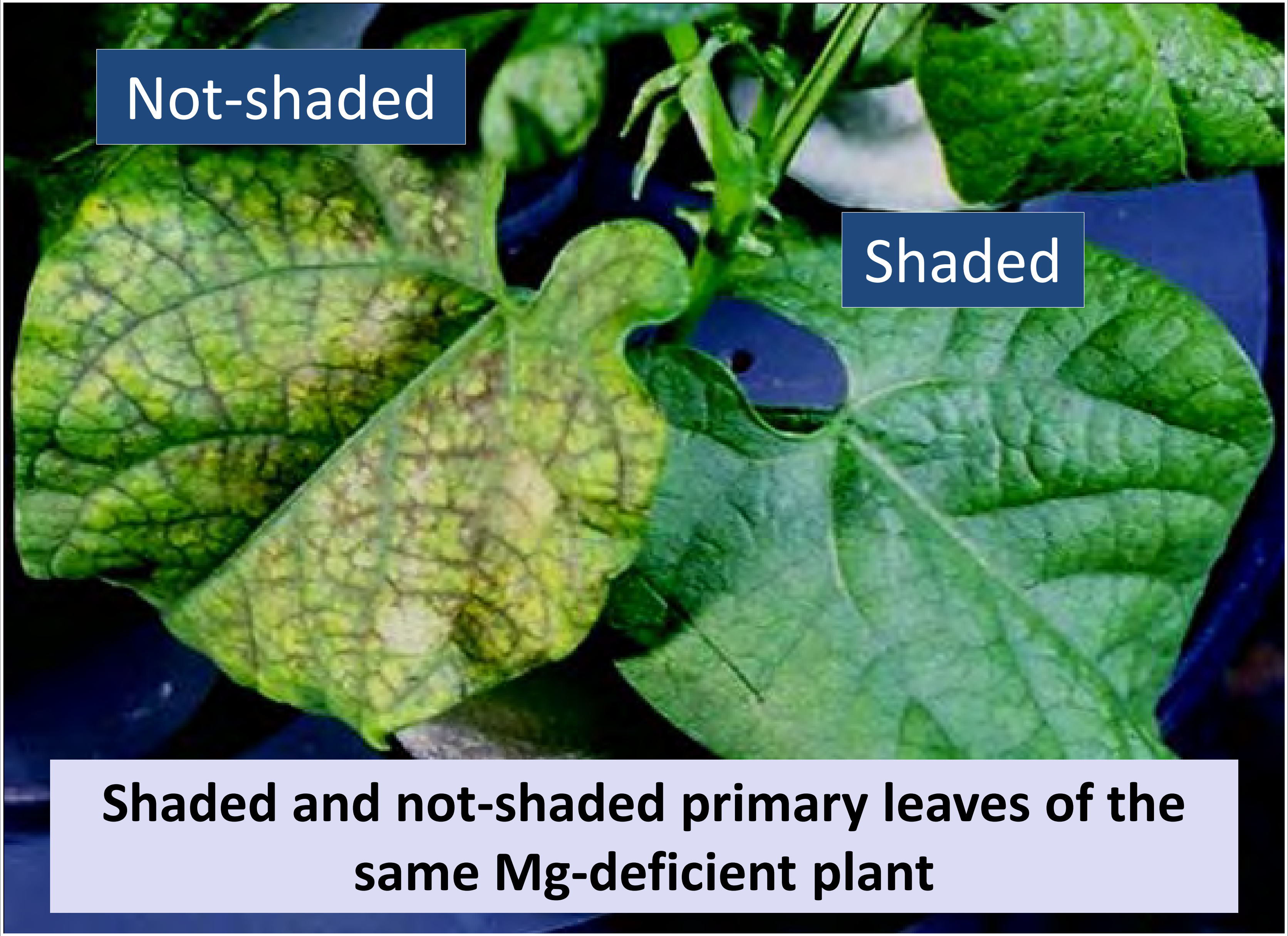


# Mg-deficient plants highly sensitive to high light




Bean plants grown at low Mg supply

Cakmak and Kirkby, 2008, Physiol Plant




**Shaded and not-shaded primary leaves of the same Mg-deficient plant**

Cakmak and Kirkby, 2008, Physiol Plant

# Partially shaded Mg-deficient leaves

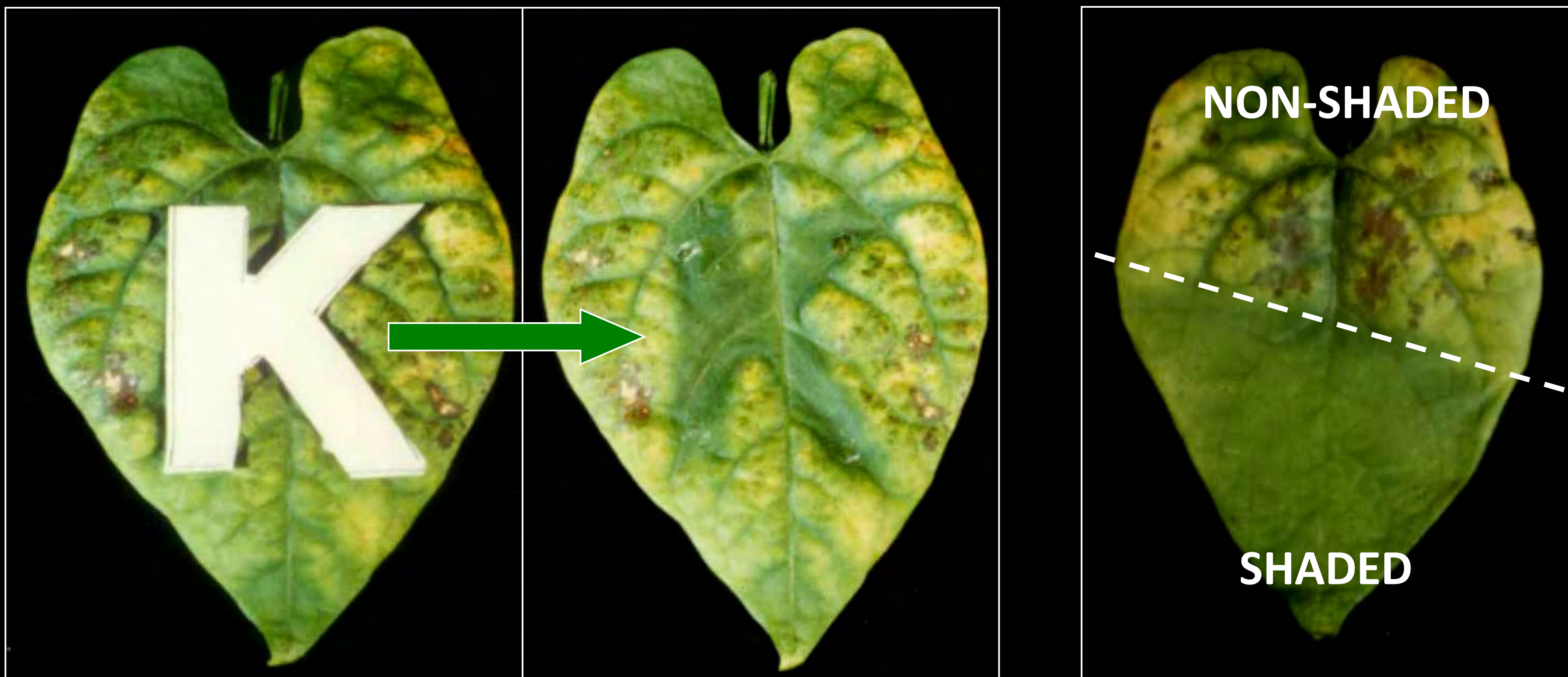
# Mg deficient plants are highly susceptible to high light intensity


Cakmak and Kirkby, 2008, Physiol Plant

# Growth of bean plants with deficient K supply under low and high light intensity

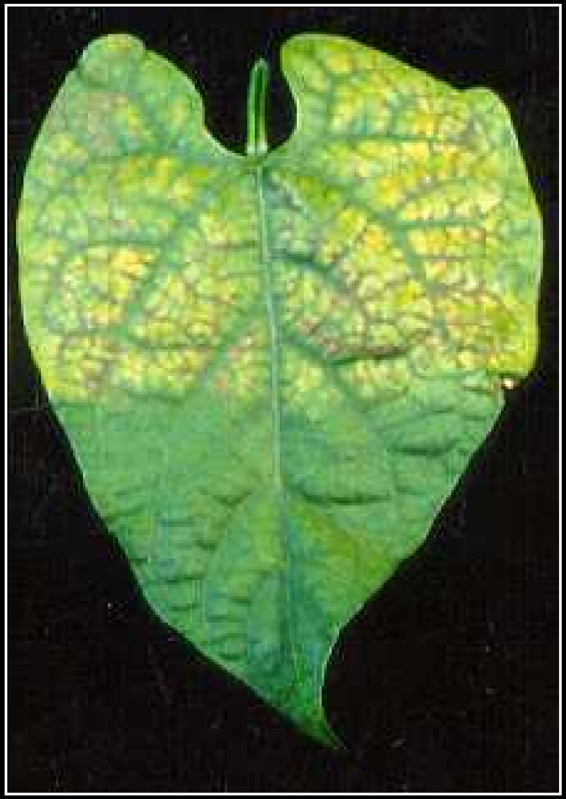

Marschner and Cakmak, 1989

# Enhancement of photooxidative damage in K-deficient leaves




**Partially shaded K-deficient bean leaves**

Marschner and Cakmak, 1989

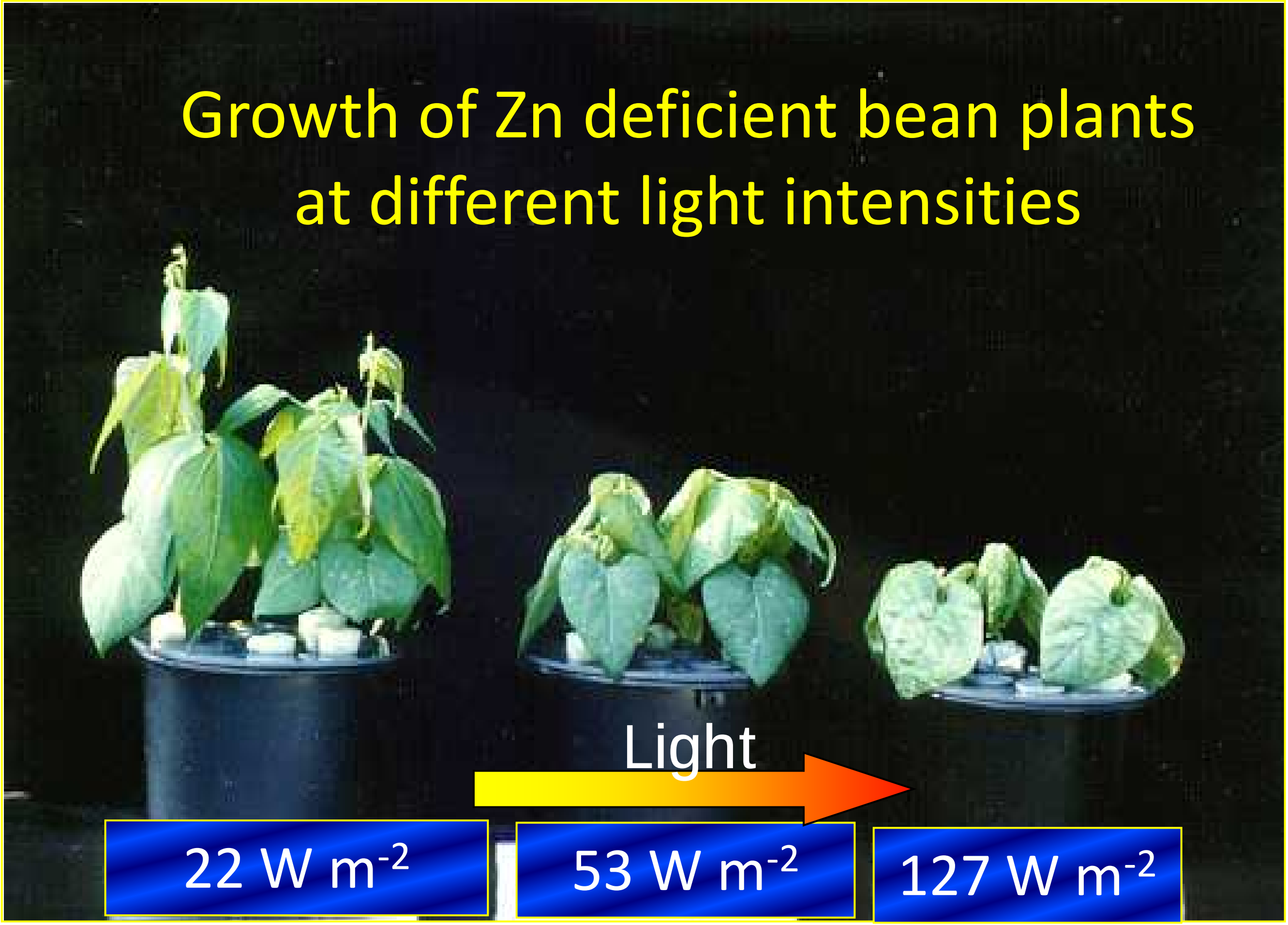


K and Mg is greatly needed for efficient use of absorbed light energy in photosynthetic $CO_2$ fixation to avoid light damage.

Plants under high light intensity have additional requirement for Mg and K in order to mitigate light damage

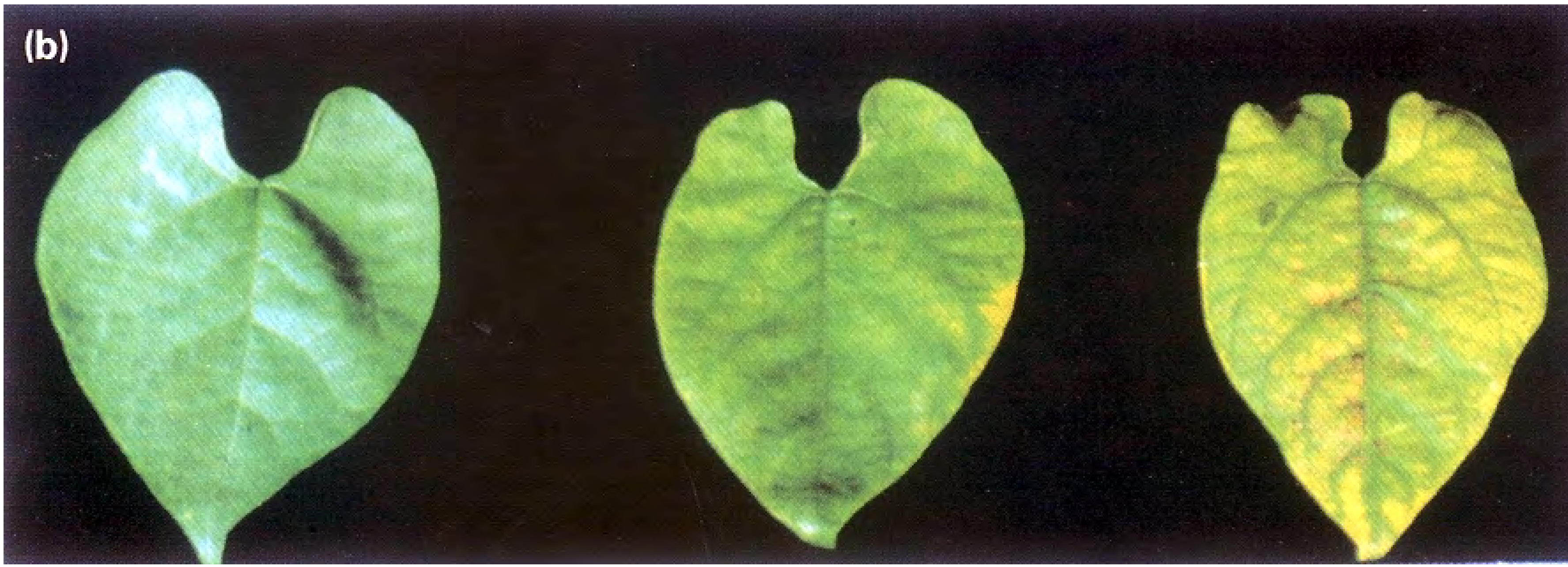
# ZINC-DEFICIENT PLANTS ARE HIGHLY PHOTOSENSITIVE

Increases in light intensity rapidly cause development of chlorosis and necrosis in Zn-deficient plants




Cakmak, 1988: PhD Thesis, Stuttgart-Hohenheim Univ.

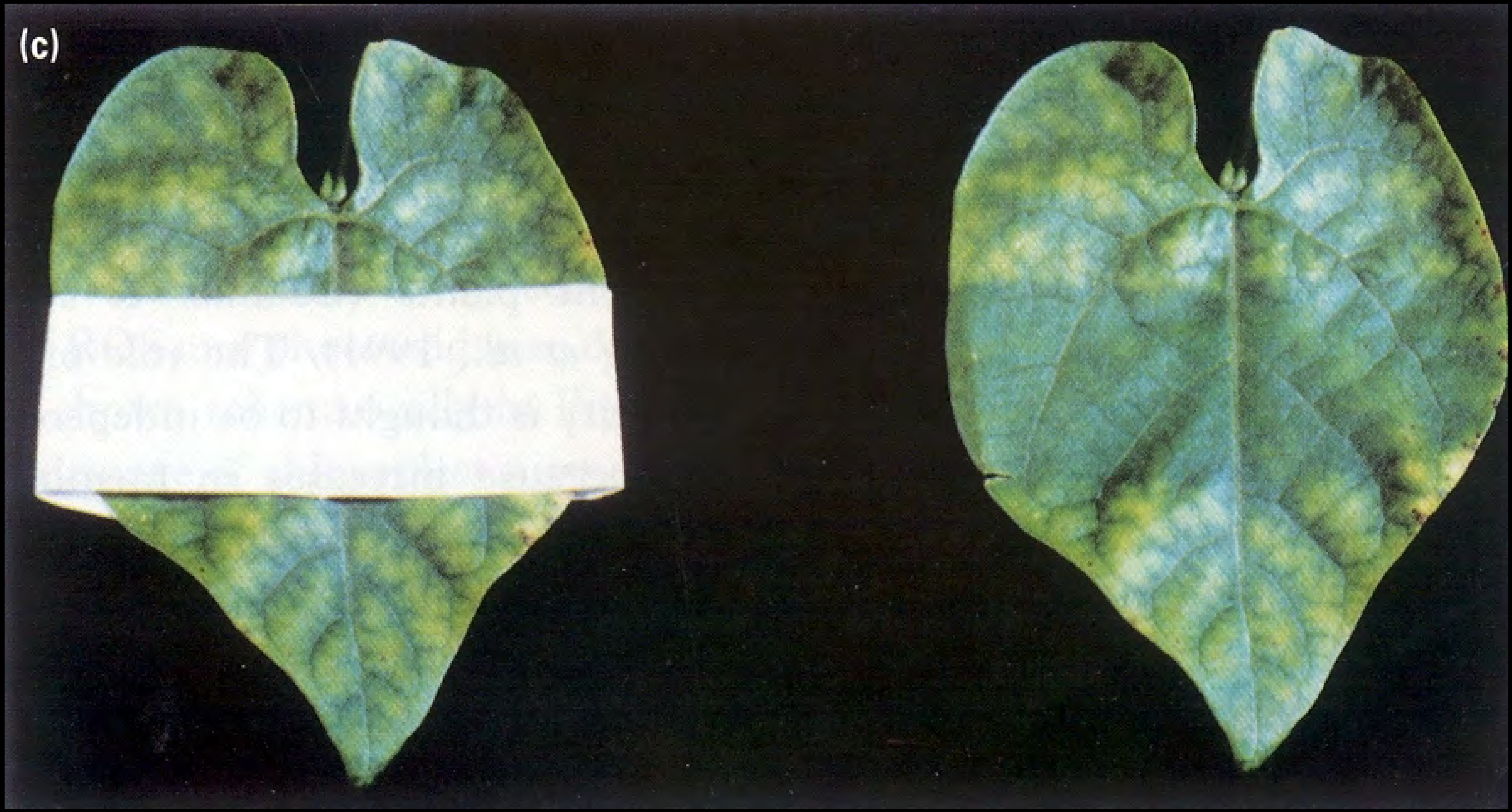
# Primary leaves of Zn-deficient bean plants grown at different light intensities




80 µmol $m^{-2}$ $s^{-1}$ | 230 µmol $m^{-2}$ $s^{-1}$ | 490 µmol $m^{-2}$ $s^{-1}$

Cakmak, 2000; New Phytologist, 146: 185-205

# Zinc Deficiency Makes Plants Susceptible to High Light




Cakmak, 2000; New Phytologist, 146: 185-205

# Zn Deficient Plants are Highly Susceptible to Zn Deficiency

**Marschner and Cakmak, 1989, J. Plant Physiol**
Cakmak, 2000; New Phytologist, 146: 185-205

# Zn Deficiency chlorosis in citrus tress occurs mostly on sunny side of trees

# **Micronutrients:** Why are micronutrients of great importance?

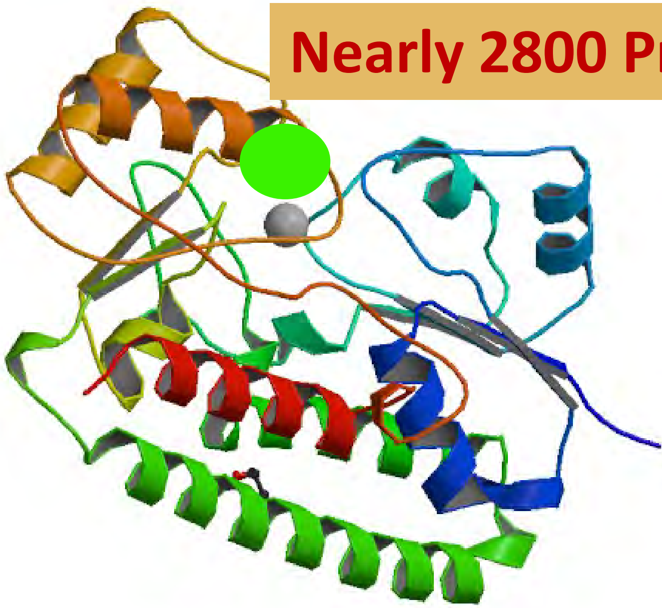
- In many different agro ecosystems micronutrients are growth limiting, and this problem is often hidden
- Micronutrients can play an important role in abiotic and biotic stress resistance (especially resistance against diseases, drought or heat).
- Micronutrients play a particularly important role in reproductive growth (e.g., in pollination)
- Micronutrients are of great importance for plant, human and animal health

# Major Functions of Plant Micronutrients

- Constituents of cell walls and membranes: B, Zn
- Constituents of enzymes: Fe, Mn, Cu, Ni
- Activation of enzymes: Zn
- Involvement in electron transport in photosystems: Fe, Cu, Mn, (Cl)
- Involvement in stress tolerance: Mn, Zn, Mo...
- Involvement in reproductive growth (flower induction, pollination, fruit set...): Cu, Mn, Zn, B
- Human Nutrition: Zn, Fe, Se, I

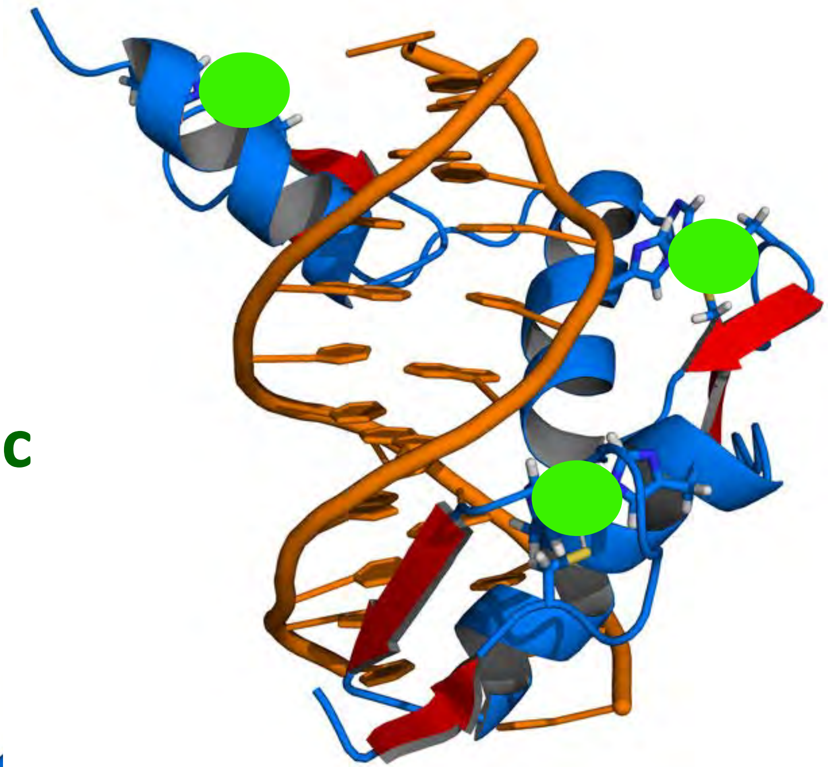
# Zinc Binding Proteins

## Nearly 2800 Proteins are Zn-dependent

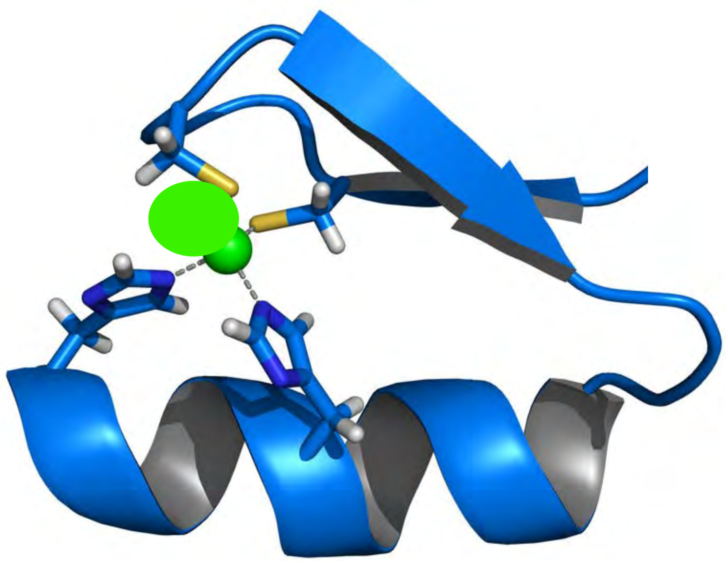


Nat.Struct.Biol. **6:** 628-633

: Zinc

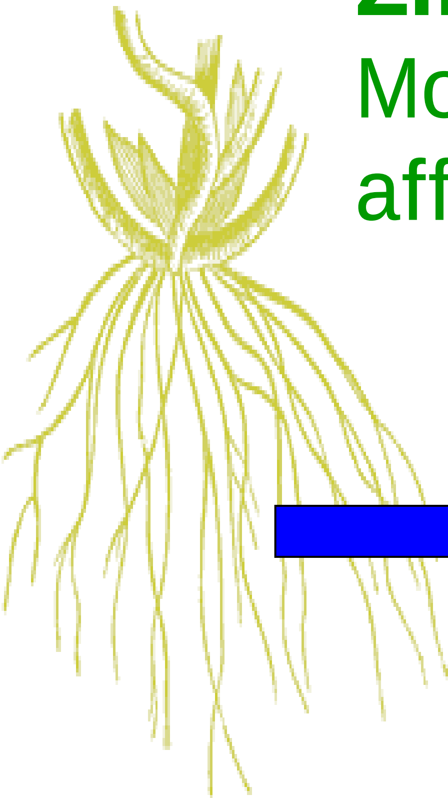


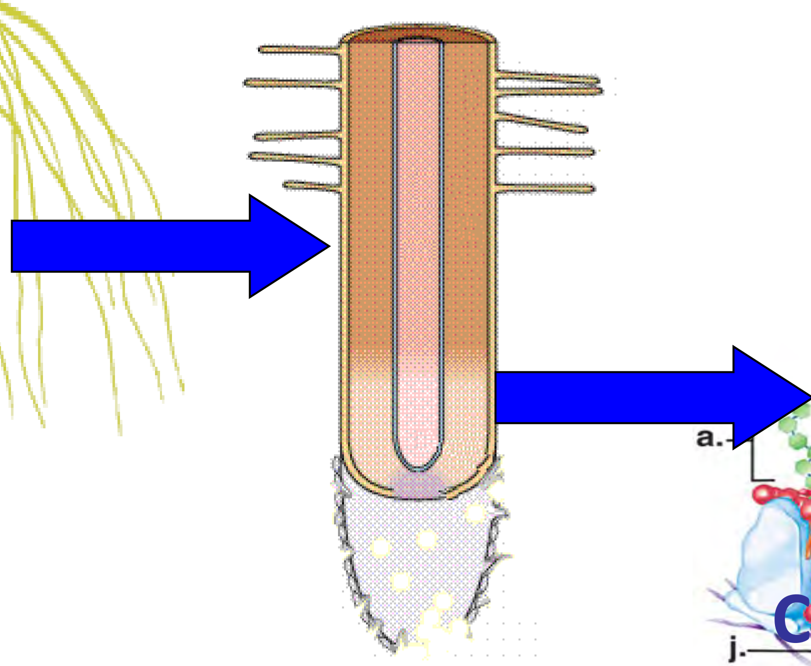
http://commons.wikimedia.org/wiki/User:Splette



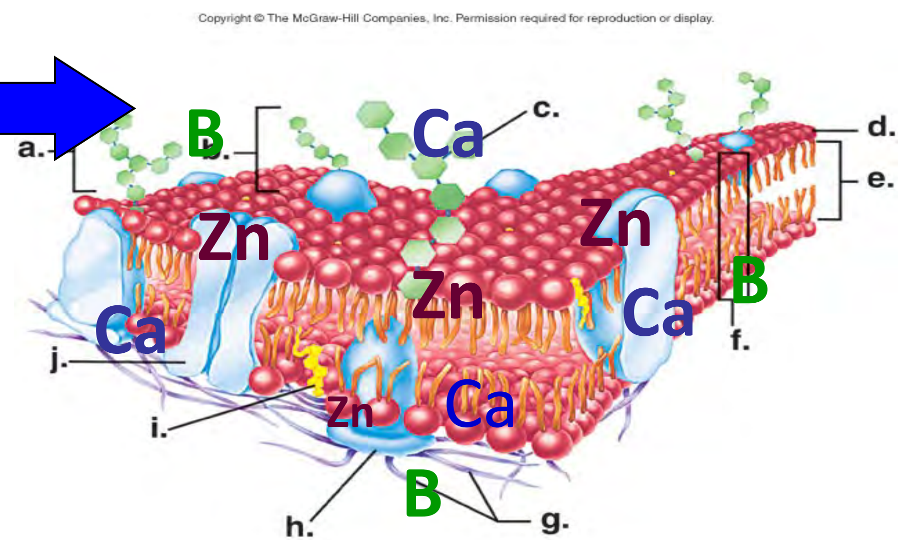
# Zinc and Boron:

Most important micronutrients affecting membrane stability





Cell Membrane



## Physiological functions of Zn in plant metabolism

Besides its basic well established function in plant metabolism, Zn plays a specific role in:

**1) pollination**

2) **mitigation of biotic and abiotic stresses** such as drought, heat, high light intensity or pathogen pressure via detoxification of toxic oxygen radicals

3) Involvement in **disease resistance**

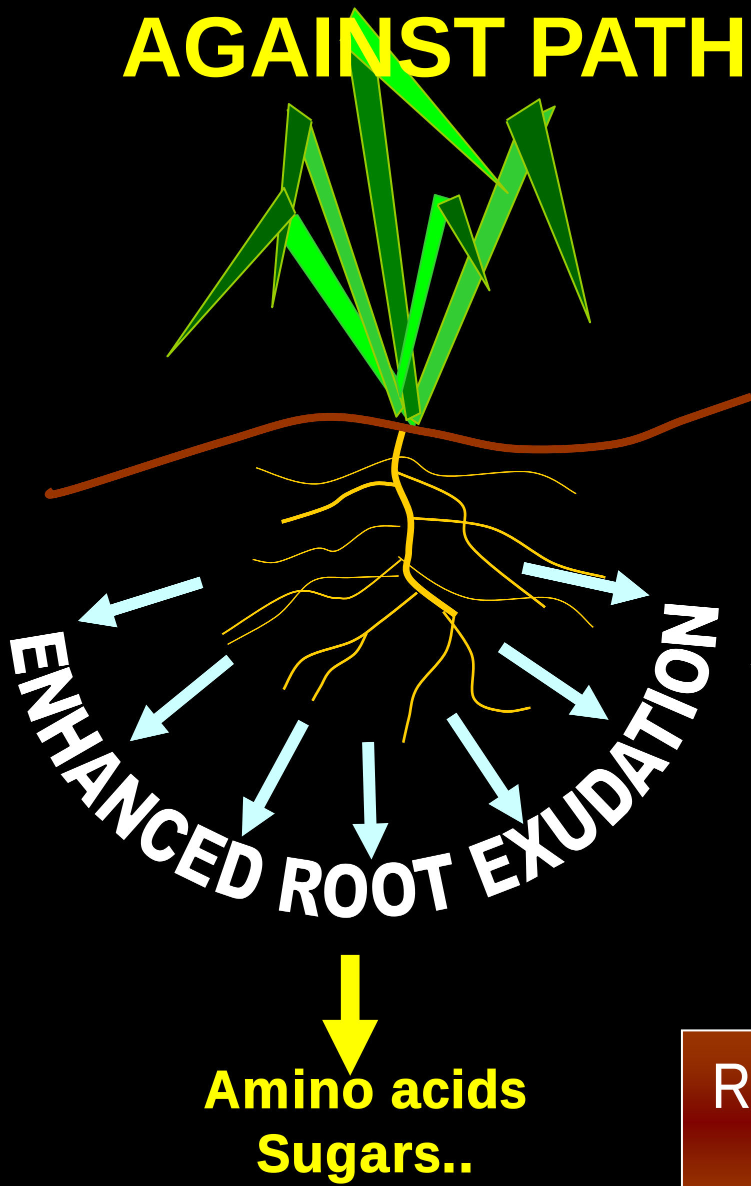
4) Involvement in **seed viability**

**Due to structural impairments in cell membranes under Zn or B deficiency**

# Zinc or Boron Deficient Roots are Leaky:

Various carbon-containing compounds are released from roots into the surrounding soil that is rich in fungal and bacterial populations

# ZINC and BORON PROVIDES RESISTANCE AGAINST PATHOGENIC INFECTION




Zinc or B is highly needed for structural and functional integrity of cell membranes

Any impairment in structural integrity of cell membranes induces membrane permeability and extensive release of exudates

ROOT EXUDATES: feeding substrates for pathogens

# Root exudation of organic compounds in cotton, wheat and apple at low (-Zn) and adequate (+Zn) Zn supplies

| 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.

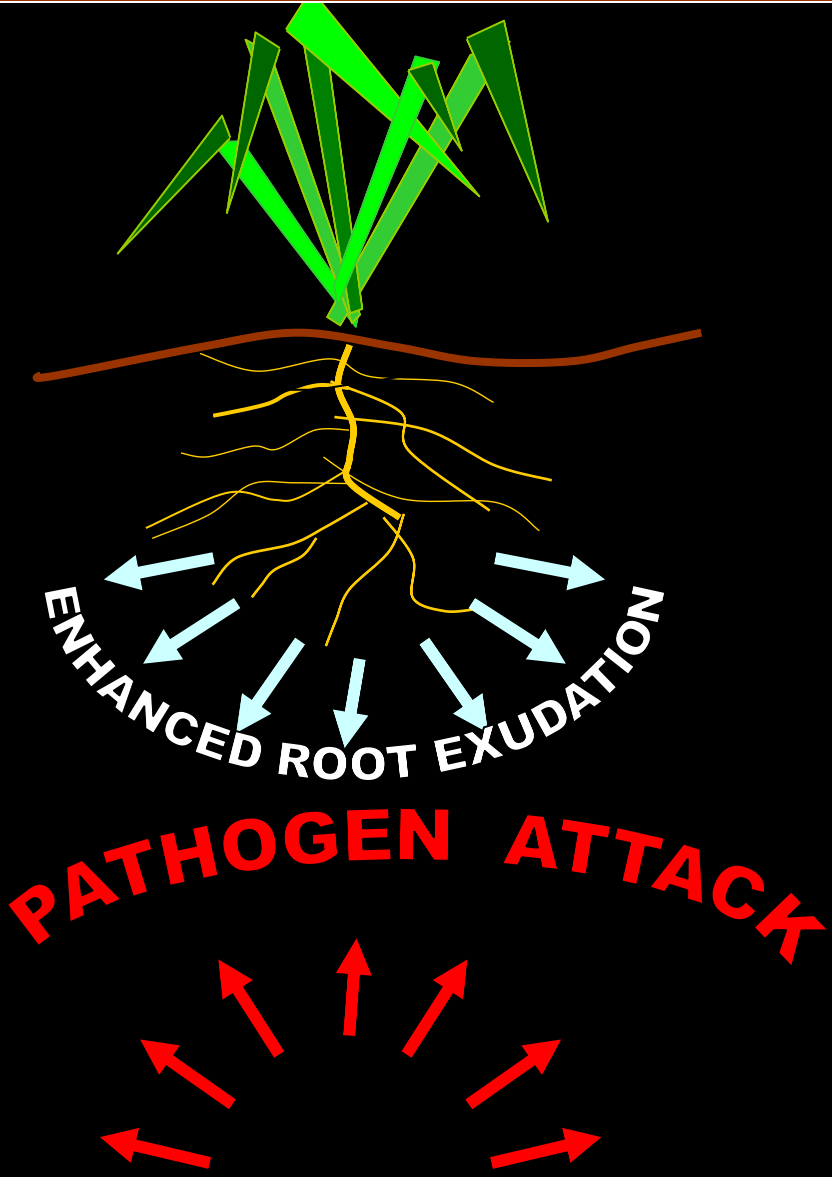
# Boron Deficiency-Induced Membrane Permeability

**Leakage of $K^+$, sucrose, phenolics and amino acids from sunflower leaves as influenced by B supply**

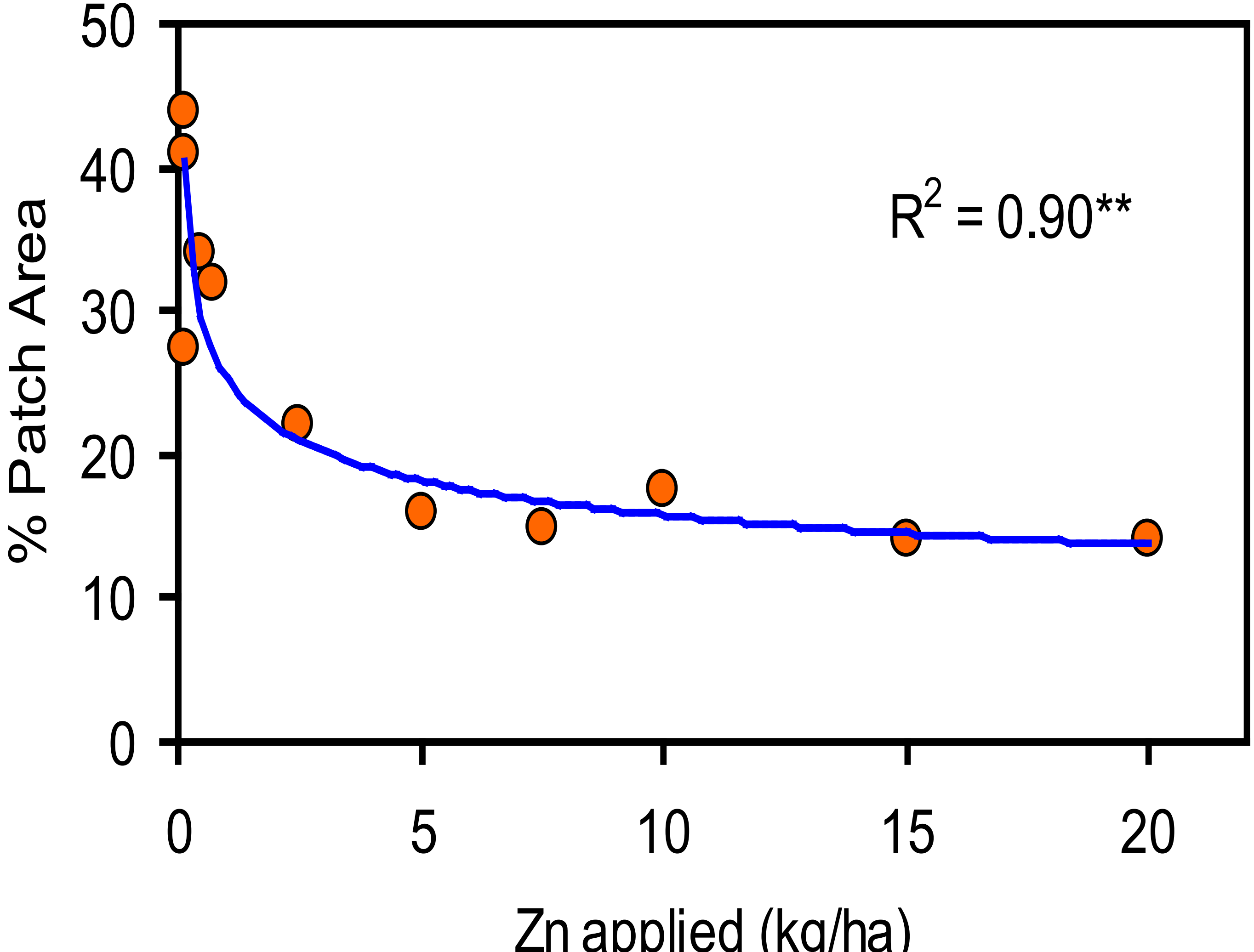
| B supply | Potassium | Sucrose | Phenolics | Amino acids |
|---|---|---|---|---|
| (µM) | | | (µg g-1 FW $[2h]^{-1}$) | |
| **0.01** | **630** | **900** | **79** | **163** |
| 0.20 | 390 | 440 | 72 | 122 |
| 1.0 | 52 | 70 | 17 | 33 |
| **20.0** | **18** | **20** | **13** | **23** |

Cakmak et al., 1995, Physiol. Plant.

# EXUDATES: Excellent feeding substrates for pathogens



# Correlation between Zn application and bare patch caused by Rhizoctonia in wheat




Thongbai et al., 1993, Plant and Soil

# Critical Roles of Micronutrients in Seed Formation

- During the transition phase from vegetative to the generative (reproductive) phase **some distinct micronutrients play specific functions in grain yield formation** through their positive impacts on pollination

**Examples**

**Transient drought spells during flowering/ pollination** results in a severe loss of grain yield through transient micronutrient  (Zn, Mn, B, Cu) deficiency in **the fast growing pollen tubes!**

# **Example Zn:** Specific high Zn demand for pollination

Effect of Zn supply on growth, grain yield, viability and Zn concentration of pollen in maize plants

| Zn supply | Shoot Dry Weight (g/plant) | Grain yield (g/plant) | Pollen viability (%) | Zn conc. in pollen (mg/kg) |
|---|---|---|---|---|
| Adequate Zinc | 74 | 70 | 85 | 75 |
| Zinc Deficiency | 67 | 18 | 20 | 27 |

Sharma et al., Plant Soil 124, 221-226; 1990

# **Example Cu:** Specific high Cu demand for reproductive growth

## Effect of Cu supply on vegetative and reproductive growth of wheat

Nambiar, Austr. J. Agric. Res. 27, 453-463; 1976

| **Cu supply** (mg Cu/pot) | **Vegetative growth** straw (g/pot) | **Reproductive growth** grains (g/pot) |
|---|---|---|
| 0 | 6.7 | 0 |
| 0.1 | 10.5 | 0 |
| 0.4 | 12.9 | 1.0 |
| 2.0 | 12.7 | 10.5 |

**Inhibited grain formation by low Cu is mainly due to low pollen viability and pollen sterility**

(Agarwala et al., Proc. Indian Nat. Sci. Acad. B 46, 172-176; 1980)

**BLIND EARS**

# **Example Mo:** Specific high Zn demand for pollination

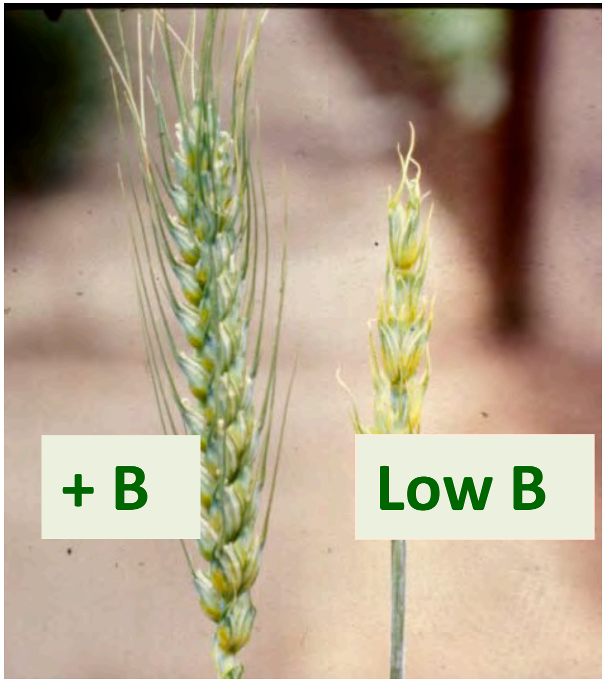
Effect of the Mo supply to maize on numbers of pollen grains and pollen germination rate (Agarwala et al., Can. J. Bot. 1978

| **Mo supply** (µg/L) | **Mo concentration of leaves** (µg/kg) | **Pollen grains** (No per anthere) | **Pollen germination** (%) |
|---|---|---|---|
| **20.00** | 92 | 2437 | 86 |
| **0.10** | 61 | 1937 | 51 |
| **0.01** | 17 | 1300 | 27 |

# **Example Boron:** Specific high **B** demand for pollination

**Effect of increasing B supply on vegetative and reproductive growth of red clover**

| B supply (mg/kg soil) | Shoot DW (g/pot) | Flowers (No/pot) | Seed yield (mg/pot) |
|---|---|---|---|
| 0 | 12.8 | 0 | 0 |
| 0.25 | 13.0 | 6 | 0 |
| 0.5 | 12.6 | 13 | 0 |
| 1.0 | 12.3 | 37 | 430 |
| 2.0 | 12.3 | 37 | 1190 |
| 4.0 | 8.7 | 34 | 740 |



(low B soil, Heilongjiang,China)

(Sherell, 1983)

**Boron deficiency limits an optimal formation of kernels and cobs.**


# Inhibited pollination and fruit set in the mutant domatoes due to inhibited B translocation.

(Nogouchi et al., 2000; Ma et al., 2004)

For fast growing tissues in which transpiration rate is low such as apices, flowers and young fruits B-delivery through phloem can be an important transport process.

# Tobacco Plants with varied B Mobility

**Wild-Type plants:**
Phloem Immobile B
**Yield: 1 g seed**

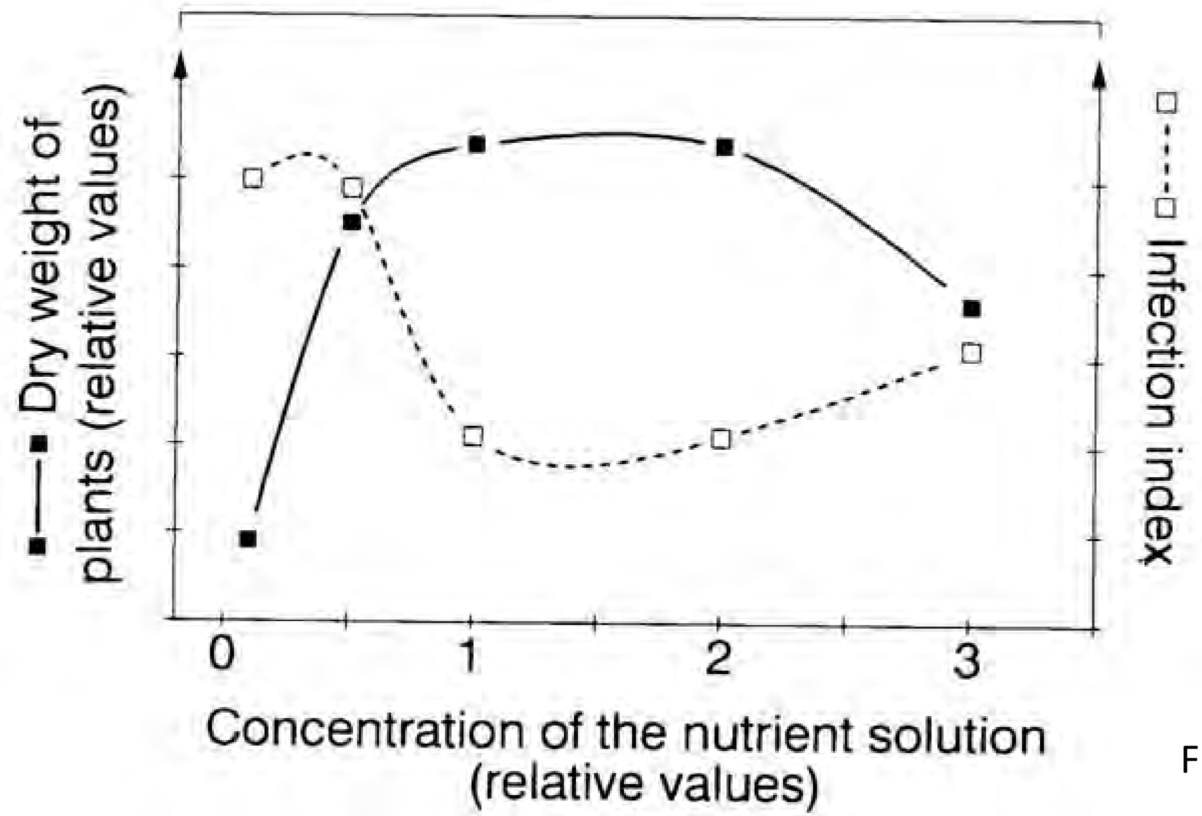
**Transgenic plants:**
Phloem Mobile B
**Yield: 21 g seed**

Courtesy: P. Brown

# Disease Tolerance and Mineral Nutrition

# Susceptibility of crop plants to pathogens is greatly affected by the nutritional status of plants

Effect of nutrient concentration on growth (non-infected plants) and on degree of a bacterial infection in *plants (relative values)*




From Marschner 1995

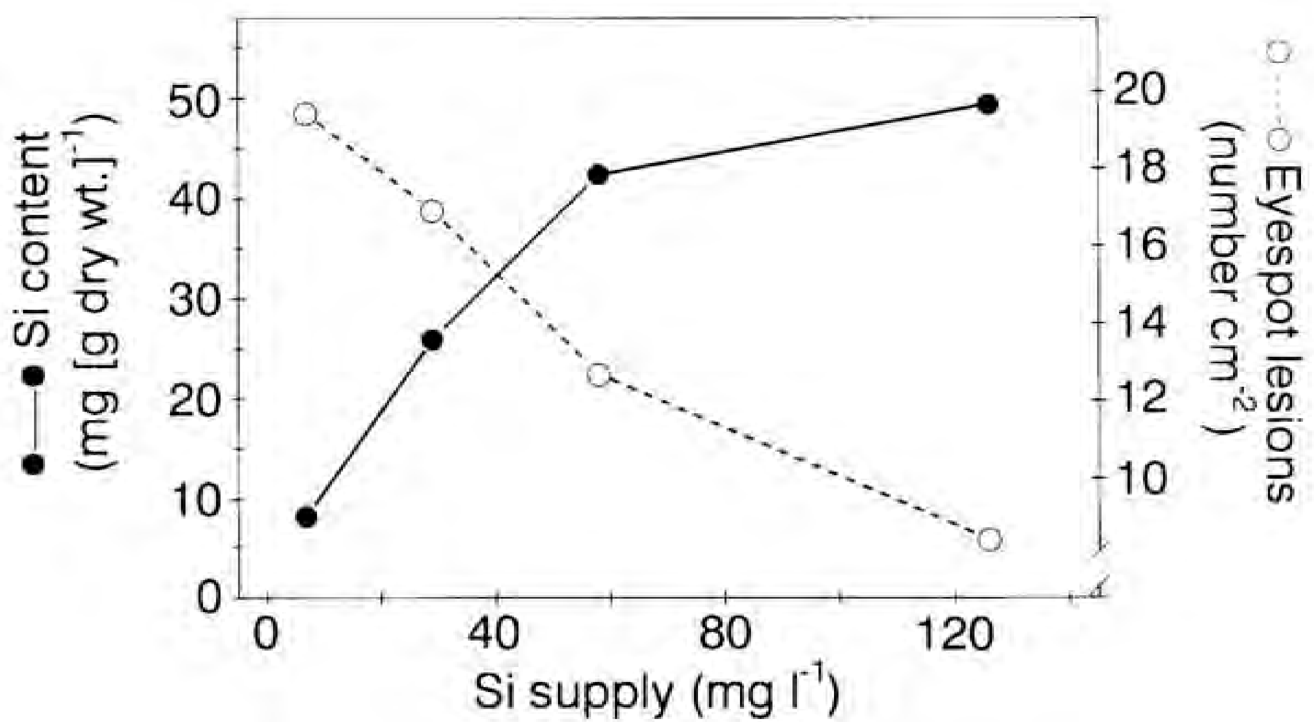
# Nutritional status of plants affects tolerance against pathogens through different mechanisms

## For example

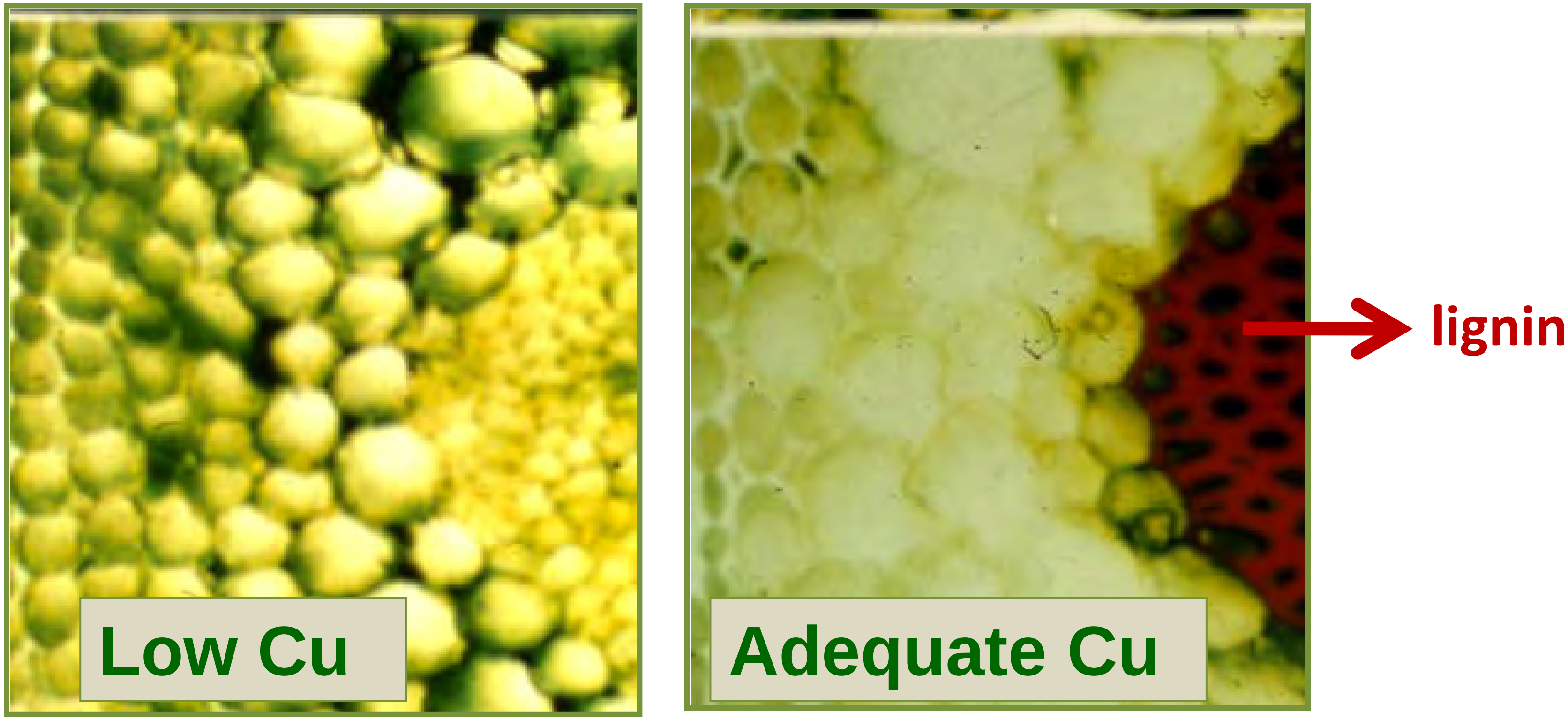
- Enhanced germination/infection of pathogen spores through exudation of sugars and amio acids from root or leaf cells caused by mineral deficiency (Ca, Zn, B deficiencies)
- Enhanced penetration of pathogens into cell walls due to instability or weakness of cell walls caused by nutrient deficiencies such as Ca, Mn, B or Cu deficiencies (e.g., reduced mechanical resistance).
- Enhanced formation of mechanical barriers (lignification, silification) and the synthesis of toxins (phytoalexins) against pathogenic attack (e.g. throghh improved supply of Si, Mn, Cu...)

## Silicium deposition in cell walls represents an important physical barrier to pathogenic attack

Influence of enhanced **Si supply on the incidence of fungal pathogens** on leaves of rice



# Increase of the mechanical resitance of cell walls by lignin deposition




**Effect of Cu deficiency on lignification of cell walls in stems of sunflower (Helianthus annuus). Red color indicate presence of lignin**

(from Marschner 1995)

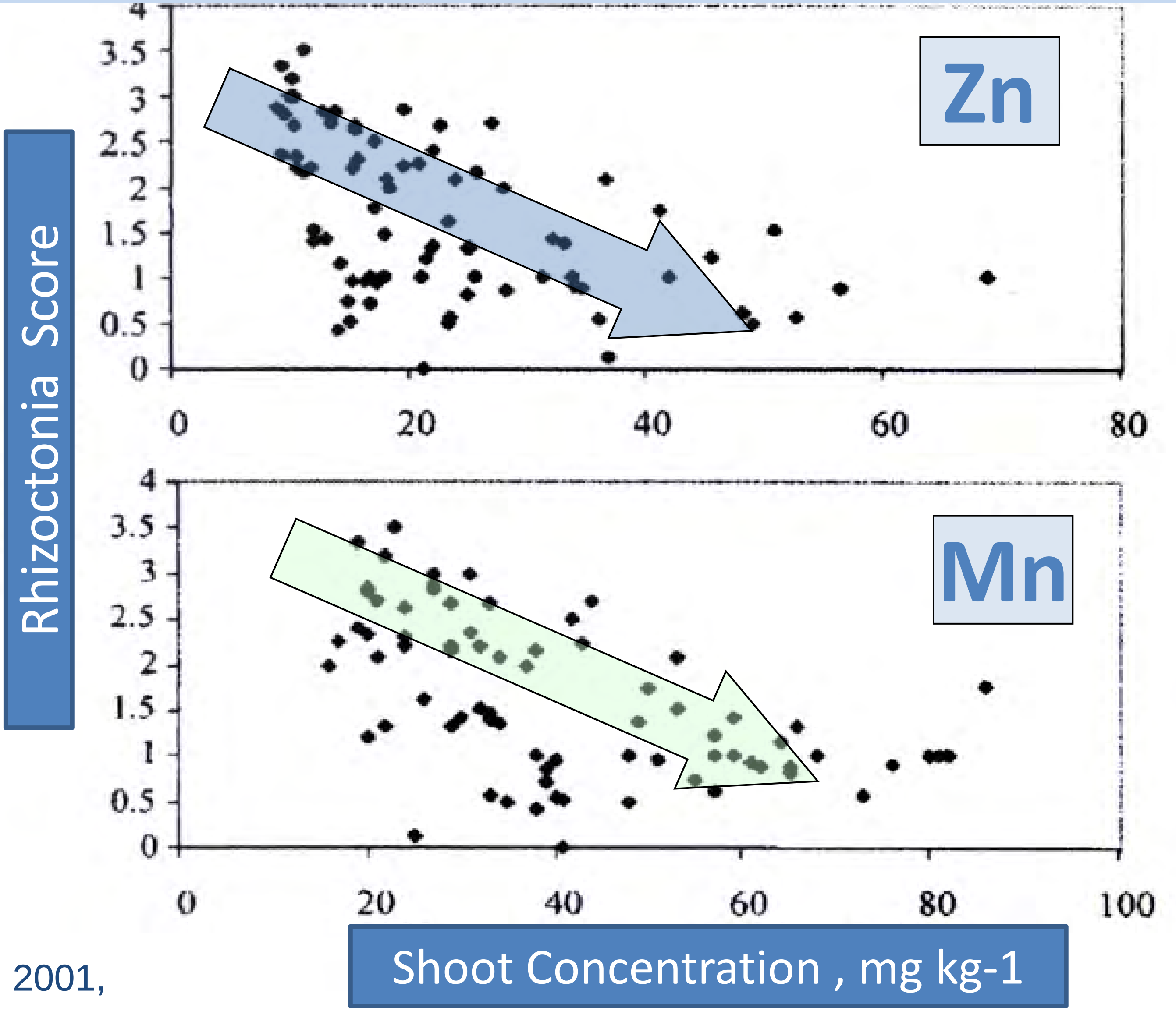
# Root lesions (take all) and lignin content in root tissue of wheat at different Mn treatments

| Variable | Total length of *Ggt* lesions (mm) | Lignin content[a] ($Abs_{280}$/root system) |
|---|---|---|
| Mn, mg/kg soil | | |
| 0 | 38 | 0.14 |
| 3 | 28 | 0.12 |
| 30 | 23 | 0.25 |
| 300 | 22 | 0.28 |

By affecting lignin synthesis Mn suppresses penetration of pathogens into plant tissue.

Rengel et al., 1994

# Relationship between shoot Zn and Mn with *Rhizoctonia* infection rate

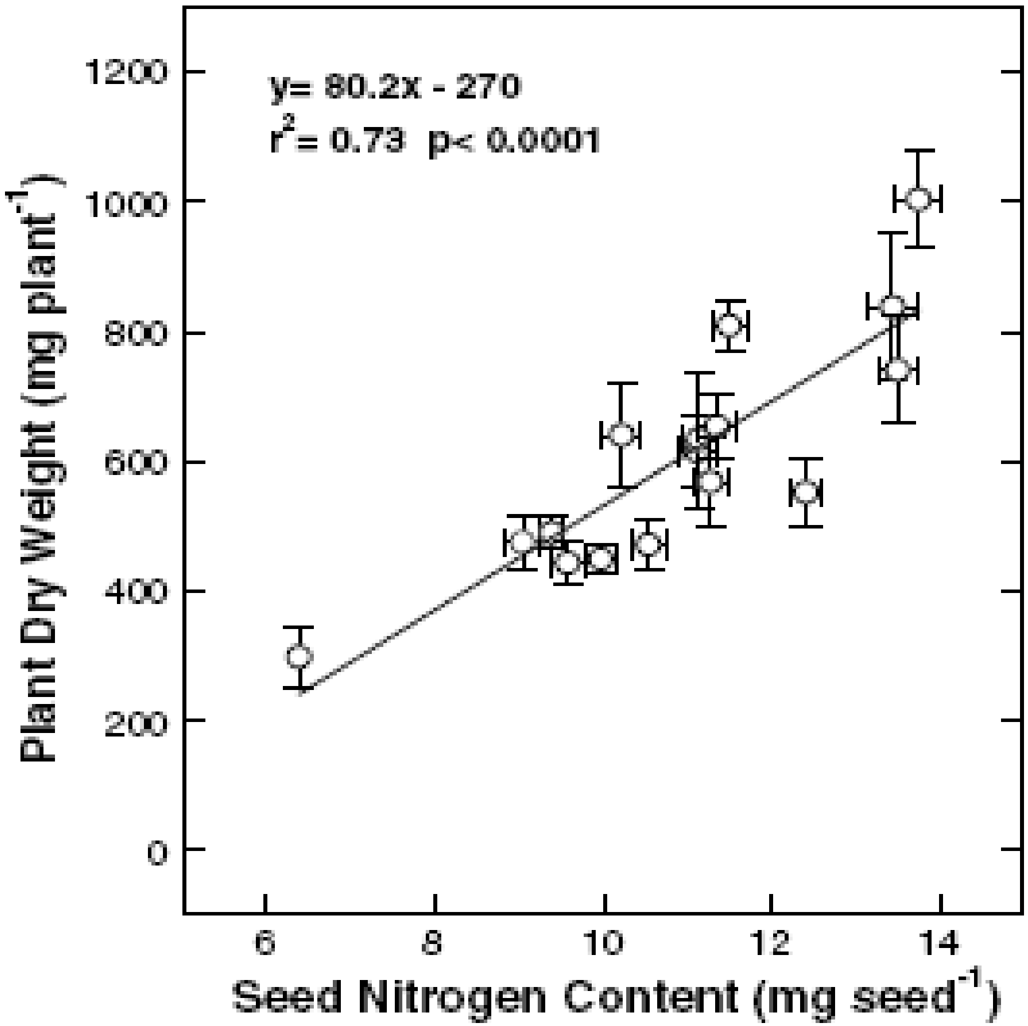



Steer et al., 2001, Plant Soil

Seedlings develop better when seeds are dense in mineral nutrients

# Seed Nutrients

# Seed nitrogen content is critical for better seedling vigor and growth




**Influence of seed nitrogen on seedling growth in soybean**

Naegle et al.,
Plant and Soil (2005) 271: 329–340

# Effect of P-seed coating on growth and grain yield

| Parameter | control | P-coating |
|---|---|---|
| **Veg. Growth** | | |
| g plant$^{-1}$ | 1.38 | 1.56 |
| g m$^{2}$ | 623 | 683 |
| **Yield** | | |
| g panicle$^{-1}$ | 1.52 | 1.77 |
| g m$^{2}$ | 687 | 774 |
| No of grains m$^{2}$ | 16 200 | 18 100 |

Data from Peltonen-Sainio (Agron. J. 2006; 98:206-211)

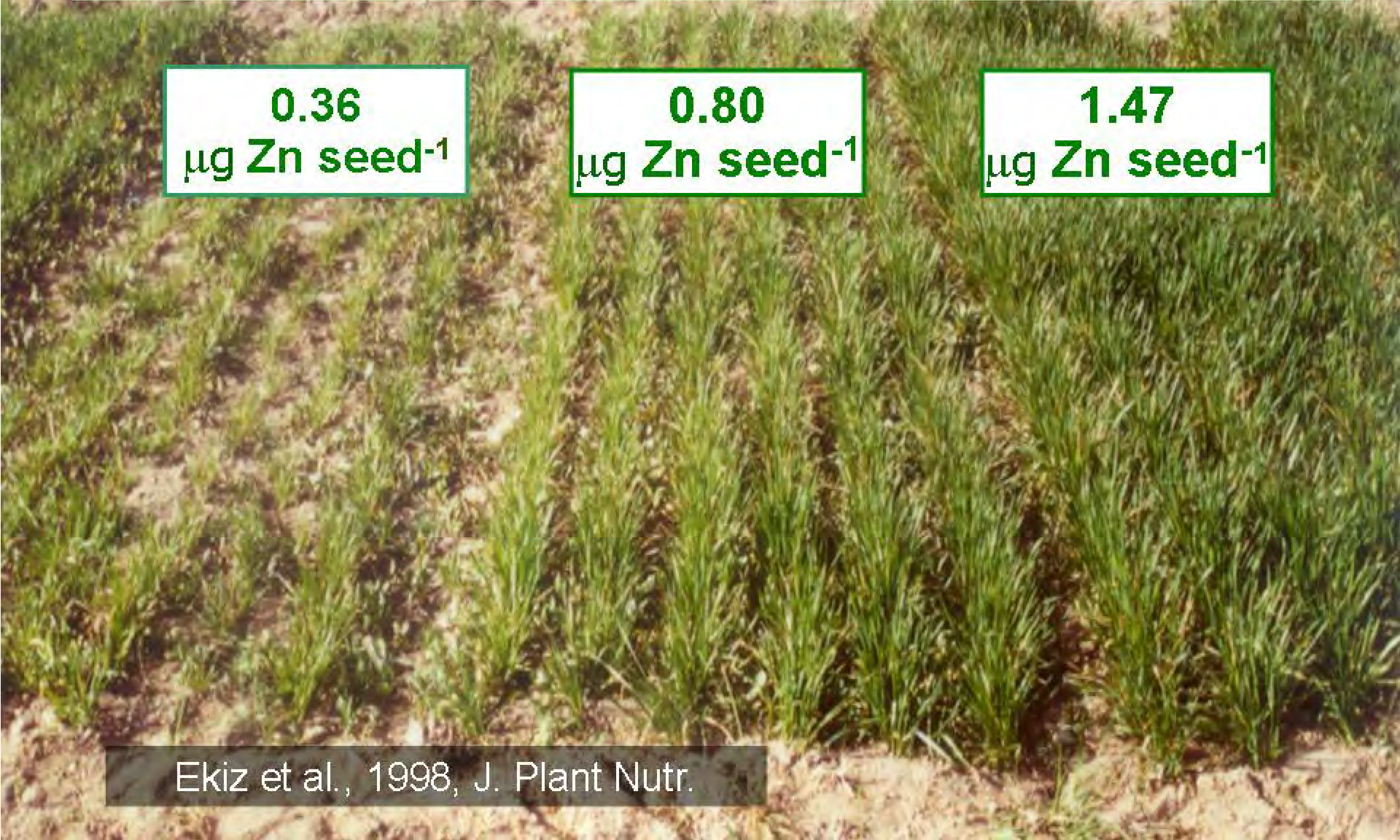
# Impact of Micronutrient Dense Rice Seed in Bangladesh

(data from J. Duxbury, 2002, Cornell Univ.)

| Seed Treatment | Yield (t/ha) |
|---|---|
| Complete (Zn, Mn, Cu, Mo, | 4.6 a |
| Zn only | 4.0 b |
| Complete - Mo | 4.1 b |
| Control | 3.6 c |

[1] letters indicate significant difference at $p < 0.1$

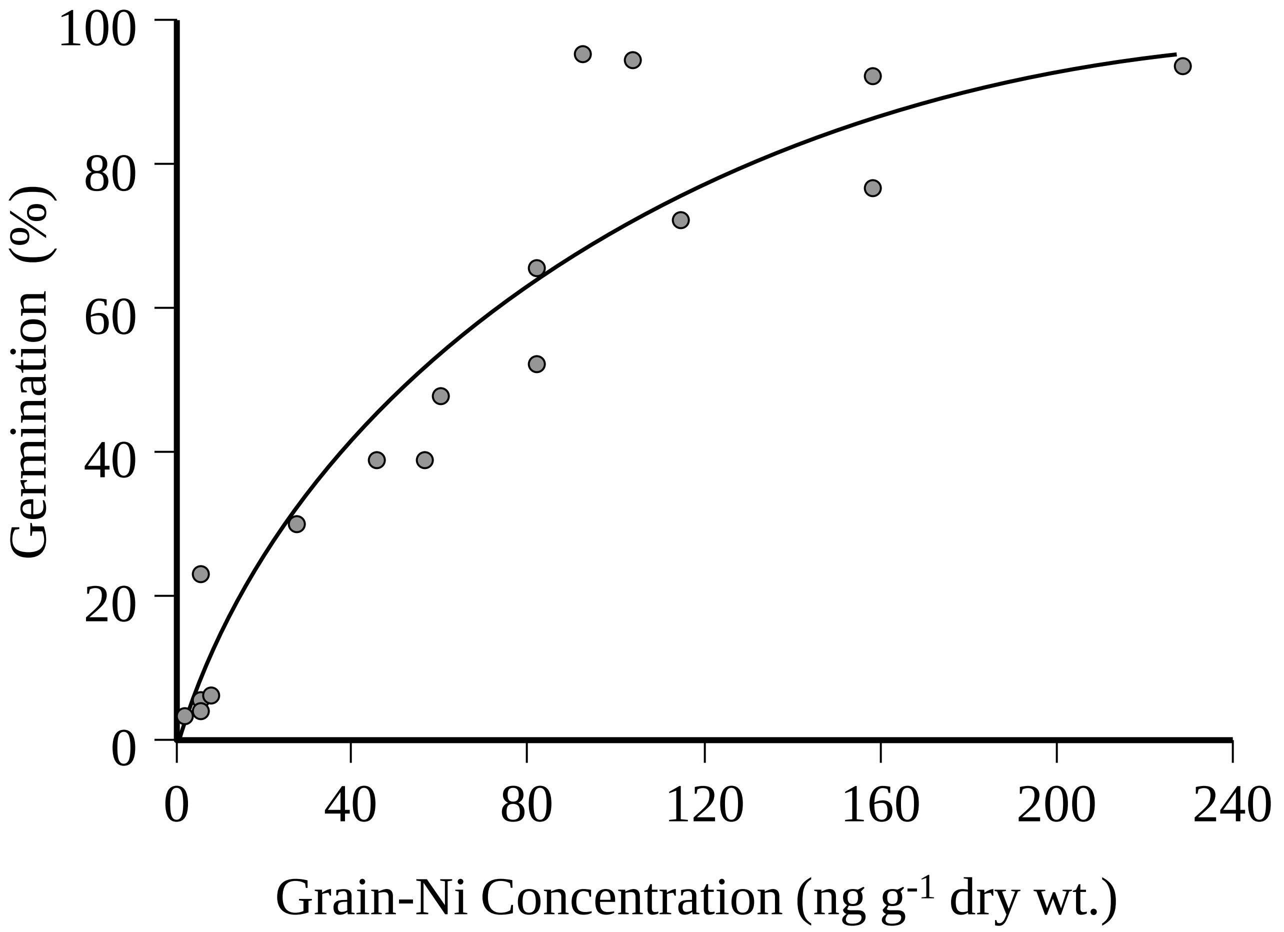
# Influence of Seed Zn Content on Growth of Bread Wheat on a Zinc-Deficient Soil in Central Anatolia




Ekiz et al., 1998, J. Plant Nutr.

# Effect of Ni Concentrations in Barley Grain on Grain Viability

(Source: Welch, 1999, In: Mineral Nutrition of Crops. Fundemental Mechanisms and Implictions, Food Products Press)



# Agricultural solutions to global micronutrient malnutrition

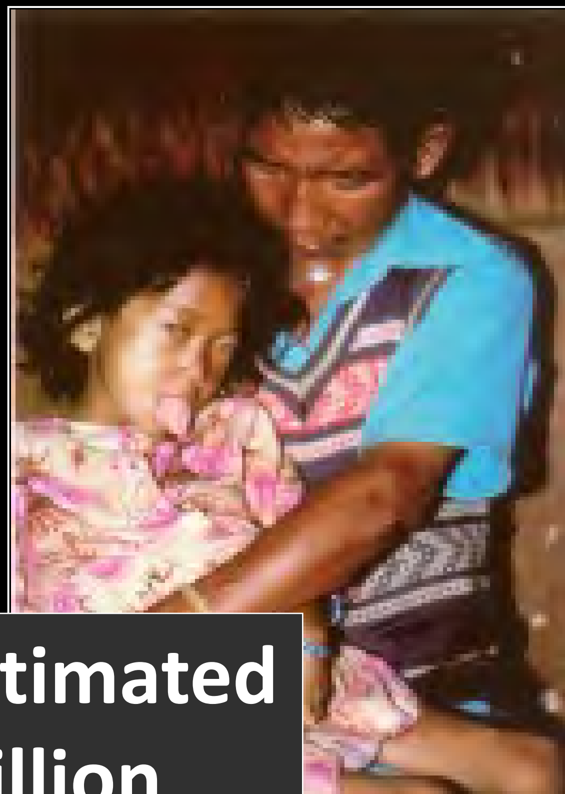


# Magnitude of the problem

| Deficiency | Population at risk | Geographical region | High risk groups |
|---|---|---|---|
| Vitamin A | ? 0.5 billion | Developing countries | Children aged <5 y, pregnant women |
| Zinc | 2.9 billion | Developing countries | Children aged <5 y |
| Iron | 2 billion | Worldwide | All, but particularly children and pregnant women |
| Iodine | 1.5 billion (1990)<br>0.5 billion (2000) | Worldwide | Children, prenatally and up to 2 y post-natally |

Brown. Food Nutr Bull 2002; Stoltzfus. J Nutr 2001;131:565S-67S; West. J Nutr 2002;132:2857S-66S.

# Micronutrient Deficiencies: Global Malnutrition Problem



**Iron Estimated 2 billion**

**Zinc Estimated 2 billion**

www.harvestplus.org

## Health Problems related to micronutrient deficiencies

- Increase in anemia,morbidity and mortality
- reductions in work productivity
- impairments in immune system, physical growth, mental development
- Kills more than 100,000 mothers during childbirth each year

(see: www.harvestplus.org)

# Children particularly sensitive

>450,000 deaths/year children under 5 – 4.4% attributed to Zn deficiency

Black et al. 2008

The Lancet Maternal and Child Undernutrition Series

**WHO REPORT (2002)**

Leading 10 Risk Factors in Developing Countries

% Cause of Disease Burden

| | |
|---|---|
| Underweight | 14.9% |
| Unsafe sex | 10.2% |
| Unsafe water | 5.5% |
| Indoor smoke | 3.7% |
| **Zinc Deficiency** | **3.2%** |
| **Iron deficiency** | **3.1%** |
| Vitamin A deficiency | 3.0% |
| Blood pressure | 2.5% |
| Tobacco | 2.0% |
| Cholesterol | 1.9% |

# ZINC SAVES KIDS

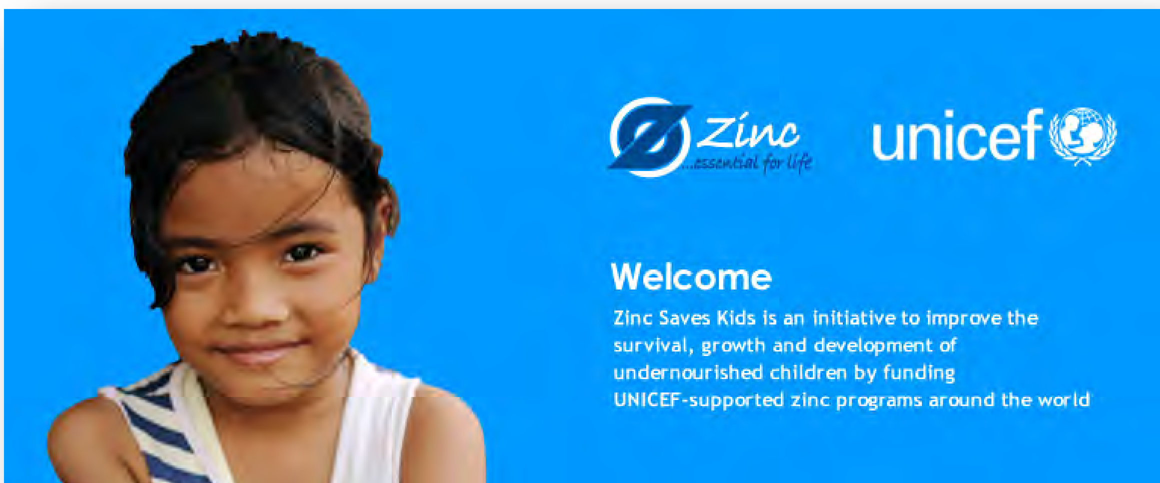
unicef

Zinc ...essential for life

Intl' Zinc Assoc.

**IZA in partnership with UNICEF started a program called 'Zinc Saves Kids'**

www.ZincSavesKids.org



# Solutions to Micronutrient Deficiencies

- Supplementation
- Food Fortification

**(not affordable in rural regions)**



**Golden Wheat Fortfied with Zn**

## Major Reason: Low Dietary Intake

**High Consumption Cereal Based Foods with Low Micronutrient Concentrations**

In number of developing countries, cereals contributes nearly 75 % of the daily calorie intake.

# Agricultural Solutions
(Breeding and Fertilizer Approaches)

- **Breeding**


- **Agronomy/Fertilizers**

HarvestPlus

Breeding Crops for Better Nutrition

# HarvestPlus-Biofortification Challenge Program

www.harvestplus.org

## **Breeding** new cereal cultivars with high micronutrient content in cereal grains

**Coordinating Institutions:**

International Food Policy Research Institute (IFPRI) Washington DC and CIAT-Colombia

**Main Sponsors:** Gates Foundation and World Bank

## Main Sponsor of HarvestPlus Program

BILL & MELINDA GATES foundation

www.gatesfoundation.org

Studying grain, Karsana, Nigeria

***"Two billion people in the developing world suffer from diets lacking essential vitamins and minerals.***

*Foods rich in vitamins and minerals are essential for a healthy diet. When diets do not contain sufficient amounts of vitamin A, folic acid, iodine, iron, and zinc, the consequences include significantly lower birth weight, a decrease in cognitive development, and increased susceptibility to other diseases."*

# Global Zinc Fertilizer Project

HarvestPlus
Breeding Crops for Better Nutrition

Int. Zinc Assoc.

## Coordinating Institution: Sabanci University

Sabancı Universitesi


HarvestZinc
exploring fertilizer use to increase zinc in cereals

HarvestPlus
Breeding Crops for Better Nutrition

# HarvestZinc

exploring fertilizer use to increase zinc in cereals

## 2011 April - 2014 March

Mosaic

KALI

OMEX

ifa

IPNI

fbsciences

ADOB

Bayer CropScience

Valagro

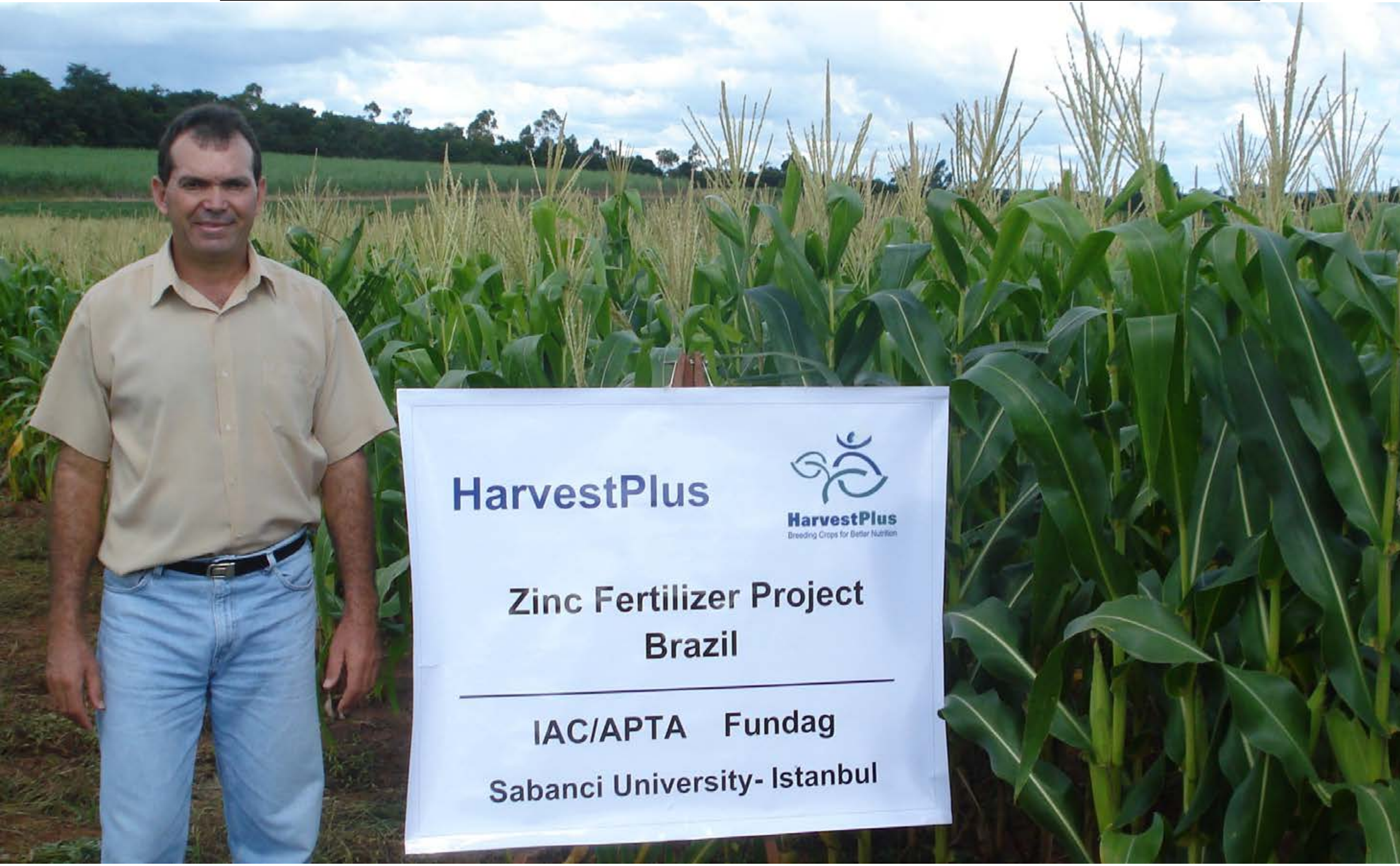
Sabancı Üniversitesi

# Rice Trials in Thailand

# Maize Trials in Zambia

# Wheat Trials in India


# Maize Experiments in Brazil



# Maize Trials in Zimbabwe

# Rice Experiments in Thailand

# Rice Experiments in Laos

# Zinc trails in Zimbabwe

# Trials in Pakistan

# Maize Trials in Mozambique

# Wheat trials in China, Yanglin-Xian

# Rice  Trials in China and Laos


## Grain Zn concentration in different countries with and without zinc fertilization

| Country/Location | -Zn | +Zn |
|---|---|---|
| | mg kg$^{-1}$ | |
| India | | |
| •Varanasi | 29 | 47 |
| •PAU-I | 25 | 81 |
| •PAU-II | 28 | 77 |
| •PAU-III | 26 | 61 |
| •PAU-IV | 49 | 65 |
| •IARI | 33 | 45 |
| Kazakhstan | | |
| •Loc-I | 19 | 54 |
| •Loc-II | 28 | 73 |
| Pakistan | | |
| •Loc-I | 27 | 48 |
| •Loc-II | 28 | 44 |
| •Loc-III | 30 | 40 |
| •Loc-IV | 29 | 60 |

| Country/Location | -Zn | +Zn |
|---|---|---|
| | mg kg$^{-1}$ | |
| Mexico | | |
| •Year-I | 21 | 45 |
| •Year-II | 36 | 60 |
| Turkey | | |
| •Konya | 12 | 29 |
| •Adana | 32 | 57 |
| •Samsun | 23 | 49 |
| •Eskisehir | 22 | 43 |
| China | | |
| •Loc-I | 28 | 54 |
| •Loc-II | 19 | 26 |
| Australia | | |
| •Loc-I | 18 | 39 |
| Germany | | |
| •Average | 20 | 32 |
| Iran | | |
| •Average | 17 | 28 |
| Brazil | | |
| •Average | 30 | 52 |

**Average of all countries -Zn: 26 +Zn:50**

## Grain Zn concentration in different countries with and without zinc fertilization

| Country/Location | -Zn | +Zn |
|---|---|---|
| | mg kg$^{-1}$ | |
| India | | |
| •Varana | | |
| •PAU-I | | |
| •PAU-II | | |
| •PAU-III | | |
| •PAU-IV | | |
| •IARI | | |
| Kazakhstan | | |
| •Loc-I | | |
| •Loc-II | | |
| Pakistan | | |
| •Loc-I | 27 | [illegible] |
| •Loc-II | 28 | 44 |
| •Loc-III | 30 | 40 |
| •Loc-IV | 29 | 60 |

| Country/Location | -Zn | +Zn |
|---|---|---|
| | mg kg$^{-1}$ | |
| Mexico | | |
| •Year-I | 21 | 45 |
| | 36 | 60 |
| | | |
| | 12 | 29 |
| | 32 | 57 |
| | 23 | 49 |
| | 22 | 43 |
| | | |
| | 28 | 54 |
| | 19 | 26 |
| | | |
| | 18 | 39 |
| | | |
| | 20 | 32 |
| Iran | | |
| •Average | 17 | 28 |
| Brazil | | |
| •Average | 30 | 52 |

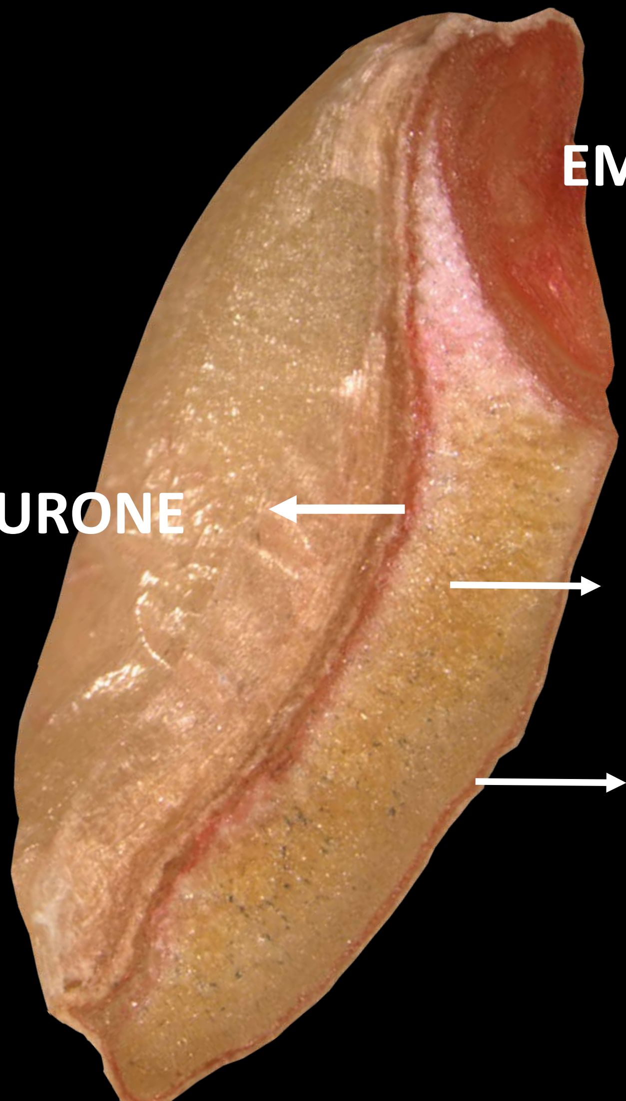
# Average Concentrations of Grain Zn

**(10 Countries with 32 locations)**

**-Zn: 26 ppm**

**+Zn: 50 ppm**

# Staining/Localization of Zinc in Wheat Grain (red color)




Cakmak et al., 2010

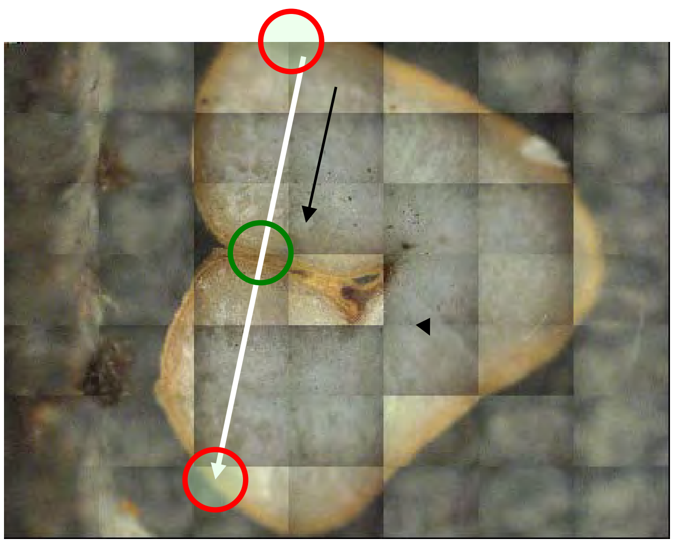
Cereal Chemistry, 77: 10-20

# Localization of Zn in grain after foliar application?

# LA-ICP-MS Tests on Seeds

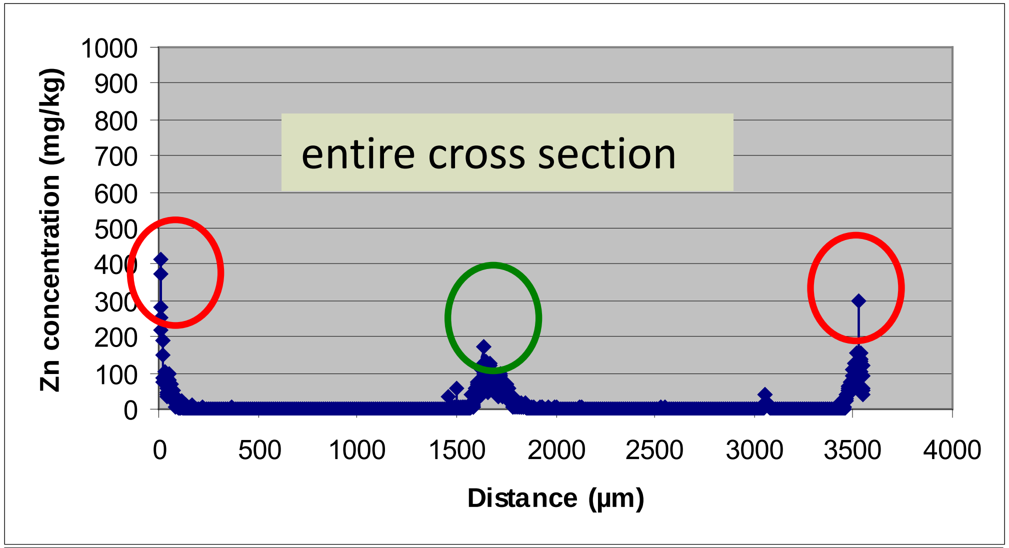
**White arrow:** Zn in entire cross section

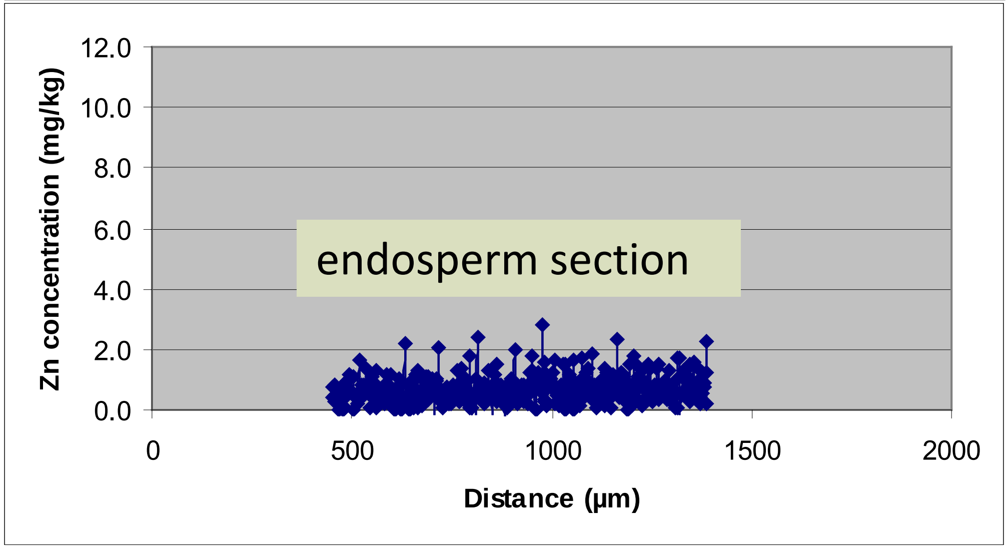
**Black arrow:** Zn in endosperm section



Cakmak et al., 2010,

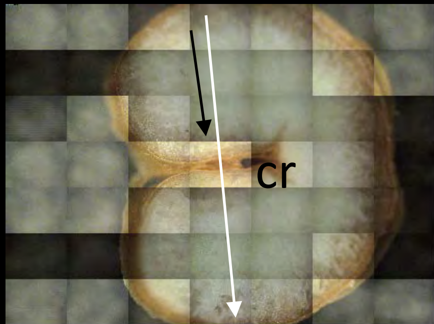
J. Agric. Food. Chem.

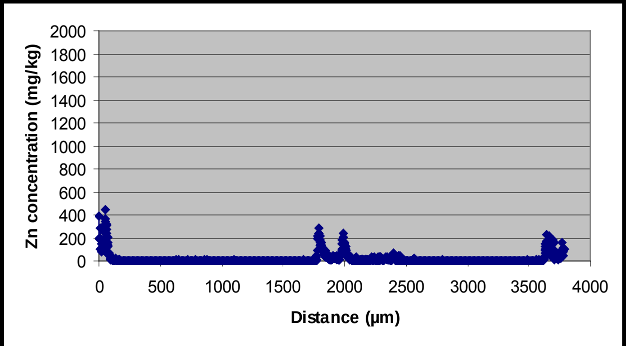


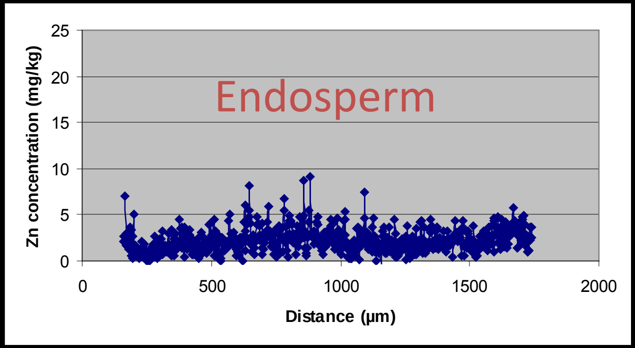



# LA-ICP-MS Tests

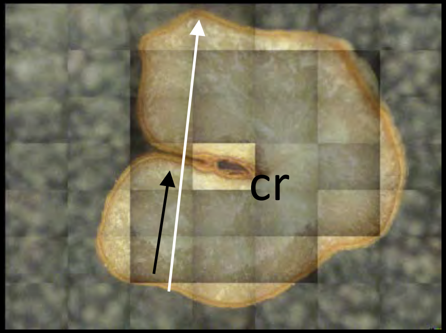
## No Foliar Zn Application

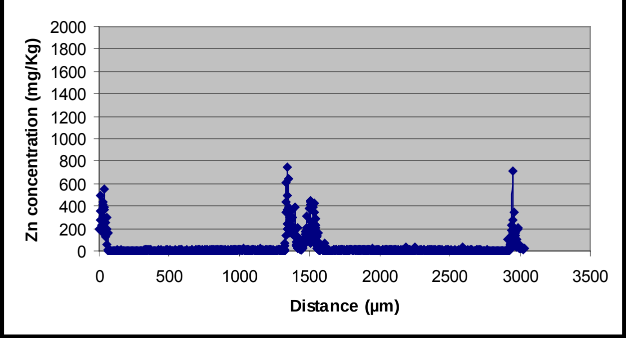


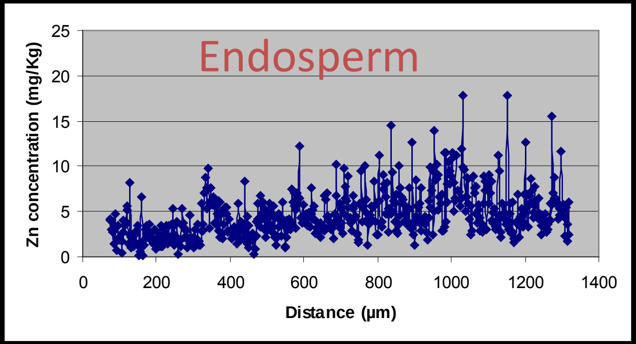



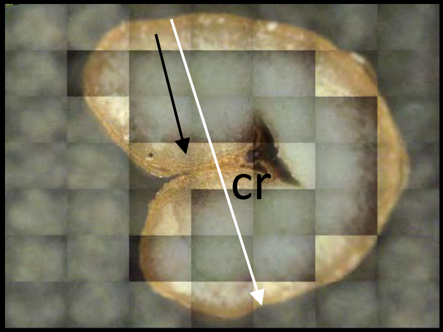

## Foliar Zn Application at Stem Elongation and Booting Stages

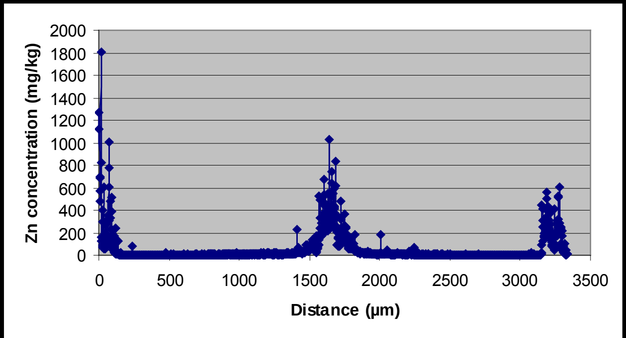


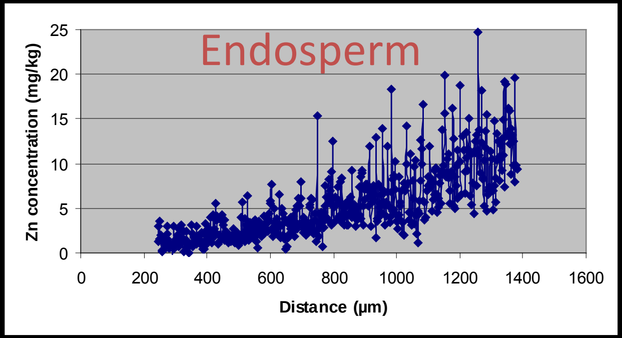




## Foliar Zn Application at Milk and Dough Stages



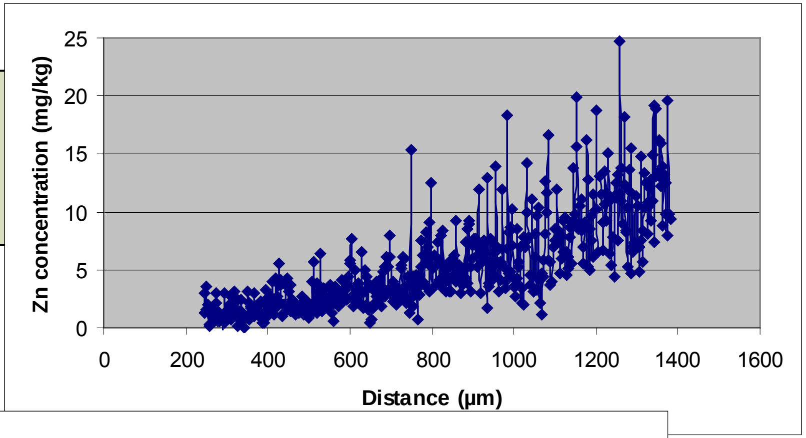



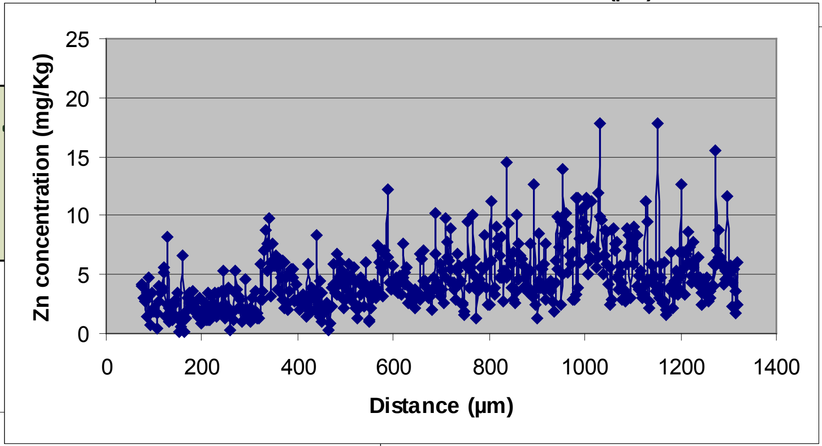

Cakmak et al., 2010, J. Agric. Food. Chem. 58:9092-9102

# Changes in Endosperm Zinc Concentrations

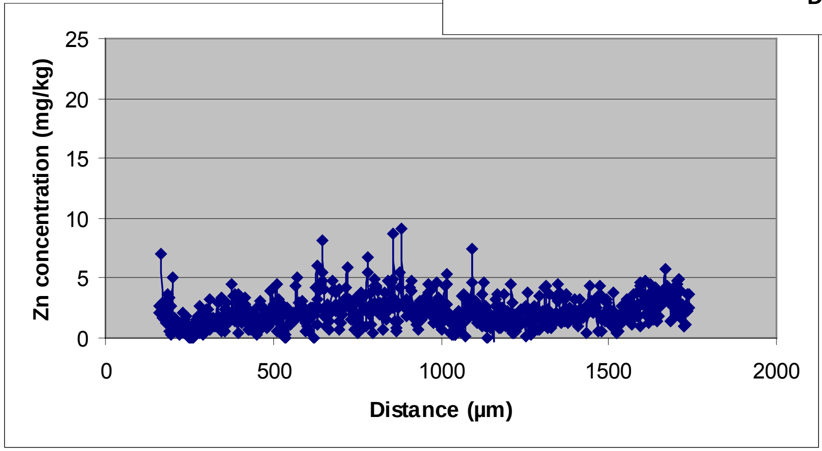
**Zn applied at milk and and dough stages**




**Zn applied at stem elonga and boot**

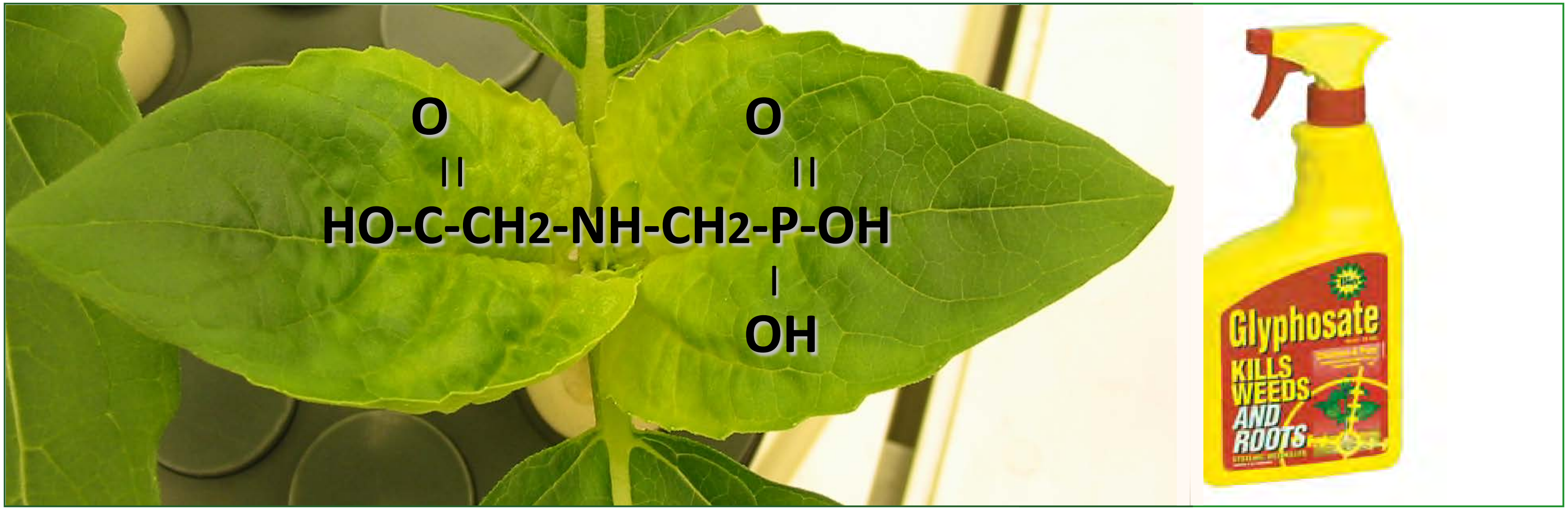



**No Zn**




Cakmak et al., 2010,

J. Agric. Food. Chem.




# Detrimental Effects of Glyphosate on Mineral Nutrition of Plants

# Water Quality for Glyphosate Spray

- Salts dissolved in water may reduce the effectiveness of glyphosate, particularly calcium and magnesium salts. These salts have a positive charge and may associate with the negatively-charged glyphosate molecule, replacing the isopropylamine or diammonium salts found in the formulated glyphosate product.

- Thus, the presence of calcium and magnesium salts in the carrier result in a reduction in glyphosate activity.

http://www.weeds.iastate.edu/mgmt/2001/glyphosate%20review.htm

**Glyphosate** binds with the cations to form a strong complexes which are not bio-available.

**Only unbound glyphosate act as a herbicide.**

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MONSANTO CANADA INC.
900 – ONE RESEARCH DRIVE
WINNIPEG, MANITOBA R3T 6E3
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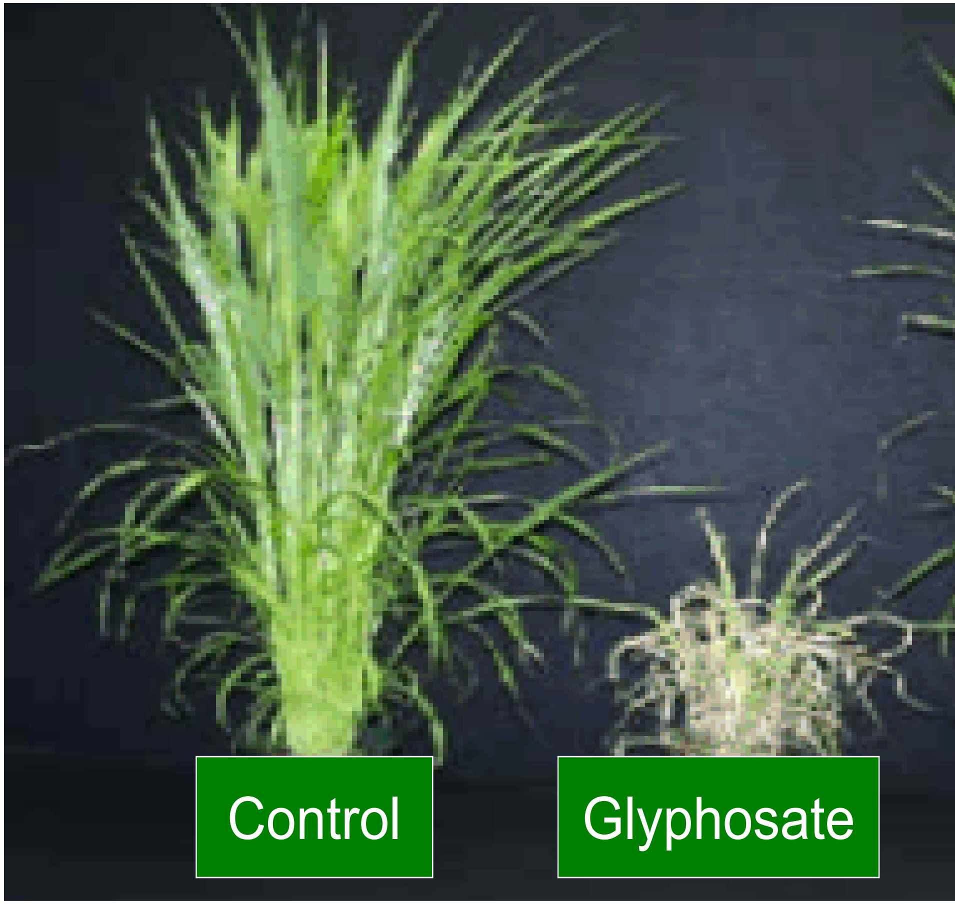
FAX (204) 488-9599

**STAKHOLDER UPDATE**
**FOR INFORMATION ONLY**
*April 25, 2008*

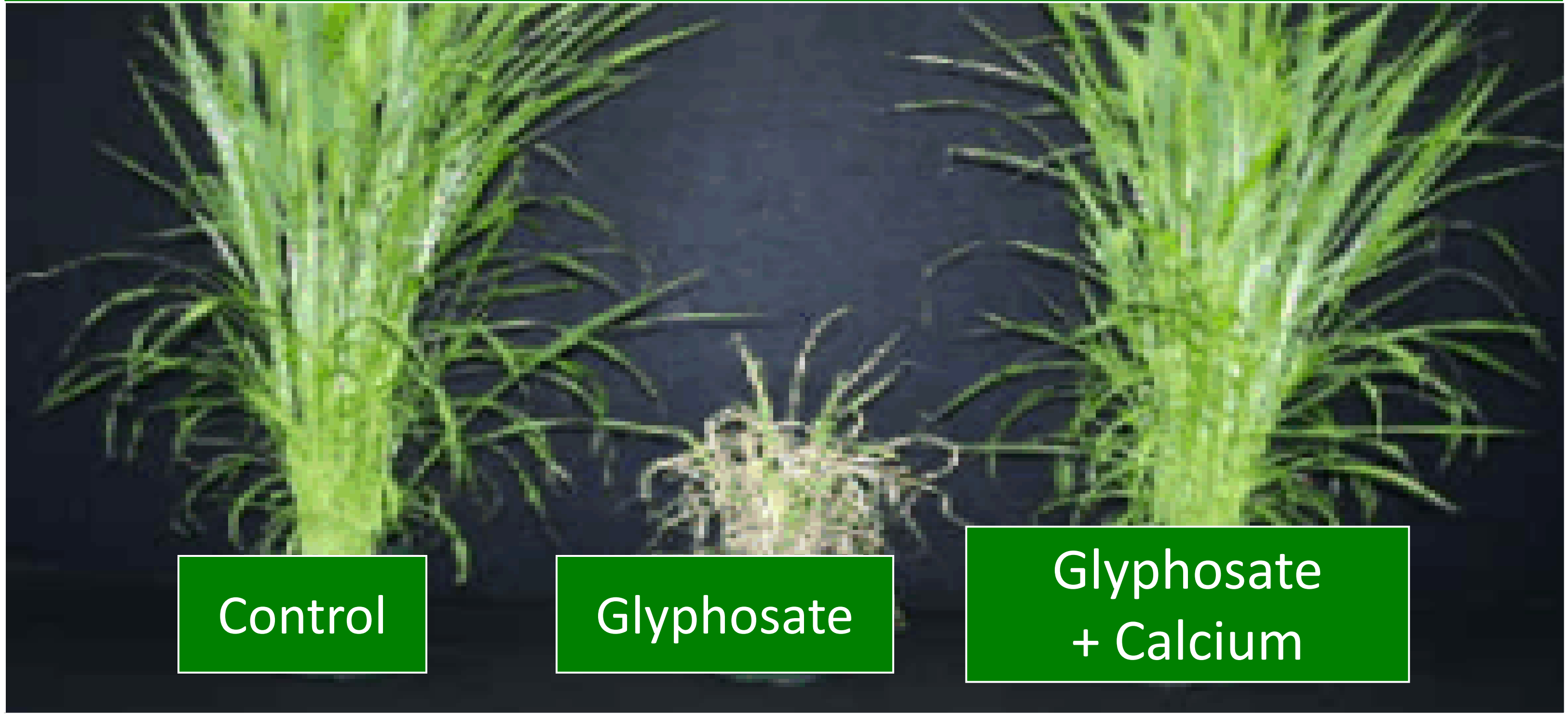
- ***“Q. Should I tank mix Roundup and fertilizers?***
- ***A.*** *Monsanto does not recommend tank mixing of Roundup and fertilizers such as manganese due to the potential for the fertilizer to cause antagonism with the weed control effects and efficacy of Roundup.”*




Hard water contains
levels of calcium (Ca
magnesium (Mg), ir
(Fe) or manganese ( .

Divalent cations atta o
negatively charged
herbicide molecules
reduce its herbicida
activity

## Effect of Glyphosate with and without calcium in the tank




Glyphosate binds with the cations to form a strong complex which is not bio-available.

Only unbound glyphosate act as a herbicide.

www.loveland.co.uk/ Gifs/X-Change-du-pont.gif

# Glyphosate Drift

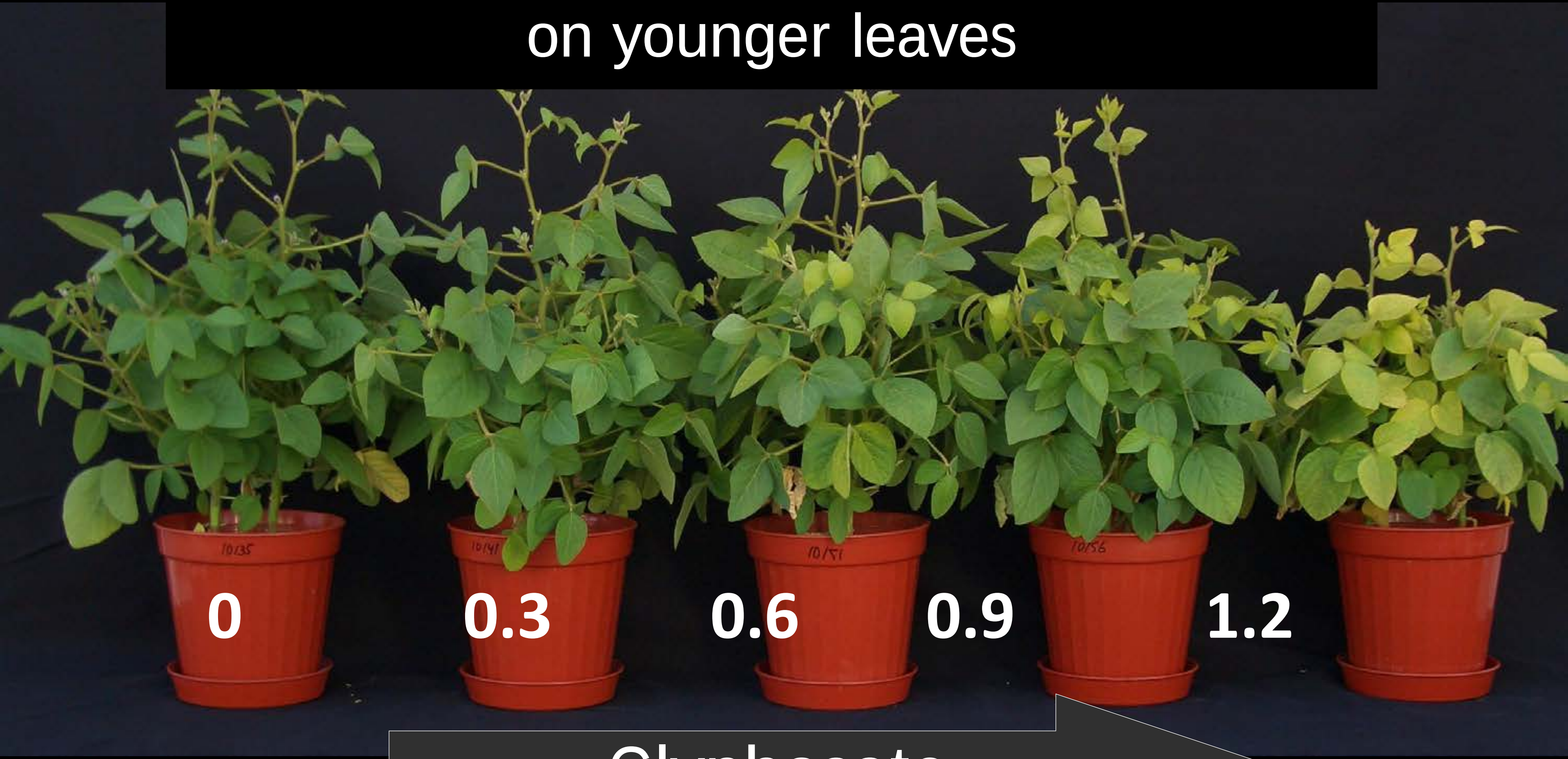

www.ipm.iastate.edu

# Glyphosate Drift

Up to 10 % of the foliarly-applied glyphosate may move to non-target plants (Al-Khatib et al., 1999; Snipes et al., 1992).

This spray drift may be as high as 37 % of the applied glyphosate rate depending on the speed of wind and accuracy of the glyphosate application method (Nordby & Skuterud 1975).

# Glyphosate-induced chlorosis/necrosis on younger leaves




Glyphosate

% of the recommended dose

Cakmak et al., 2009, Eur. J. Agronomy, in press

## Effect of at increasing glyphosate application on **leaf concentrations** of macronutrients in soybean

| Glyphosate Rate | **Ca** | K | P | **Mg** |
|---|---|---|---|---|
| (% of recommended) | | (%) | | |
| 0 | **2.23** ± 0.23 | 2.63 ± 0.51 | 0.23 ± 0.06 | **0.88** ± 0.14 |
| 0.06 | **1.84** ± 0.10 | 2.40 ± 0.02 | 0.22 ± 0.02 | **0.72** ± 0.01 |
| 0.2 | **1.92** ± 0.16 | 2.56 ± 0.17 | 0.23 ± 0.02 | **0.76** ± 0.09 |
| 0.6 | **1.56** ± 0.58 | 2.52 ± 0.98 | 0.23 ± 0.09 | **0.58** ± 0.22 |

Cakmak et al., 2009, Eur. J. Agron.

## Effect of at increasing glyphosate application on **leaf concentrations** of micronutrients in soybean

| Glyphosate Rate | Fe | **Mn** | Zn | Cu |
|---|---|---|---|---|
| (% of recommended) | | (mg kg$^{-1}$) | | |
| 0 | 49 ± 10 | **232** ± 62 | 93 ± 15 | 5 ± 1 |
| 0.06 | 54 ± 8 | **160** ± 3 | 78 ± 5 | 5 ± 1 |
| 0.2 | 51 ± 0 | **190** ± 27 | 84 ± 11 | 5 ± 1 |
| 0.6 | 40 ± 16 | **121** ± 48 | 65 ± 23 | 4 ± 1 |

Cakmak et al., 2009, Eur. J. Agron.

# Conclusion

- Glyphosate is antagonistic to the uptake, transport and accumulation (tissue concentration) of divalent cations such as Mg, Mn  and Ca, possibly due to the <u>formation of poorly soluble glyphosate-metal complexes (??)</u>

- A new risk assessment for glyphosate including the changes in nutritional status of plant is urgently needed,

# Thank You...

# Sabanci University

# www.zinccrops2011.org

3rd International

# ZINC SYMPOSIUM

## Improving Crop Production and Human Health

Hyderabad, India - October 10-13, 2011

Zinc ...essential for life

FAI ENSURING FOOD SECURITY

International Fertilizer Industry Association

HarvestPlus
Breeding Crops for Better Nutrition

# Istanbul 2013

International Plant Nutrition Colloquium

1. IPNC  1954 Nancy- France

…

…

12. IPNC 1993 Perth- Australia
13. IPNC 1997 Tokyo- Japon
14. IPNC 2001 Hannover-Germany
15. IPNC 2005 Beijing-China
16. IPNC 2009 Sacramento/Davis-ABD

**17. IPNC 2013 Istanbul-Turkey**


XVII IPNC 2013
Istanbul TURKEY