Impacts of Mineral Nutrition on Growth of Crop Plants

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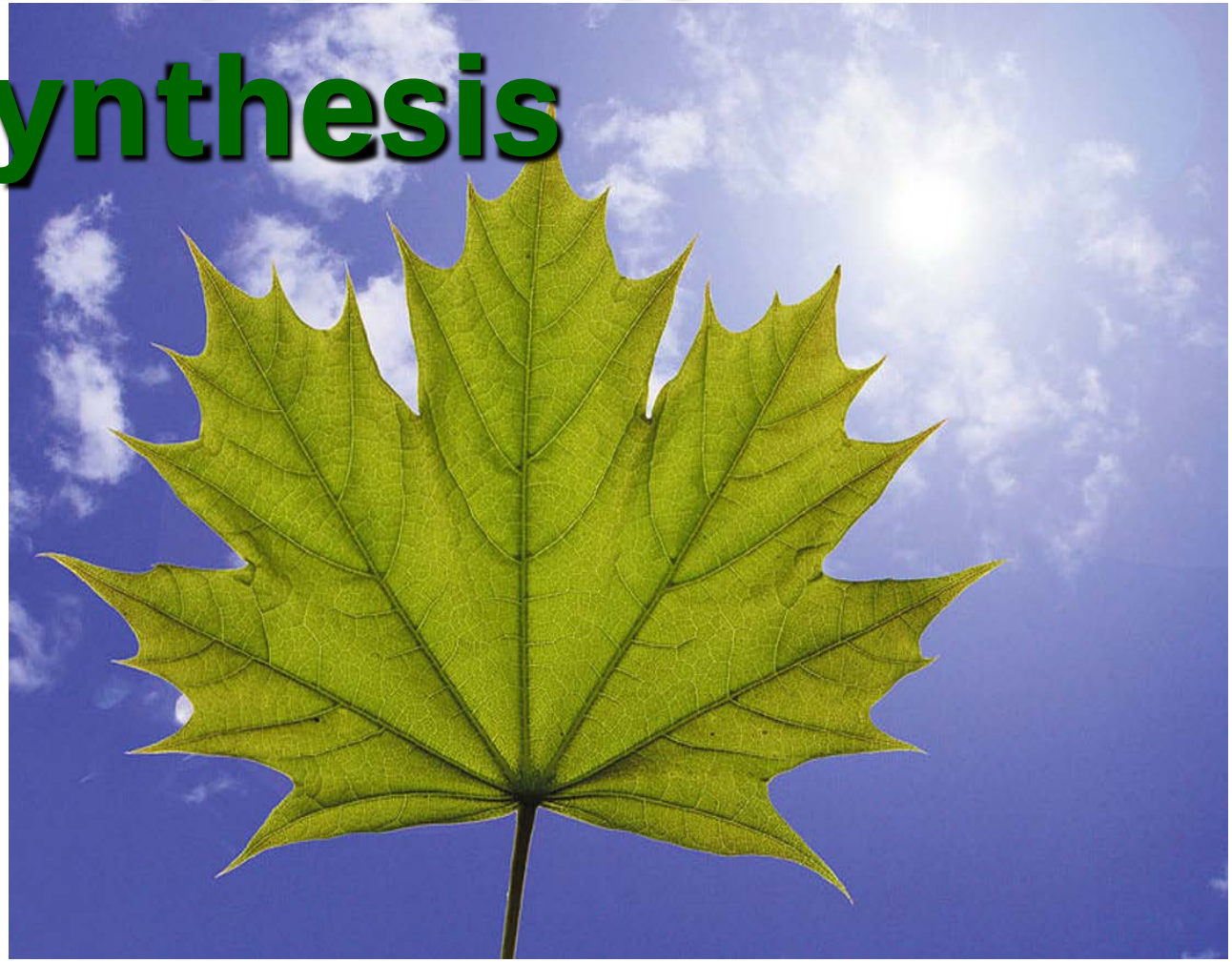
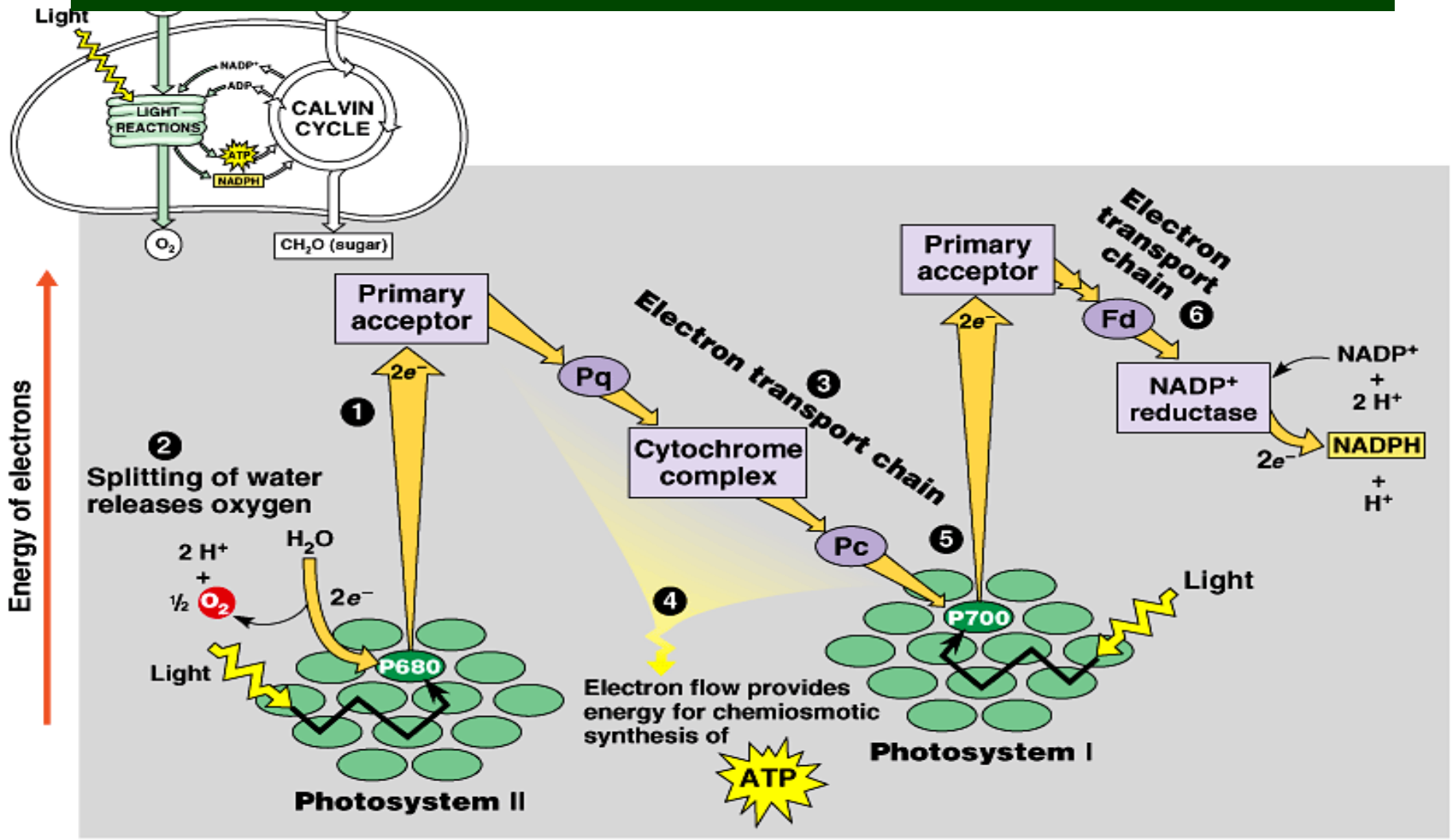
TOPICS

- 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

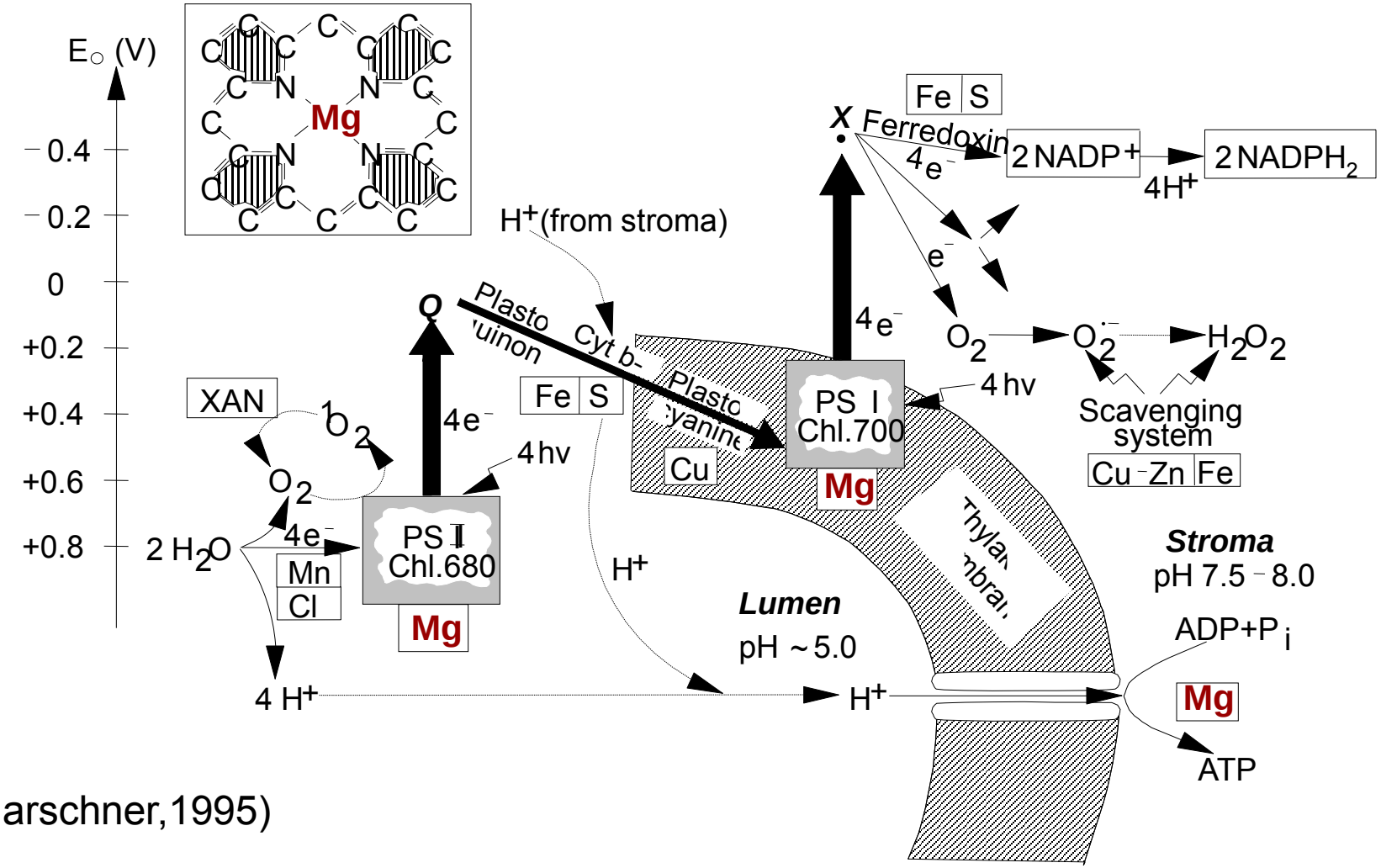
Mineral Nutrients in Photosynthesis



Mineral Nutrients required for photosynthetic electron transport and for ATP formation



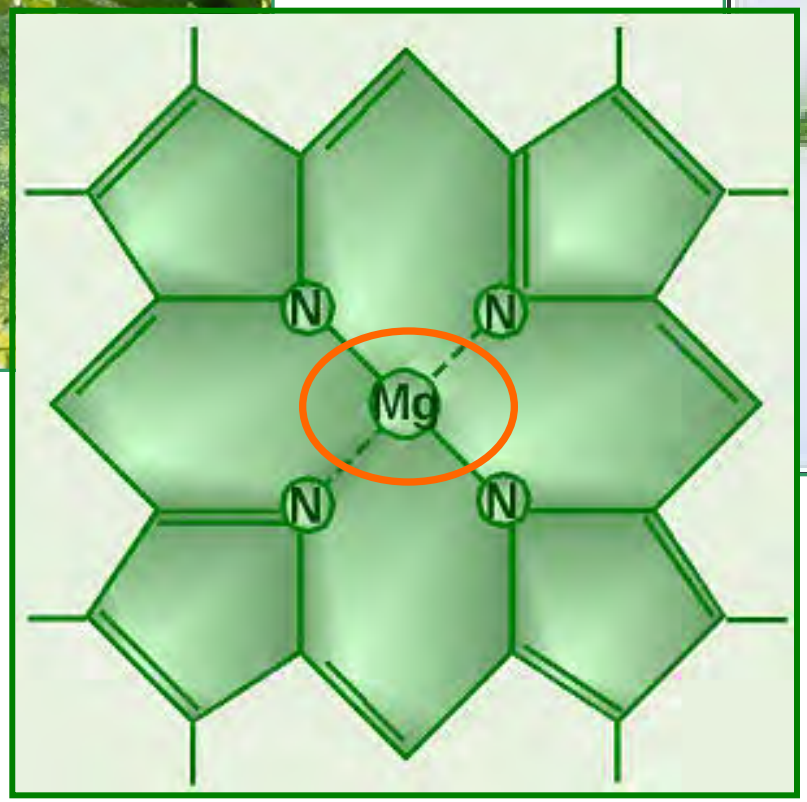
Mineral Nutrients required for photosynthetic electron transport as well as for ATP formation



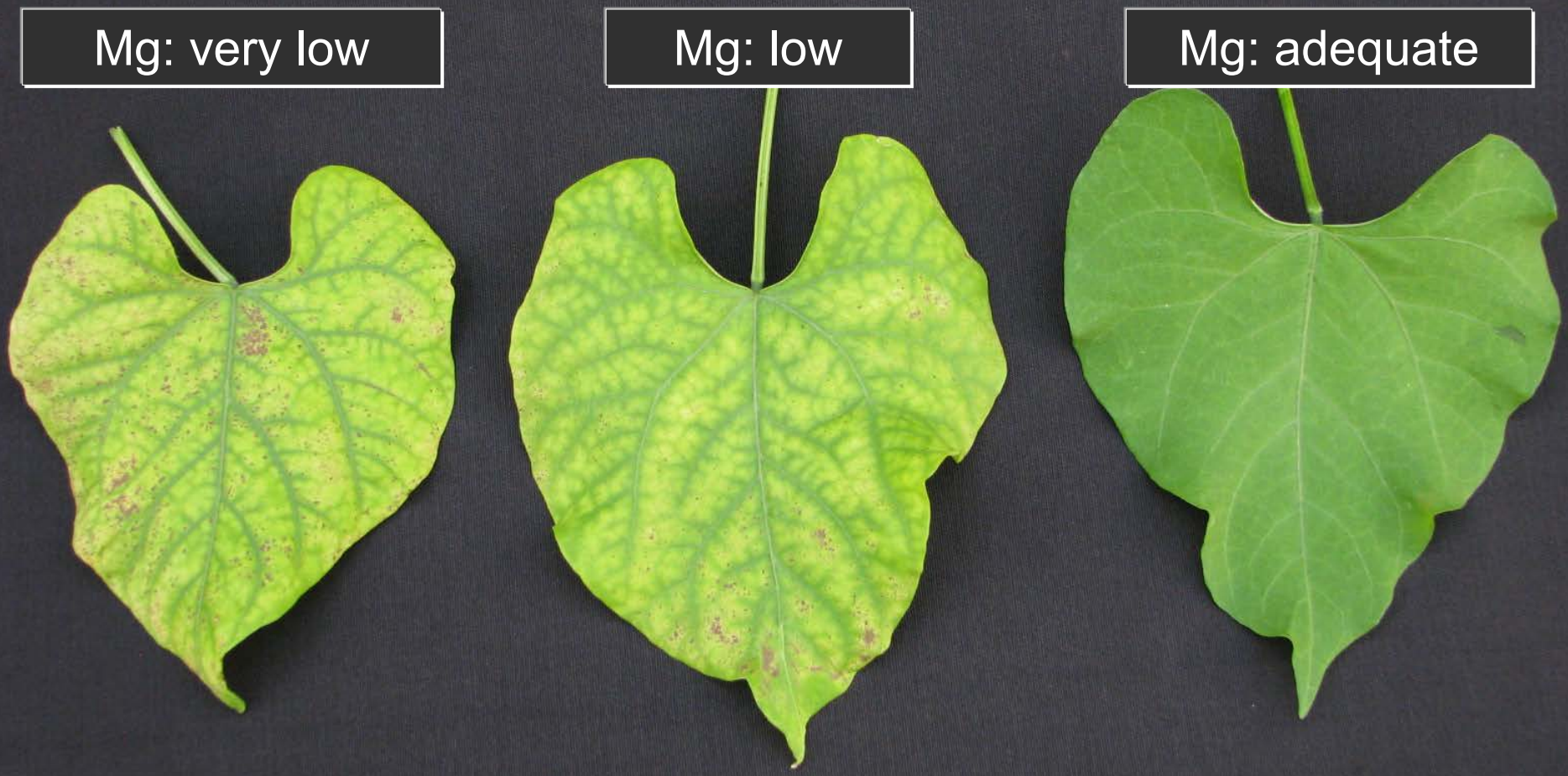
(Marschner,1995)

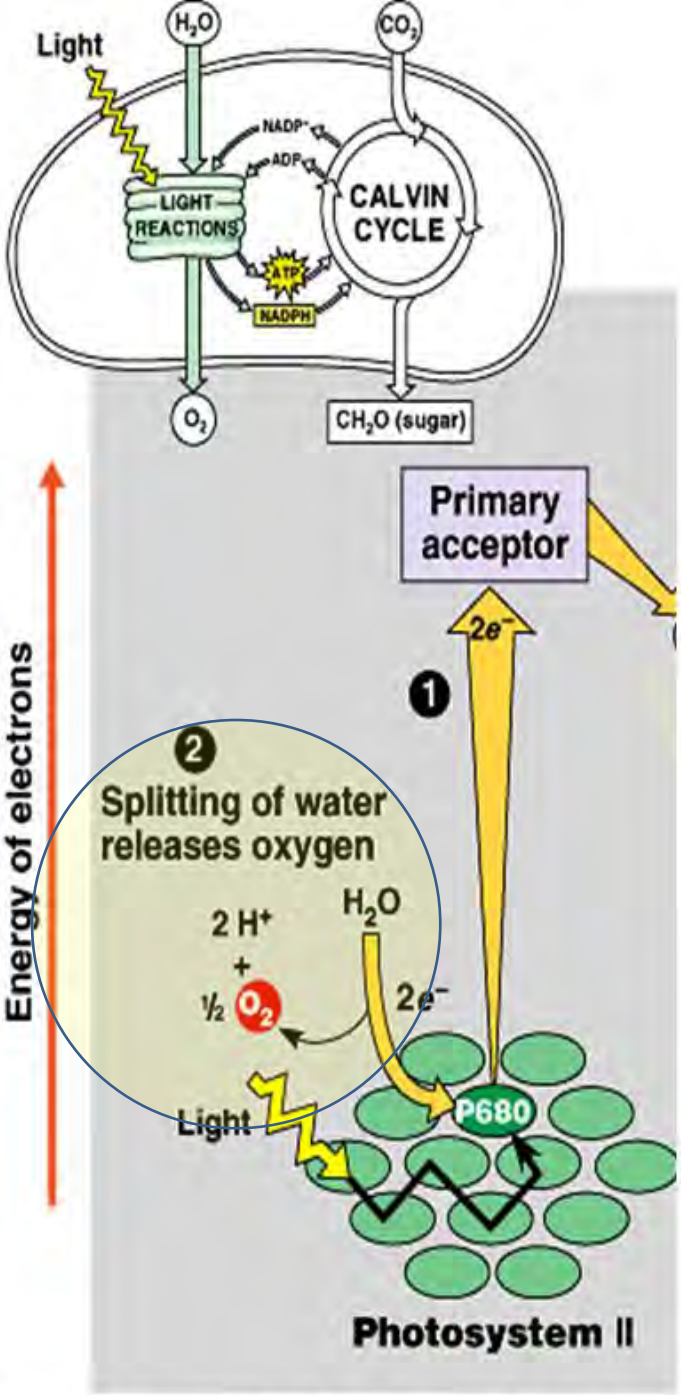
Photosynthetic electron transport chain with photosystem II and I photophosphorylation;

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



Magnesium Deficiency in Bean





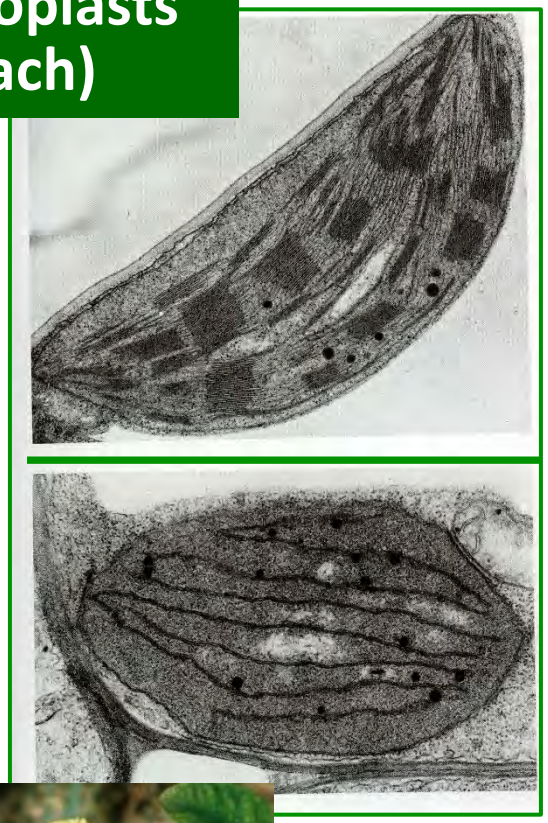
Major function of manganese in photosynthesis

- 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

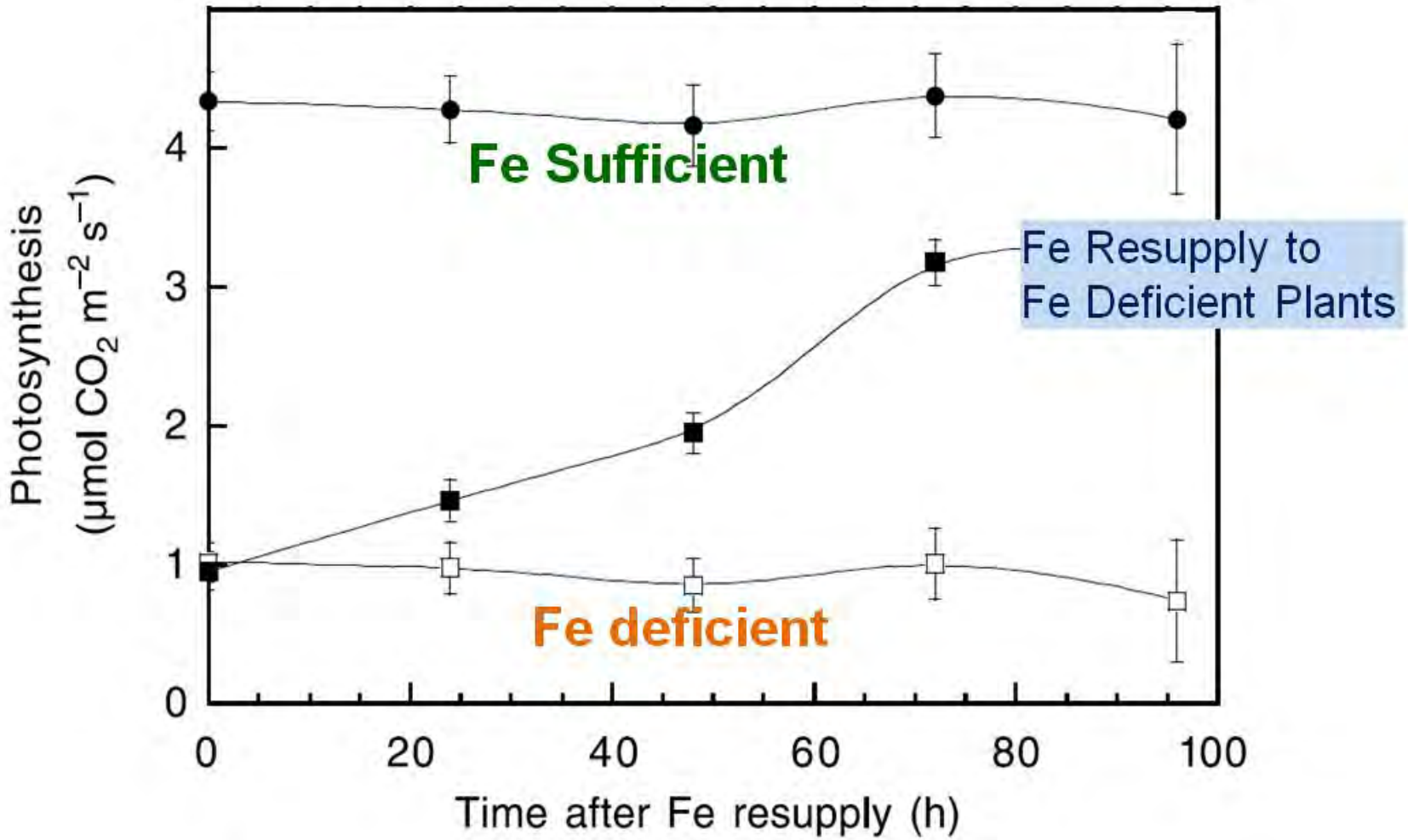
Chloroplasts (Spinach)



+ Fe

- Fe

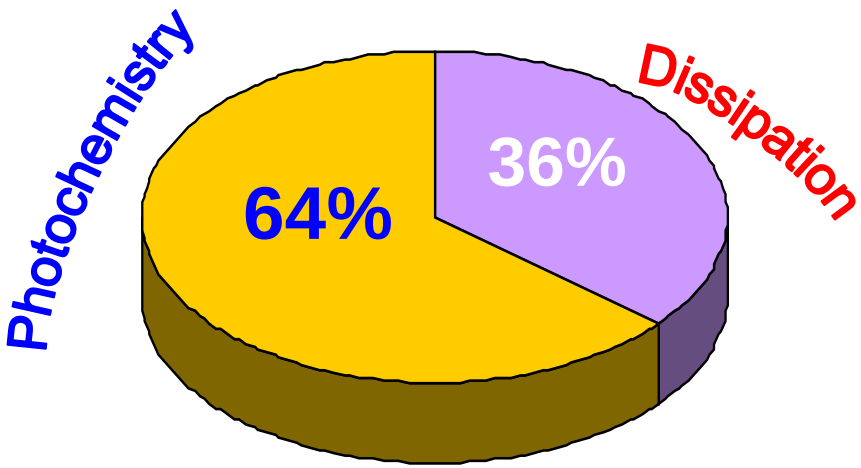
Effect of Fe Supply on Photosynthesis in Sugarbeet



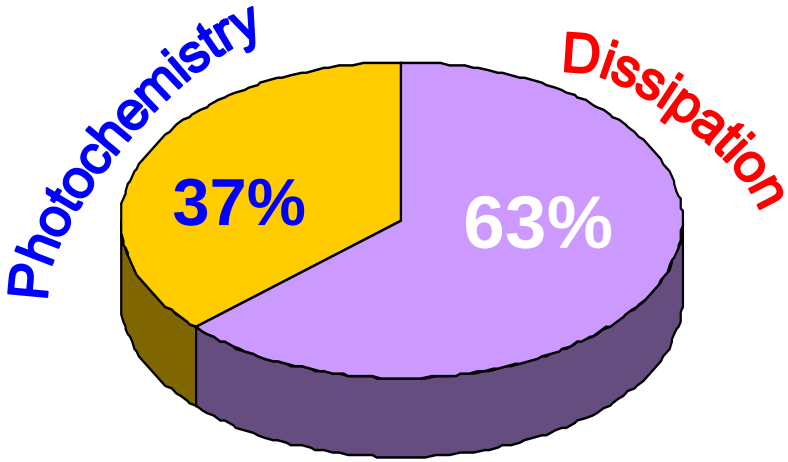
Larbi *et al. 2004*) *Photosynth. Res.* 89, 113-126

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

Adequate N

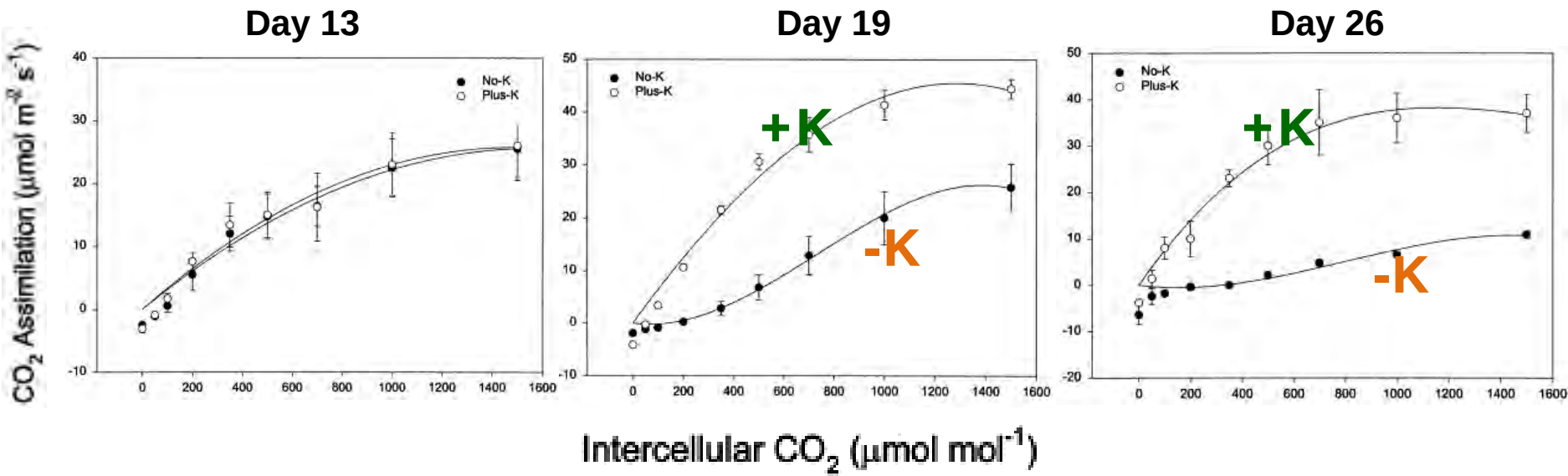


Low N



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

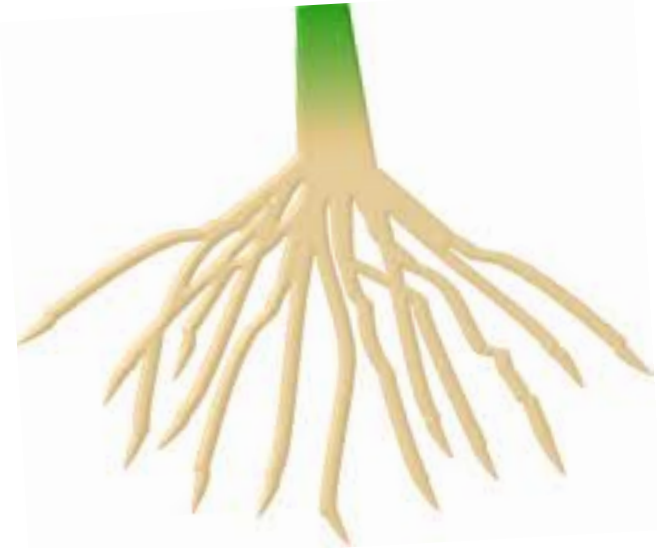
Effect of Potassium on Photosynthesis in Cotton

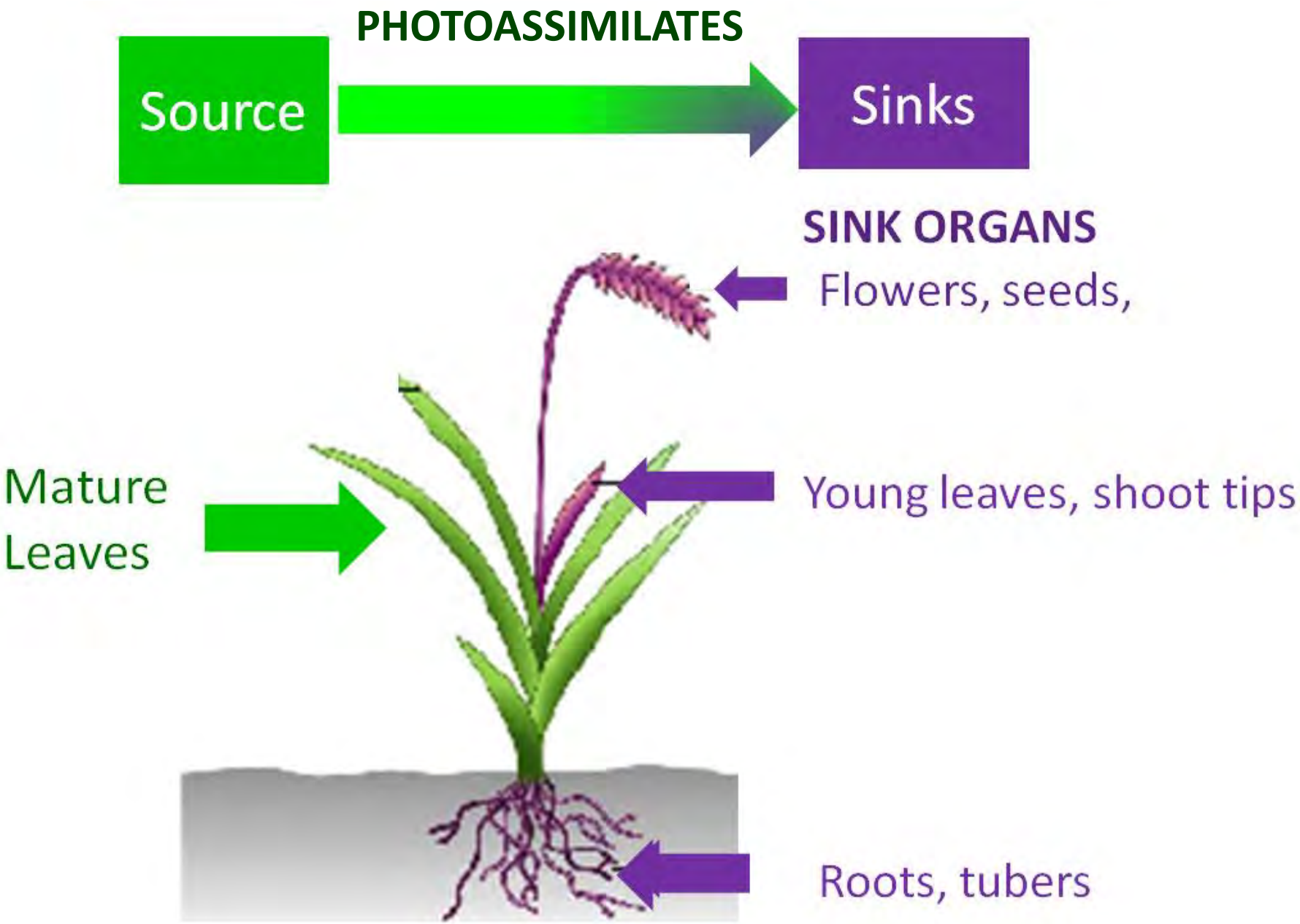


Severity of K deficiency

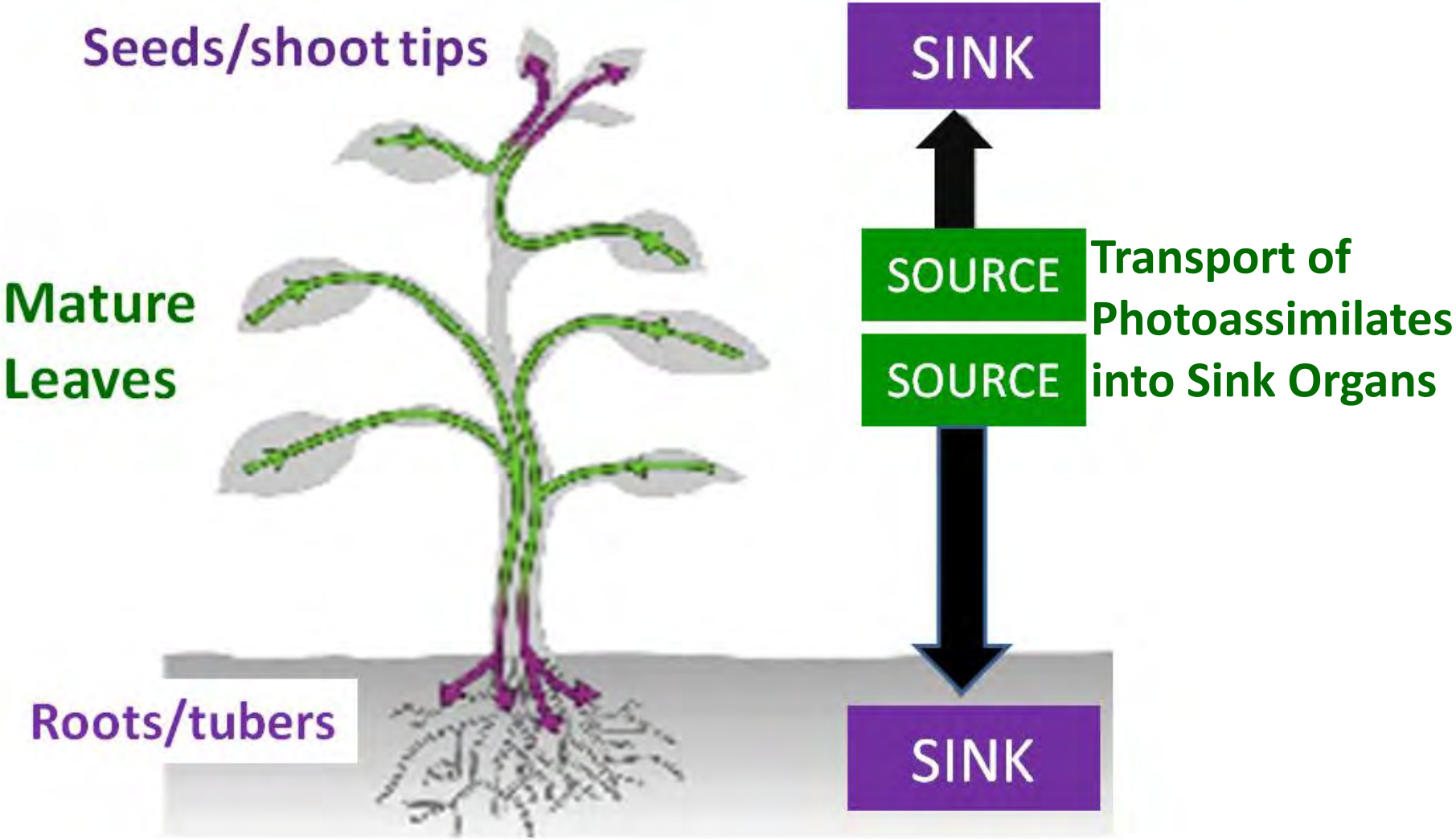
Bednarz, et al. 1998, Environ. Exp. Bot. 39: 131-139

Translocation of Photoassimilates within Plants and Role of Mineral Nutrients

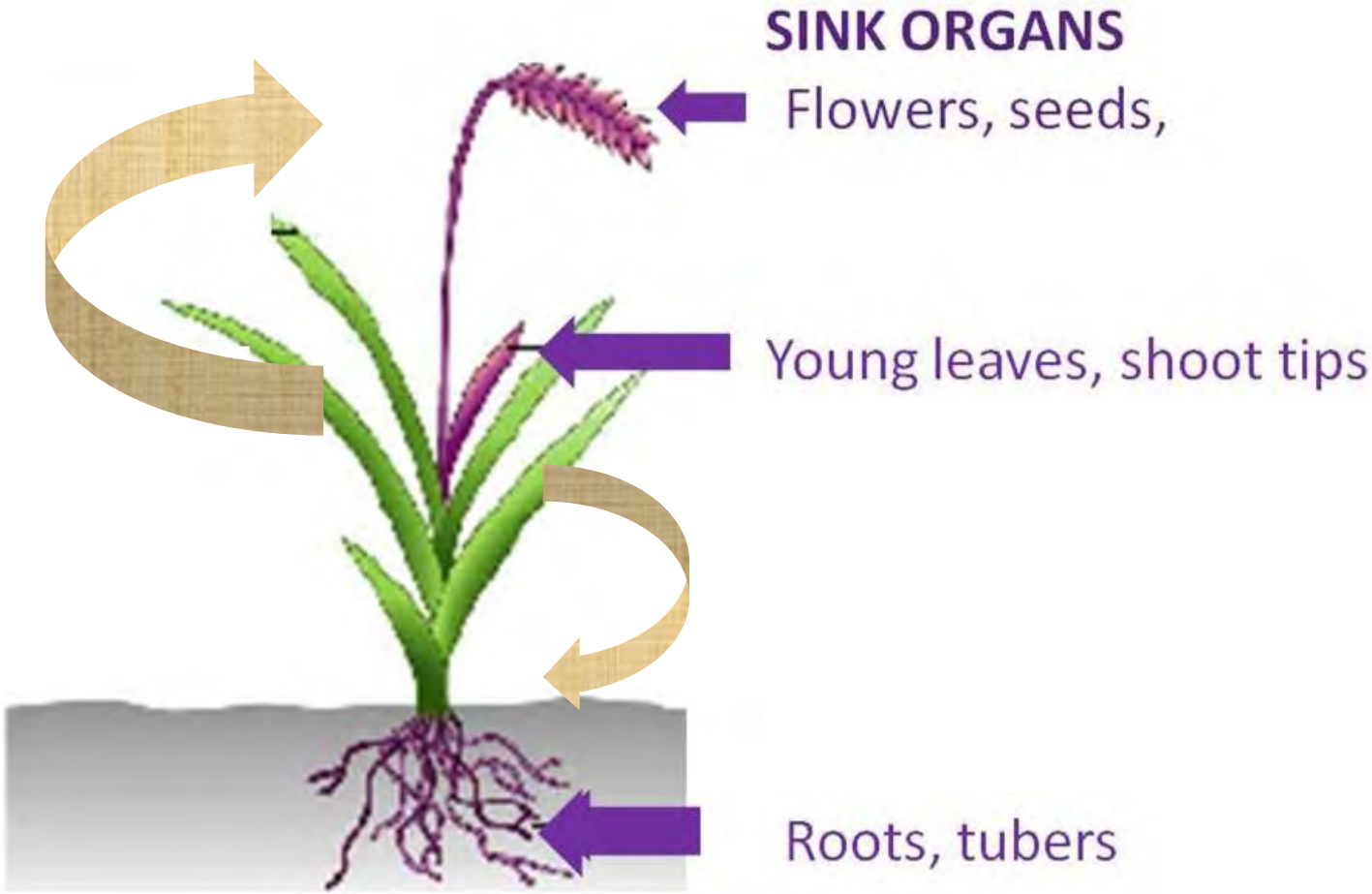



PHOTOASSIMILATES
Source
Sinks
SINK ORGANS
Flowers, seeds,
Mature Leaves
Young leaves, shoot tips
Roots, tubers

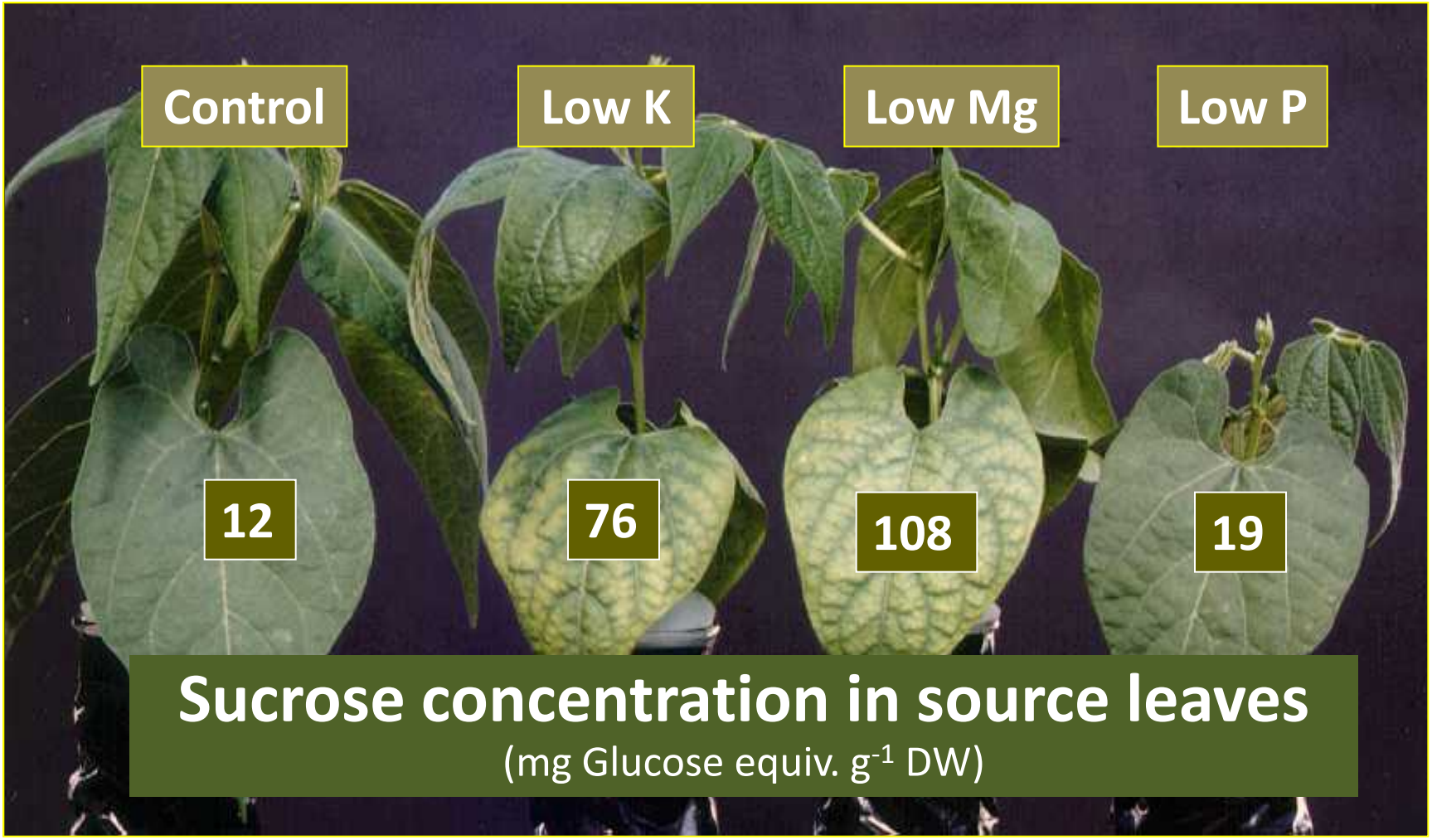
Source leaves deliver sugar to tissues on the same end of the plant



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



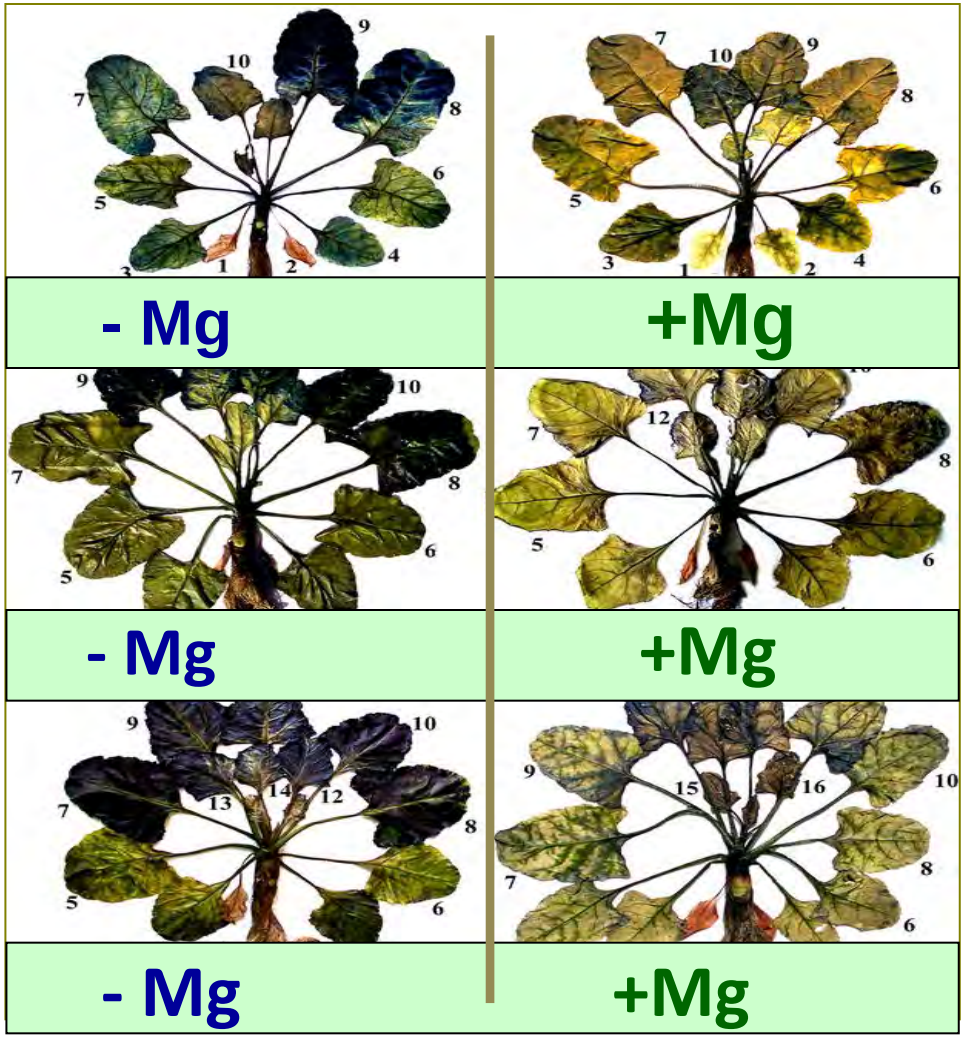
Cakmak et al., 1994b, J. Exp. Bot.

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

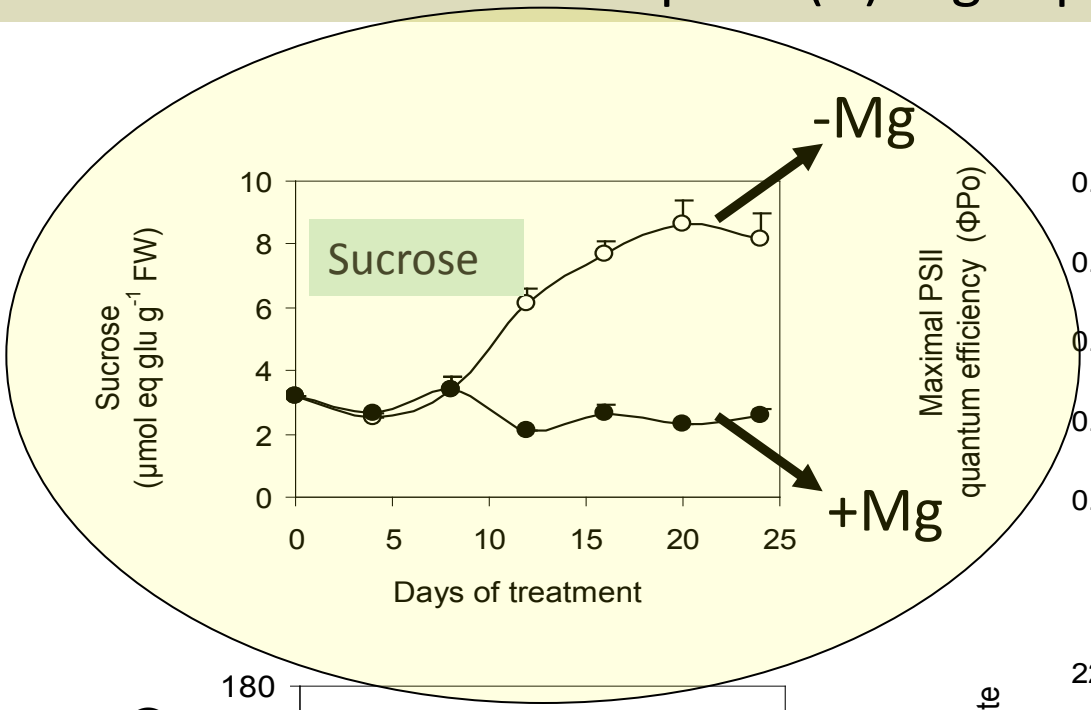
Days 16

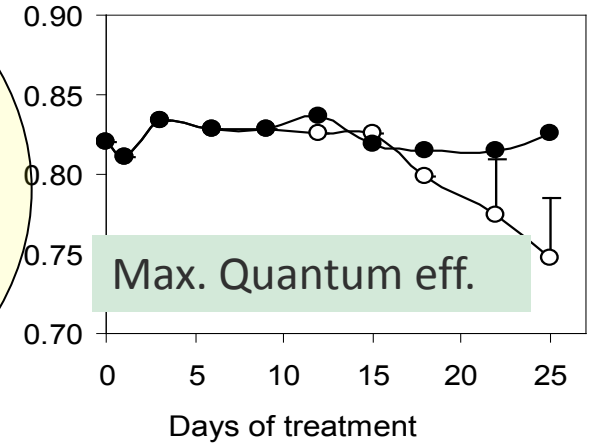
Days 20

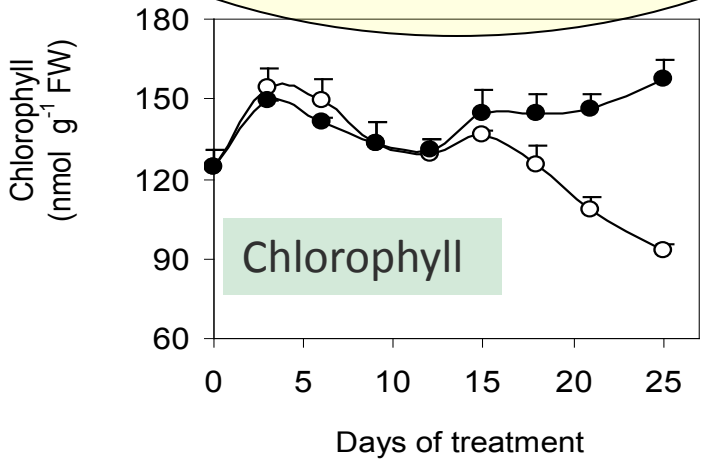
Hermans et al., 2005
Planta 220: 541-549

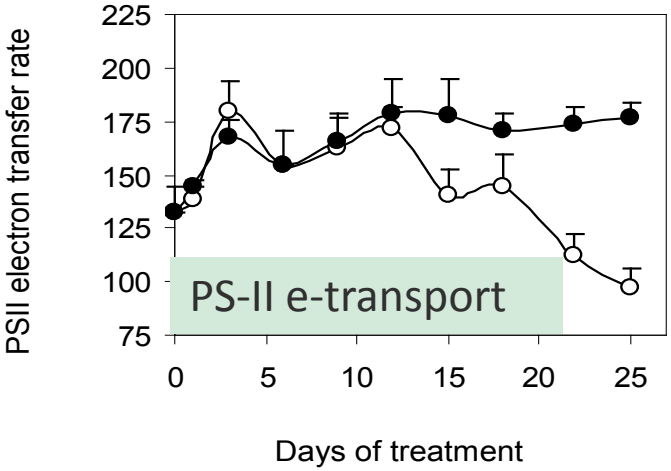
Sucrose, chlorophyll and maximal quantum efficiency and electron transport rate of PSII in sugar beet plants with deficient (O) and adequate ( ) Mg supply.

Hermans et al., 2004 Planta

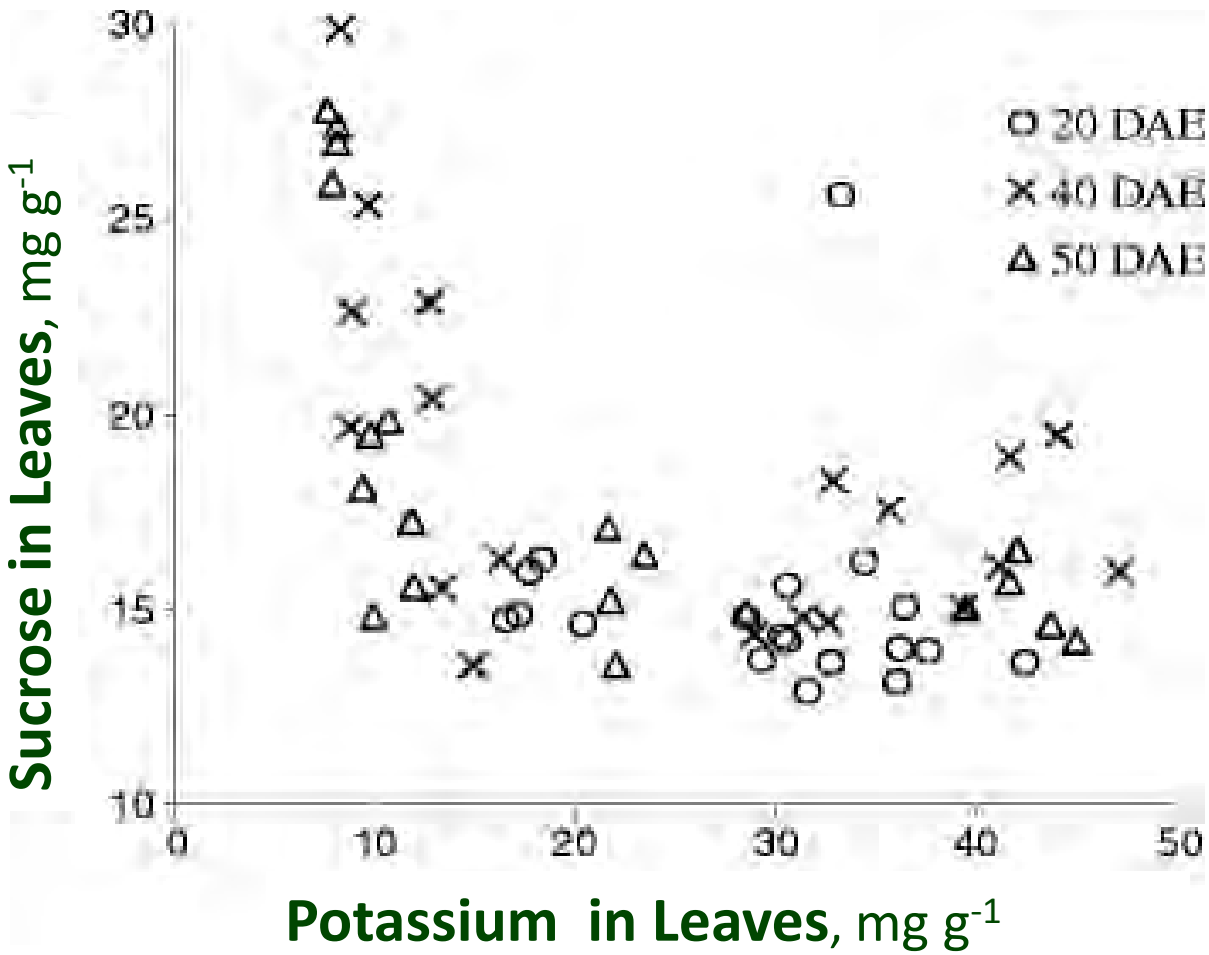








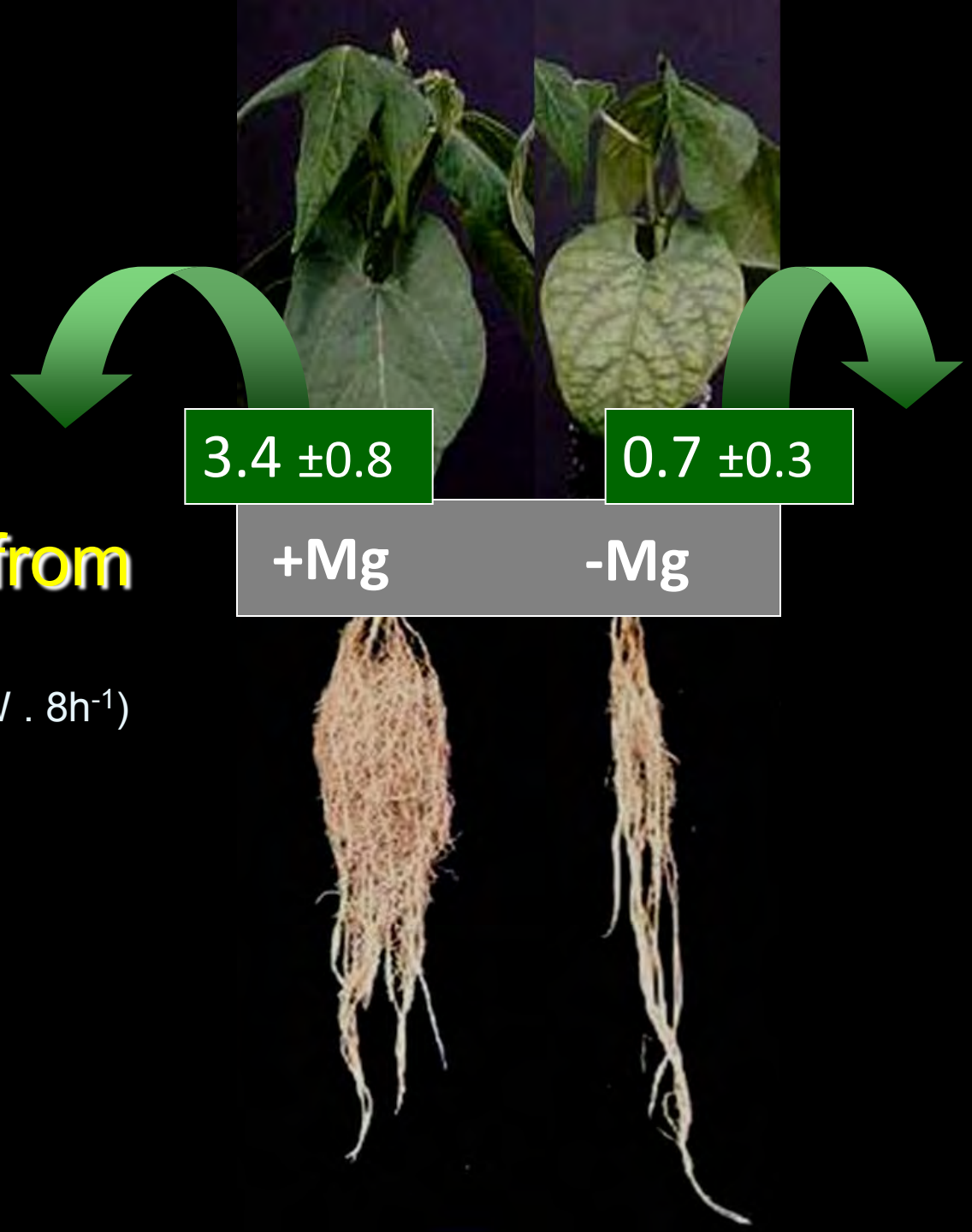
Relationship between sucrose and potassium concentrations in the first expanded leaves of cotton



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

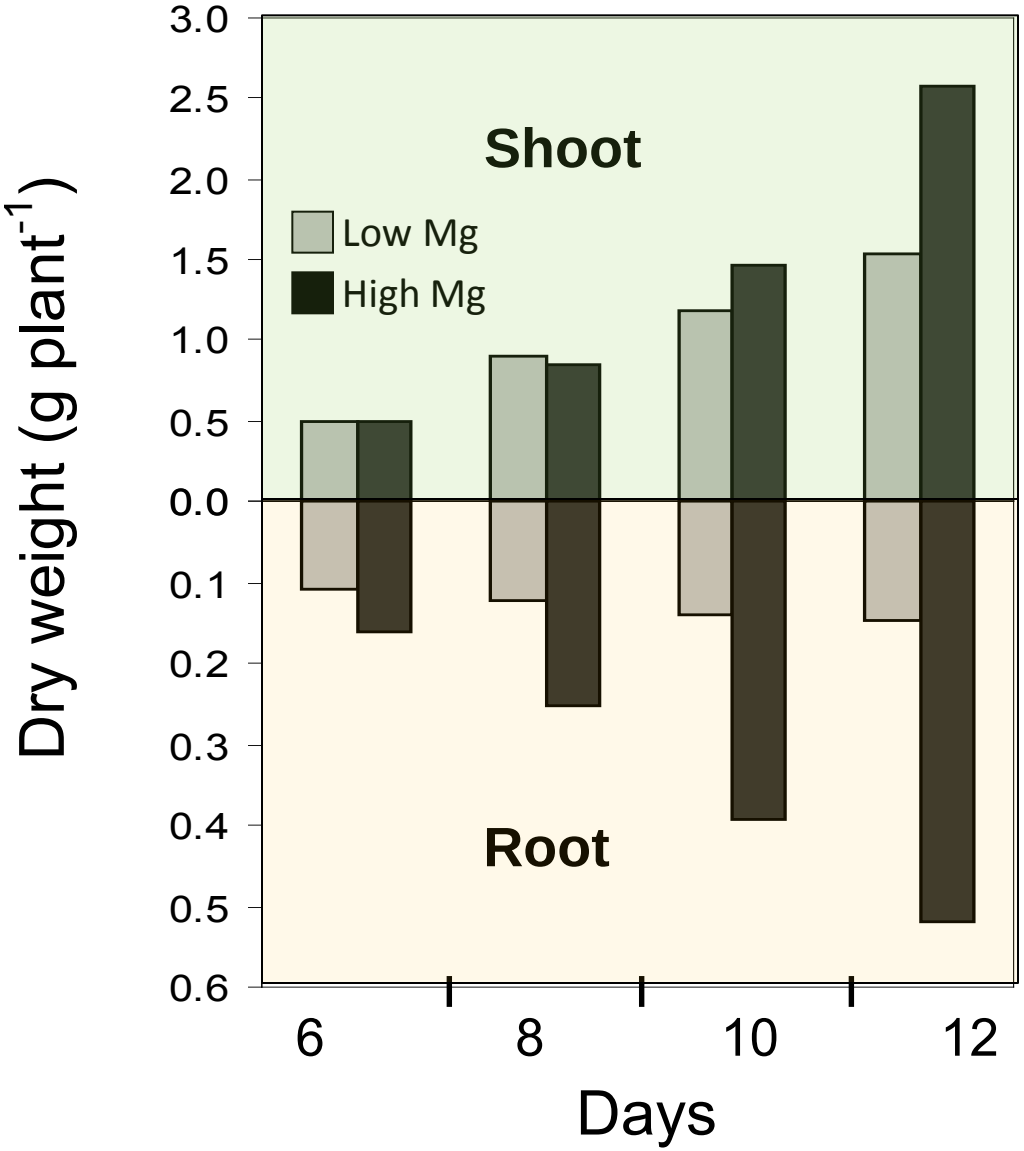
Sucrose export from Leaves

(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.

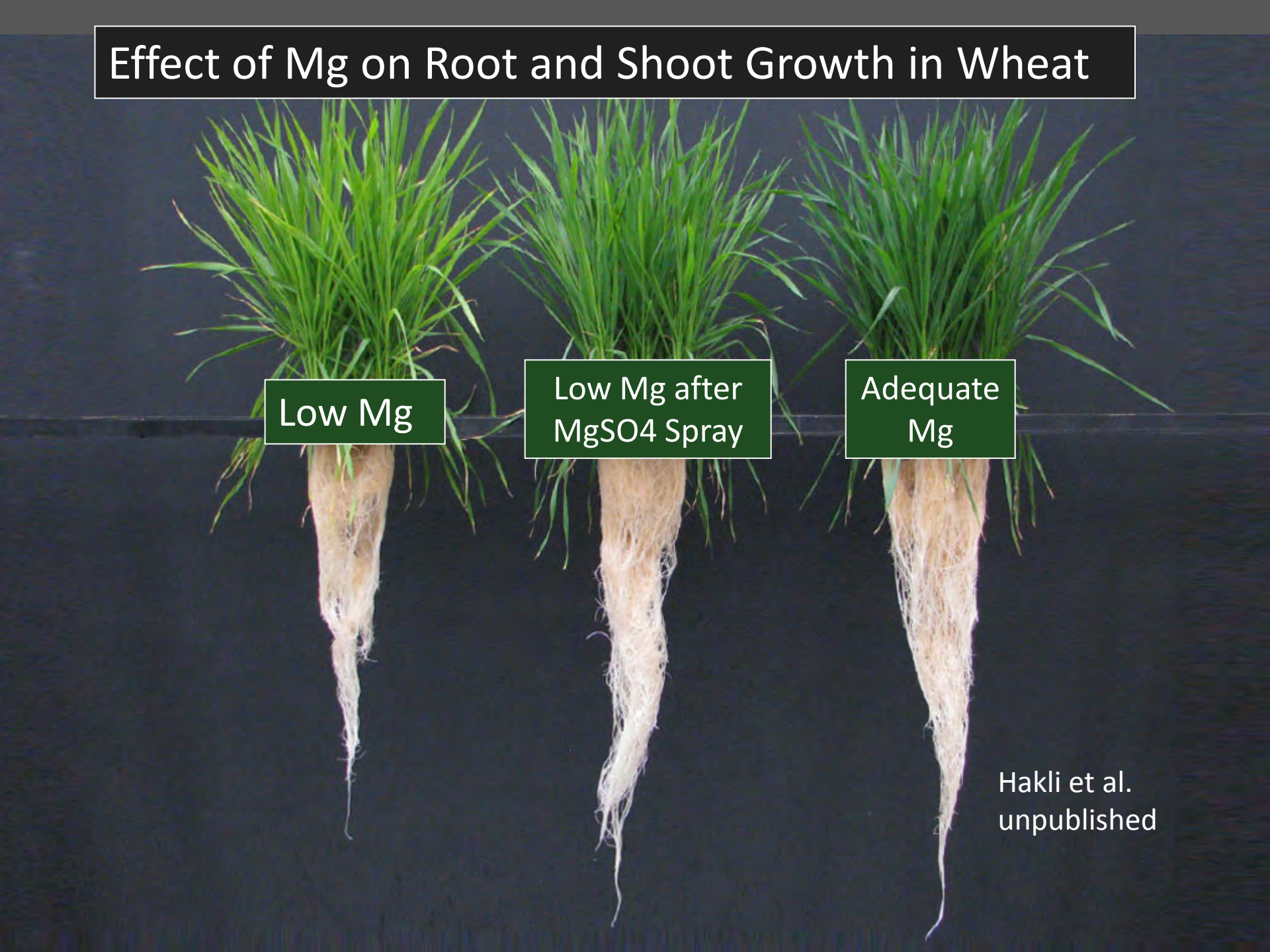
In field, impaired root growth under low Mg supply is not recognised !!

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

Effect of Mg on Root and Shoot Growth in Wheat

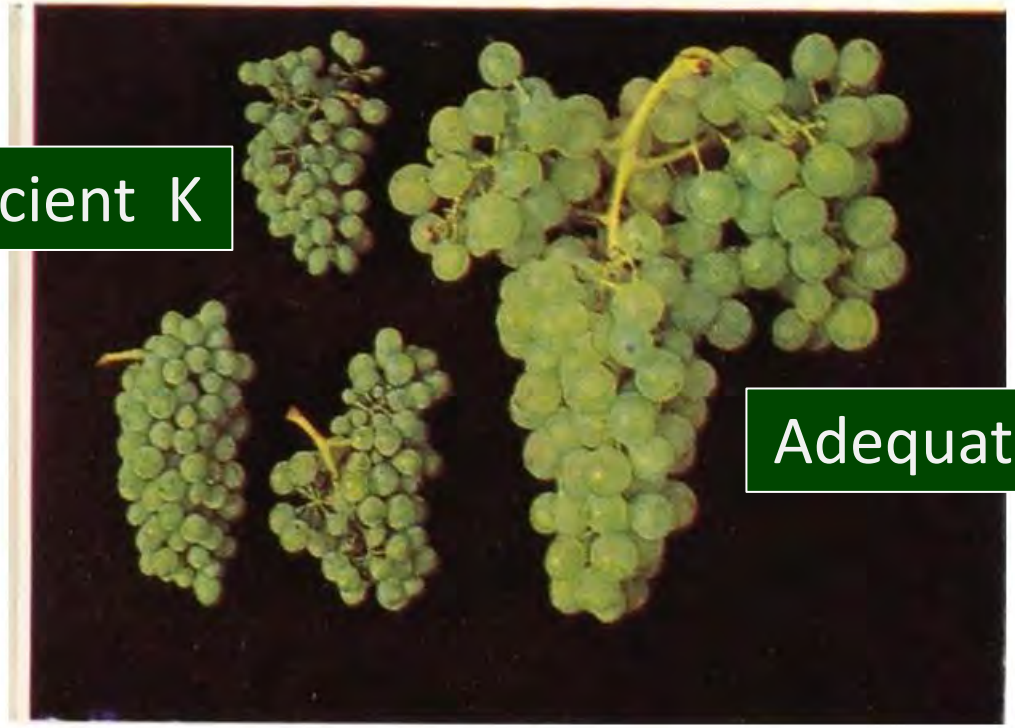
Hakli et al.
unpublished

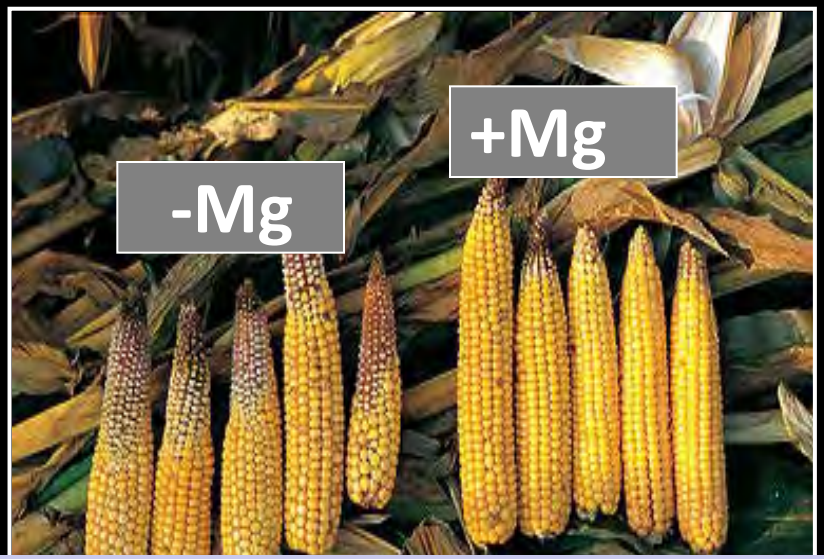
Effect of Mg on Root and Shoot Growth in Wheat



Hakli et al. unpublished

Sink Organs are very sensitive to K and Mg deficiencies





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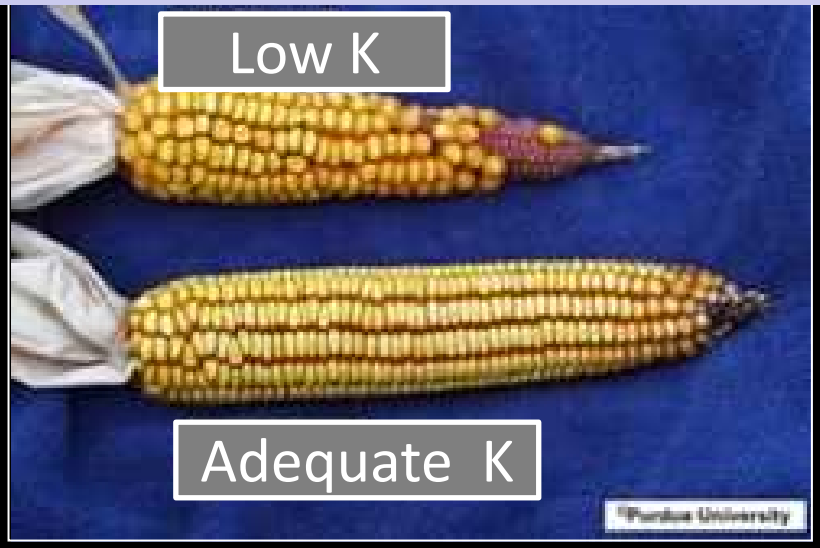


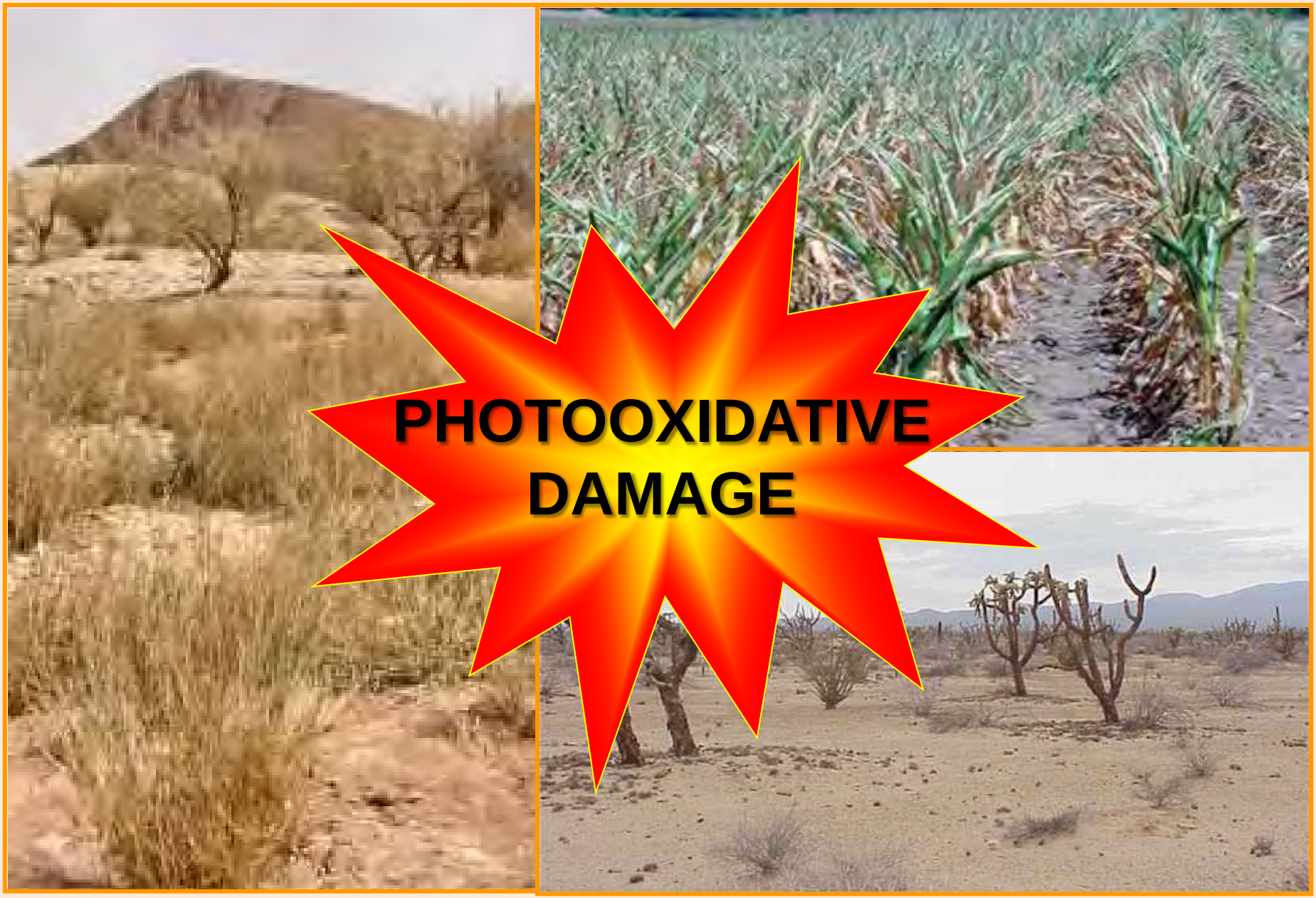
Cakmak and Kirkby, 2008, Physiol. Plant.

Video Film

Root growth with low and adequate Mg Suypply

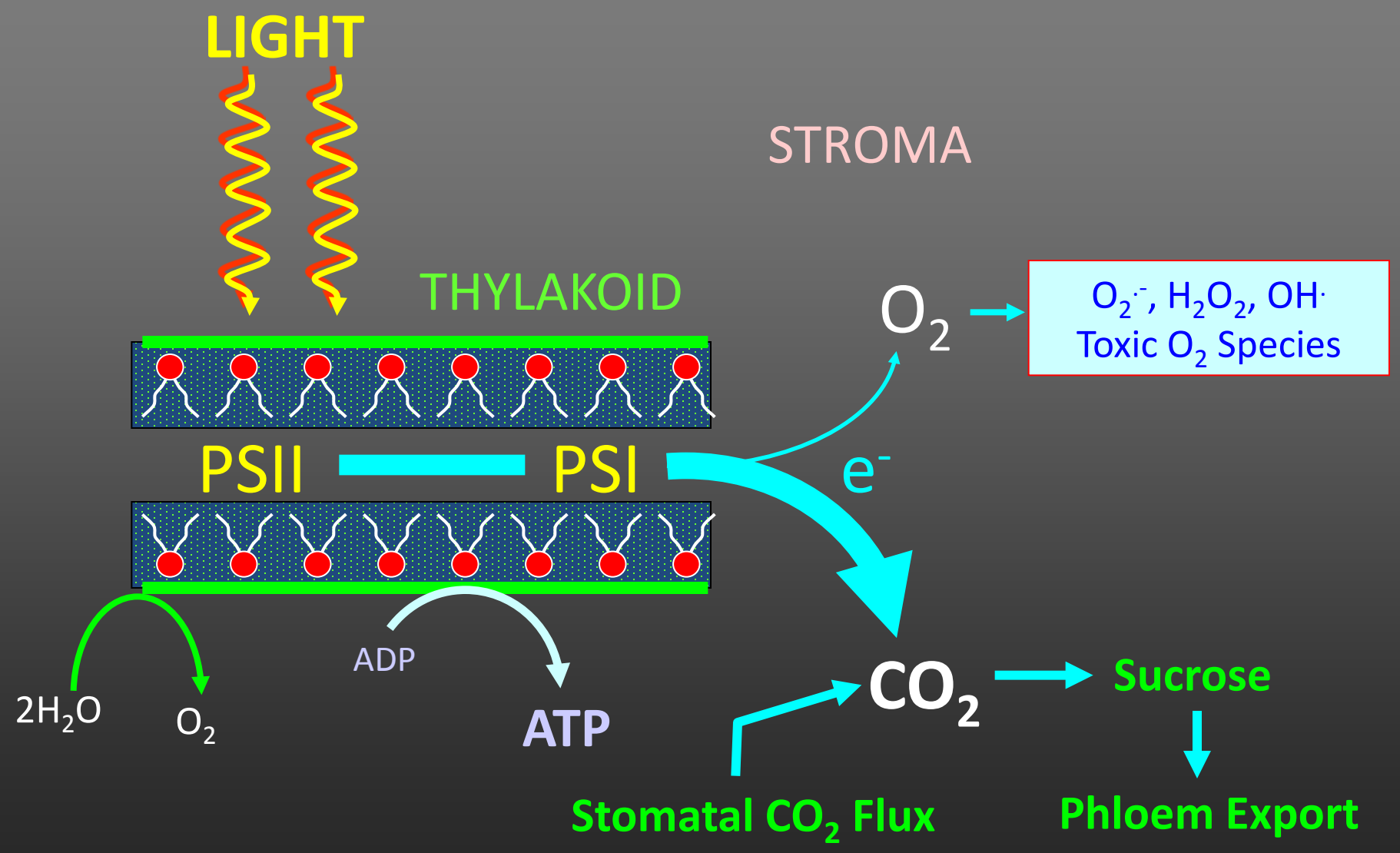
Some Conclusions Regarding K and Mg Effect on Sugar Transport

- 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

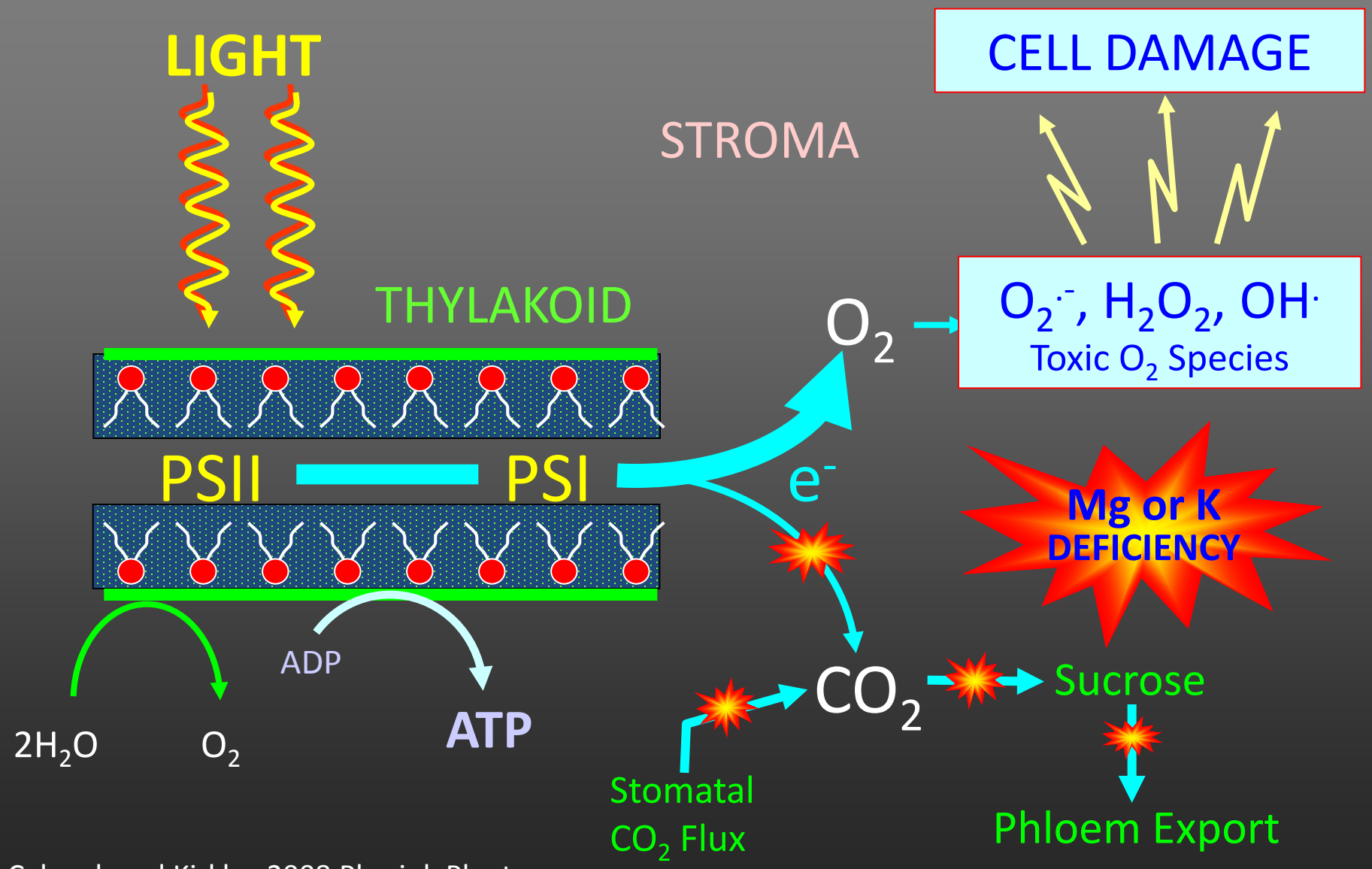
PHOTOOXIDATIVE DAMAGE UNDER MINERAL NUTRIENT DEFICIENCY

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



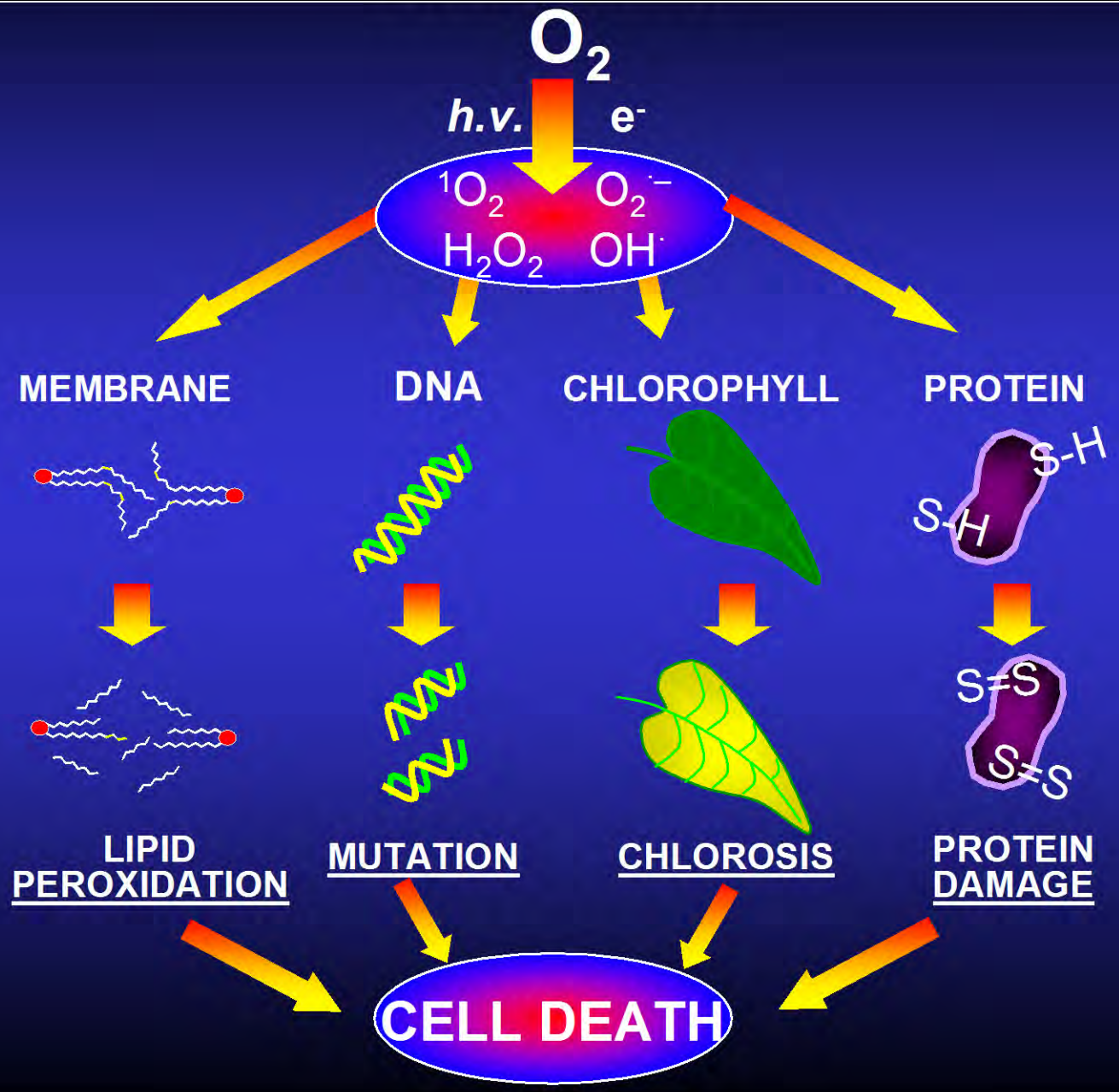
Cakmak, 2005; Soil Sci. Plant Nutr.

Photosynthetic Electron Transport and Superoxide Radical Generation

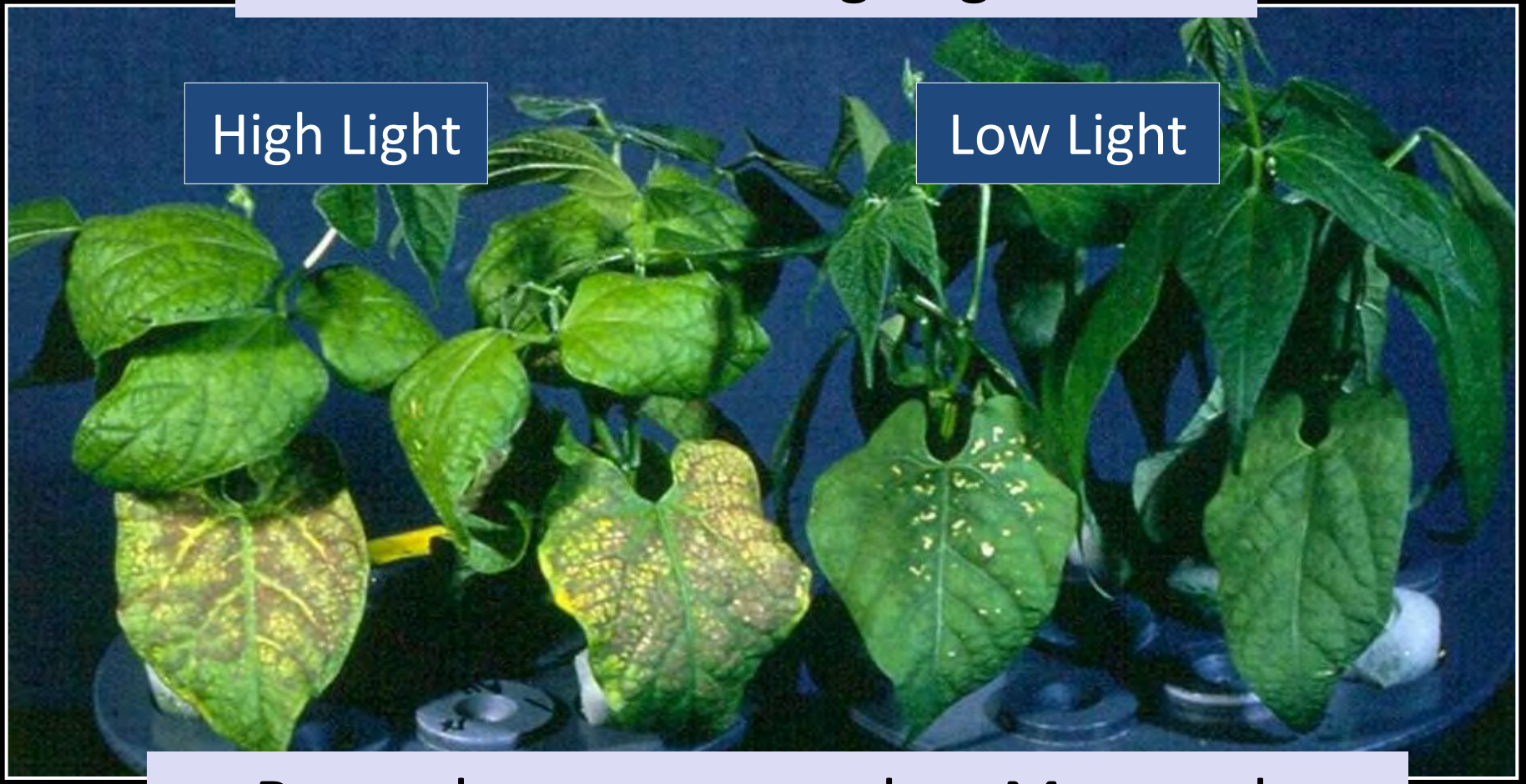


Cakmak and Kirkby, 2008 Physiol. Plant

FREE RADICAL DAMAGE TO CRITICAL CELL CONSTITUENTS

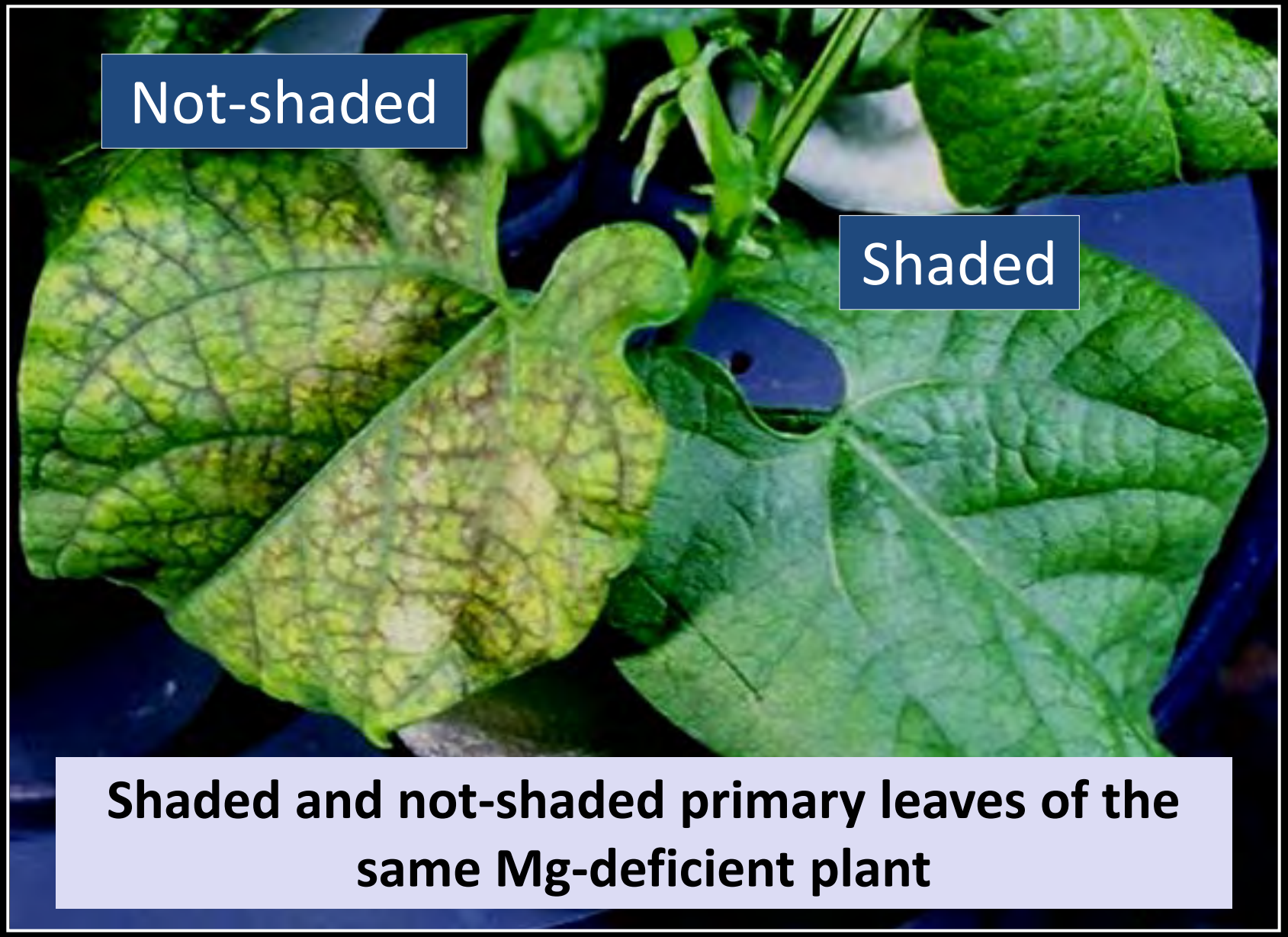


Mg-deficient plants highly sensitive to high light



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

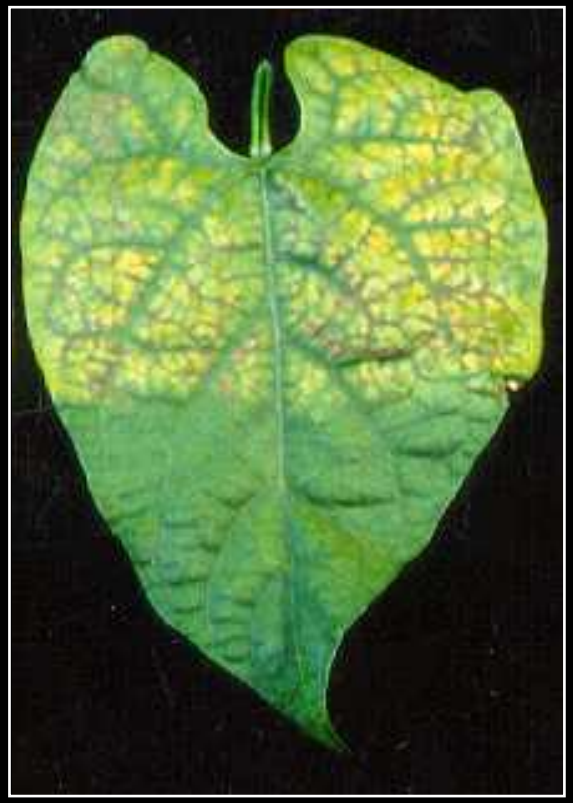
Growth of bean plants with deficient K supply under low and high light intensity

Marschner and Cakmak, 1989

Enhancement of photooxidative damage in K-deficient leaves

Partially shaded K-deficient bean leaves

Marschner and Cakmak, 1989

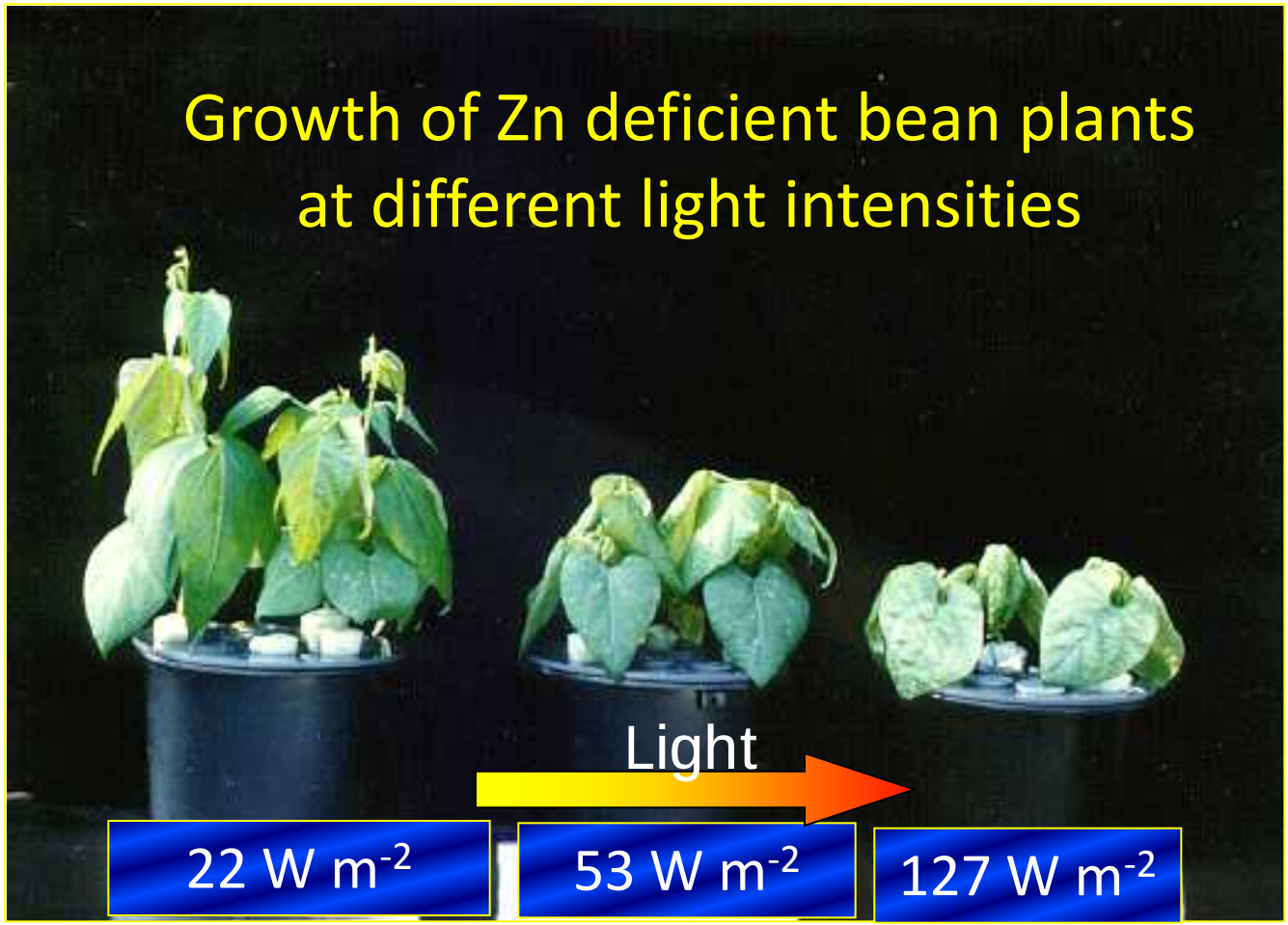


K and Mg is greatly needed for efficient use of absorbed light energy in photosynthetic CO_2 fixation to avoid light damage.

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

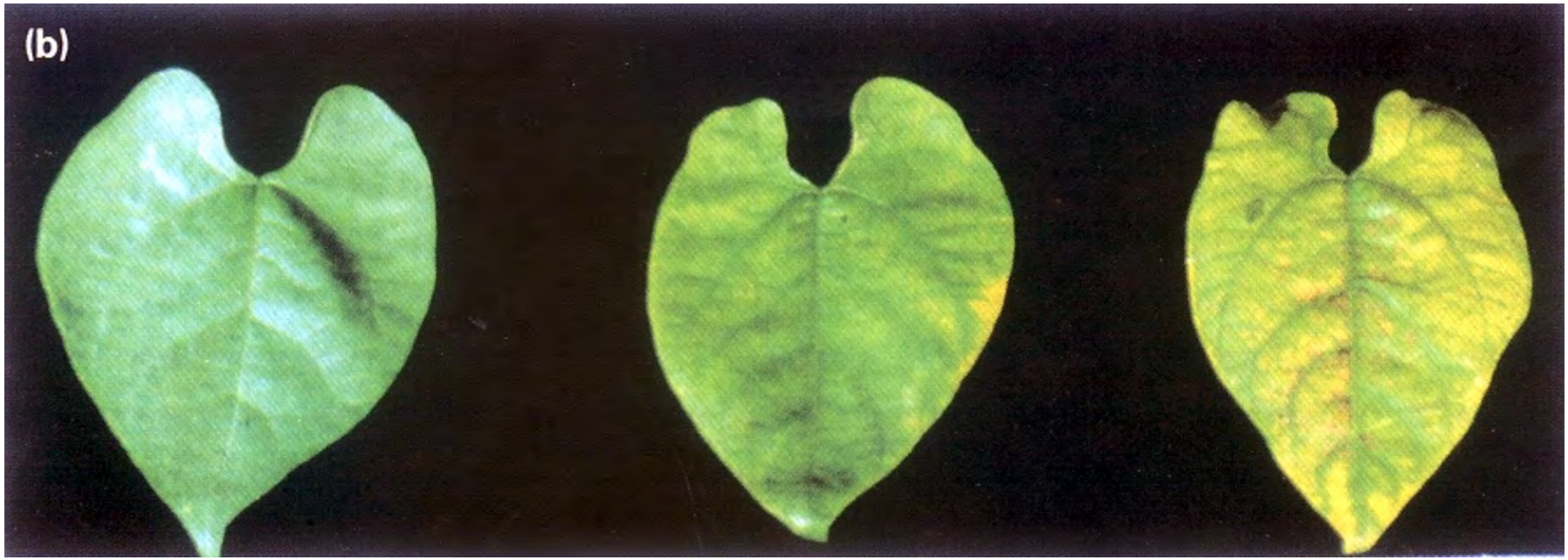
ZINC-DEFICIENT PLANTS ARE HIGHLY PHOTOSENSITIVE

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?

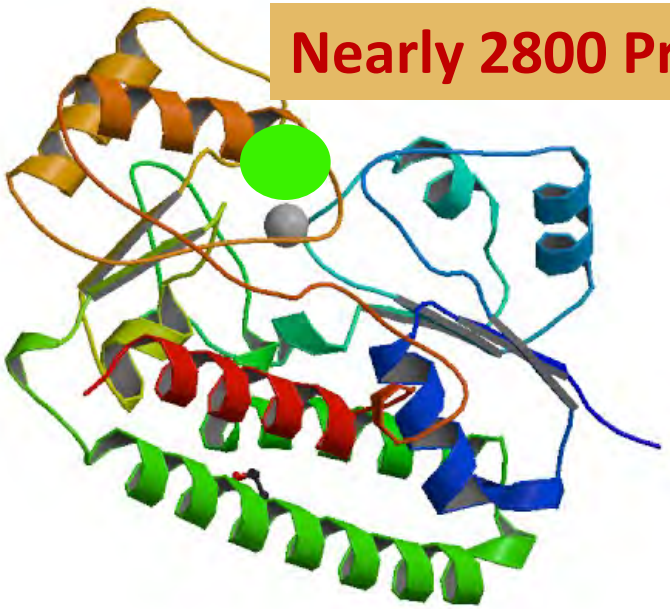
- In many different agro ecosystems micronutrients are growth limiting, and this problem is often hidden
- Micronutrients can play an important role in abiotic and biotic stress resistance (especially resistance against diseases, drought or heat).
- Micronutrients play a particularly important role in 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

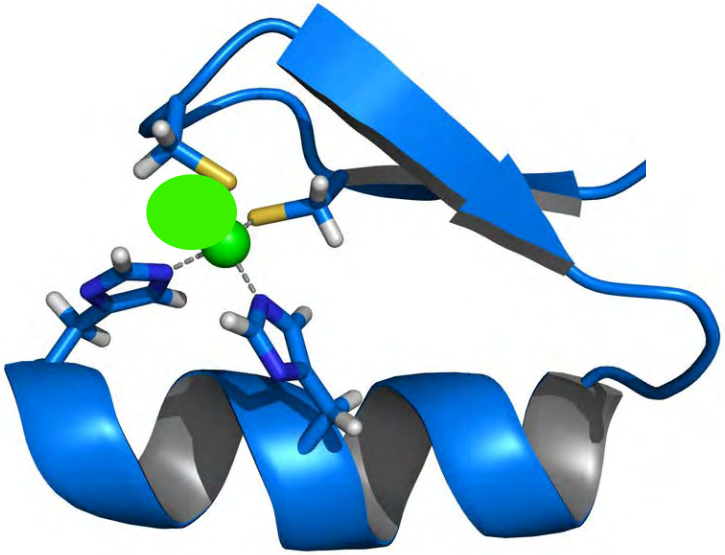
Nearly 2800 Proteins are Zn-dependent



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

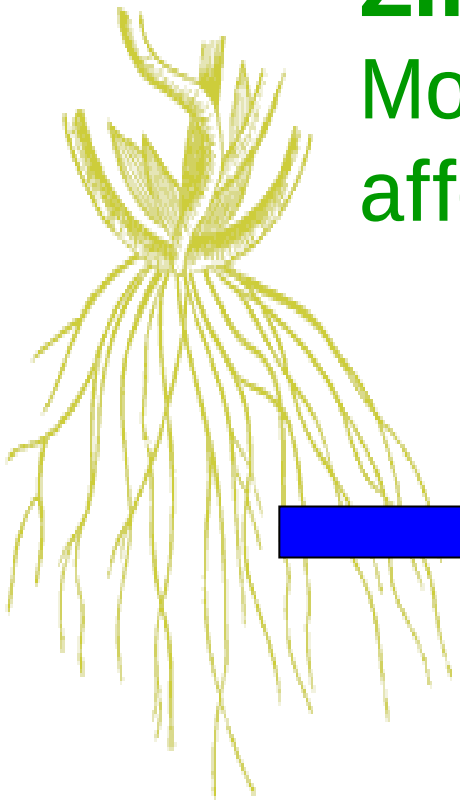
: Zinc

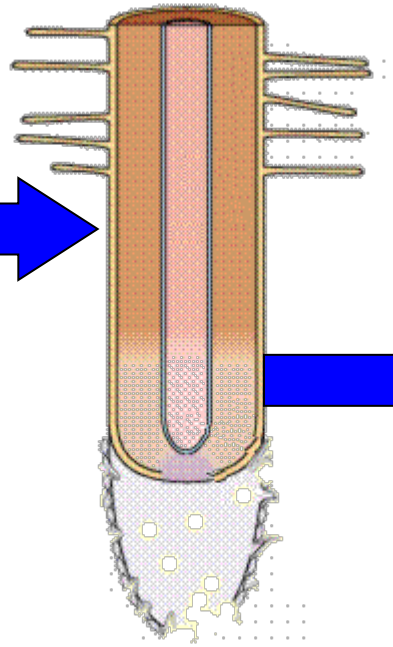
http://commons.wikimedia.org/wiki/User:Splette



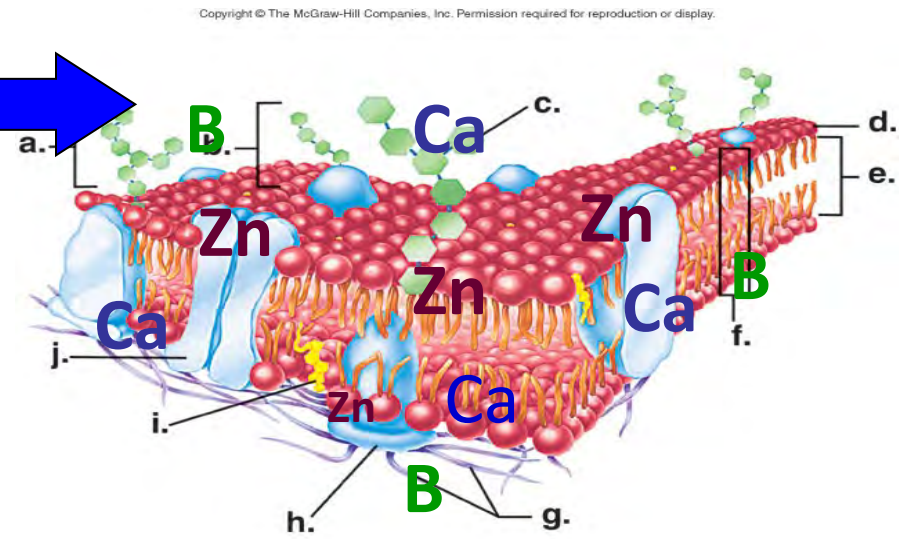
Zinc and Boron:

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**

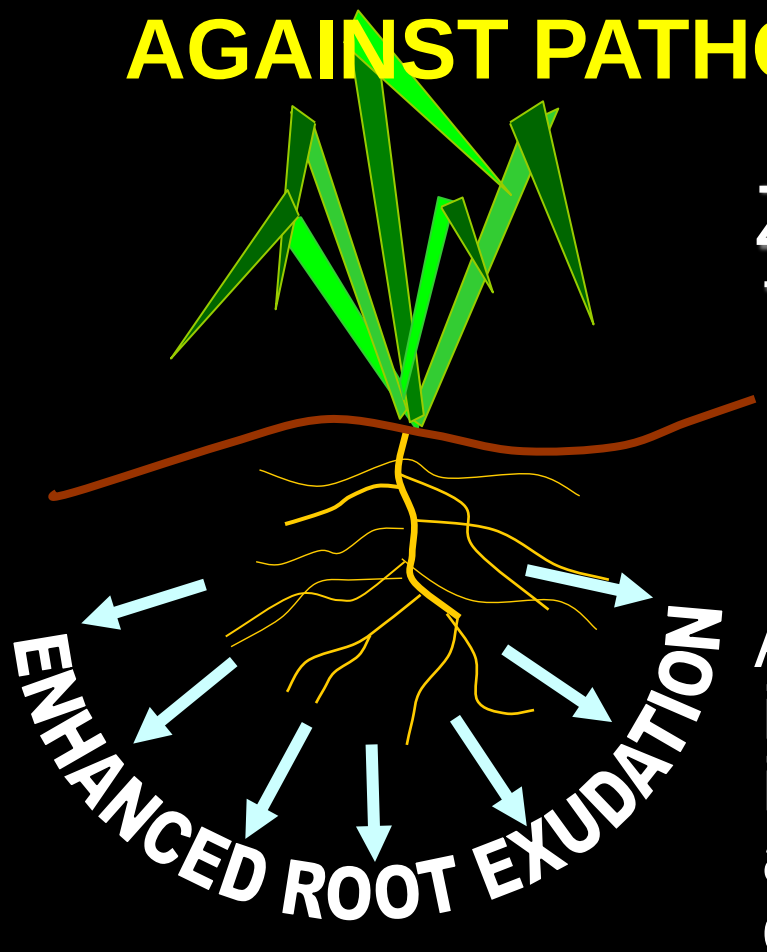
4) Involvement in **seed viability**

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



Amino acids
Sugars..

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.

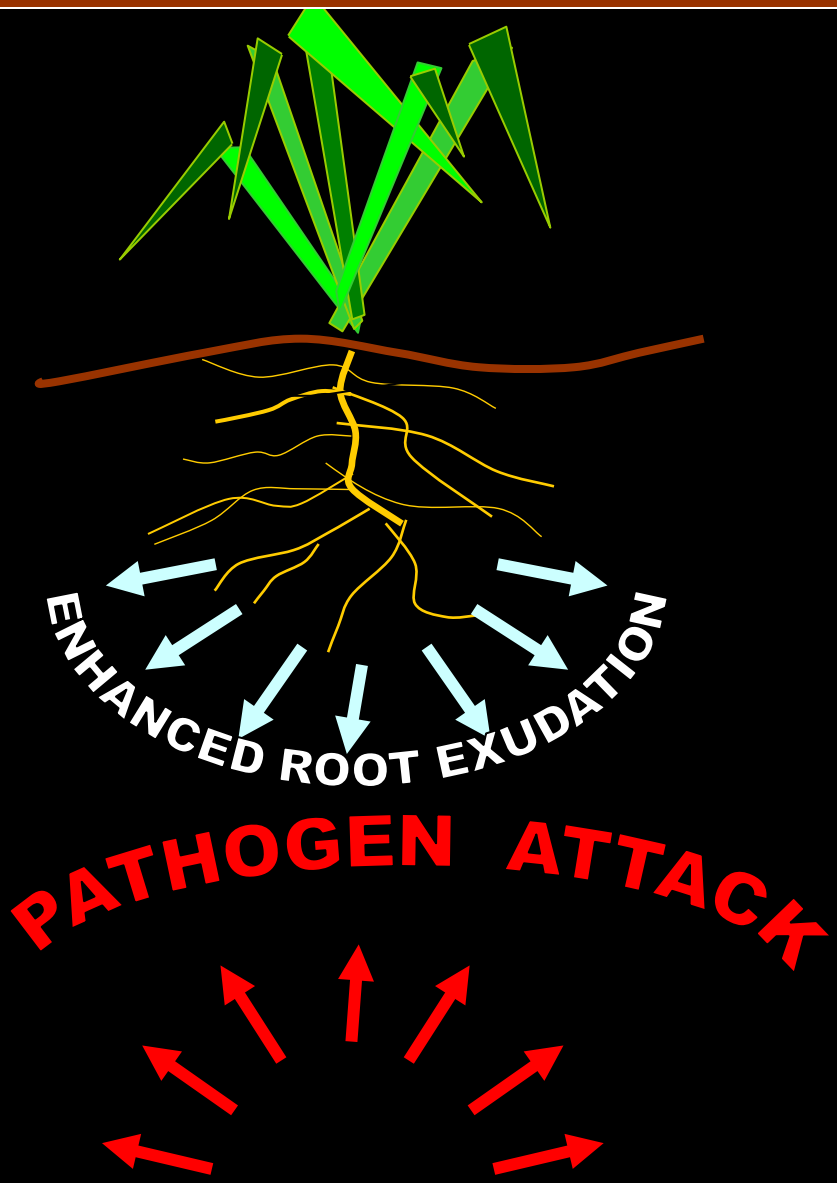
Boron Deficiency-Induced Membrane Permeability

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

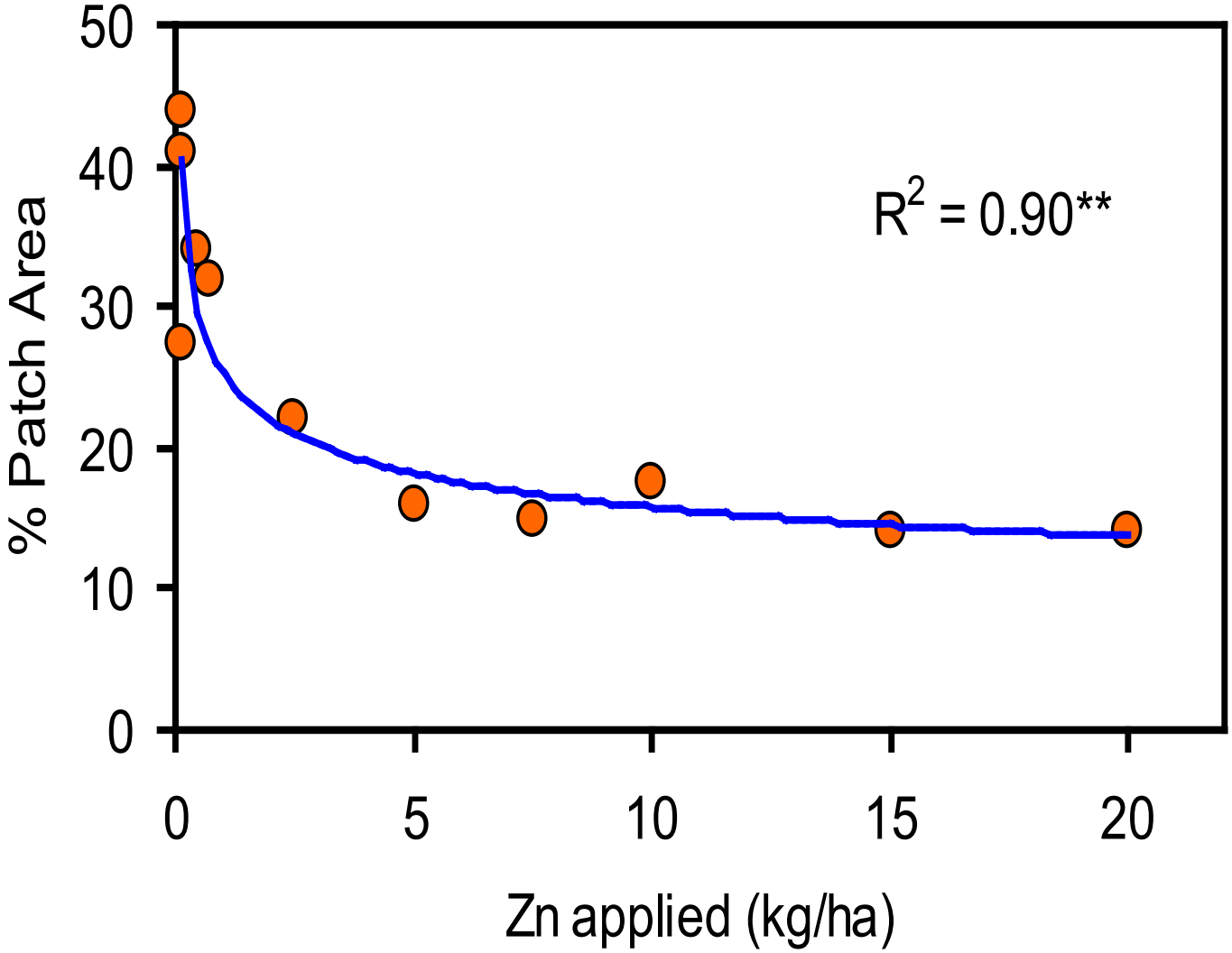
B supply	Potassium	Sucrose	Phenolics	Amino acids
(µM)			(µg g-1 FW [2h]$^{-1}$)	
0.01	**630**	**900**	**79**	**163**
0.20	390	440	72	122
1.0	52	70	17	33
20.0	**18**	**20**	**13**	**23**

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

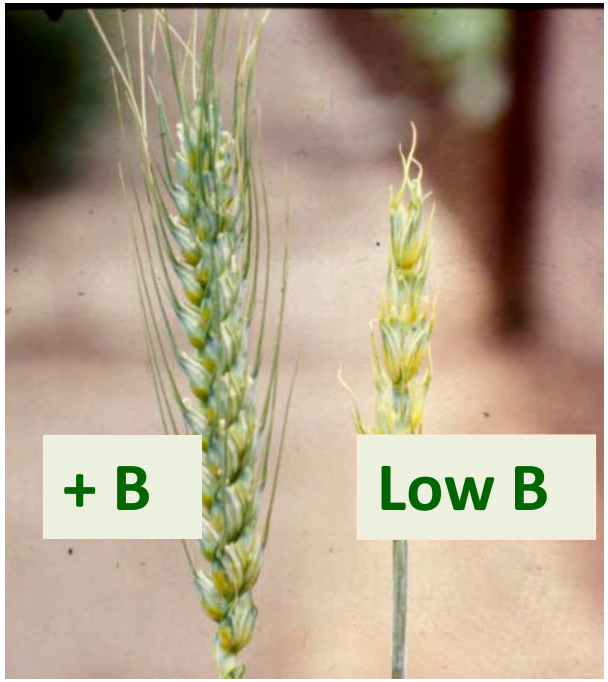
Effect of the Mo supply to maize on numbers of pollen grains and pollen germination rate (Agarwala et al., Can. J. Bot. 1978

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

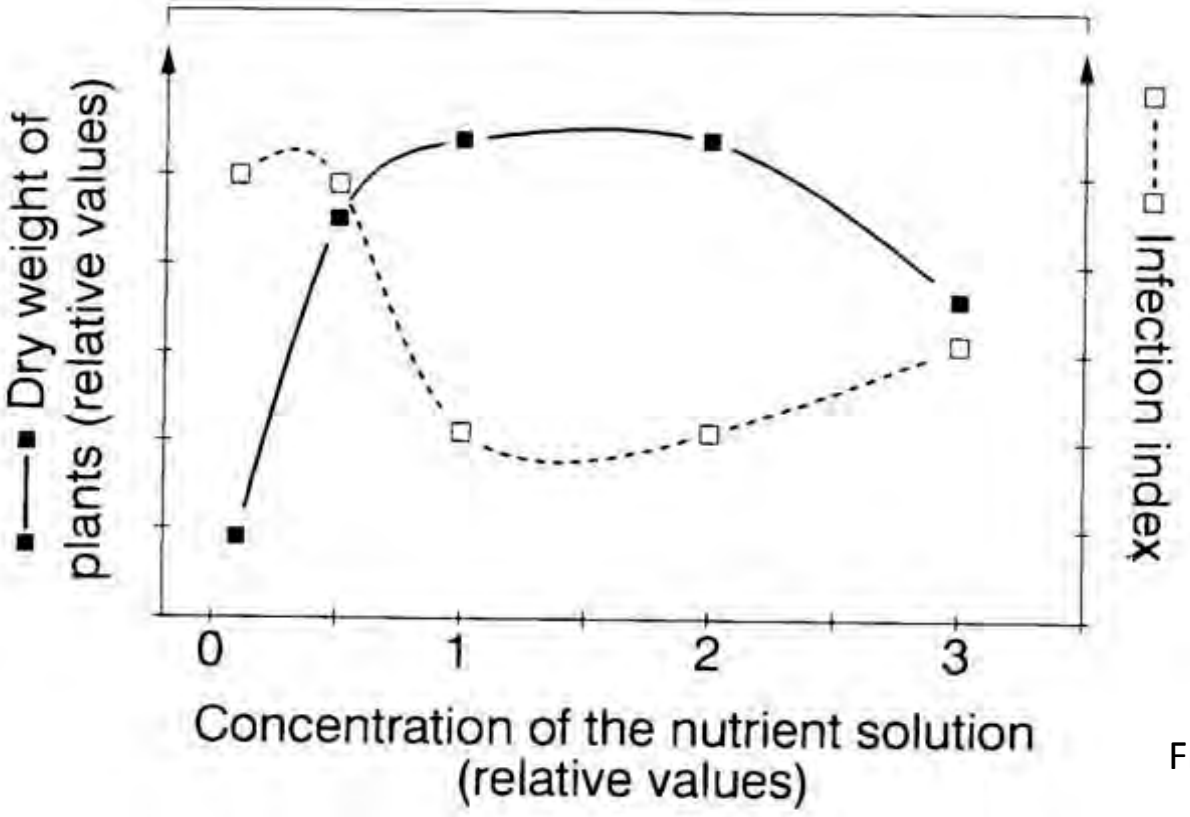
Transgenic plants:
Phloem Mobile B
Yield: 21 g seed

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

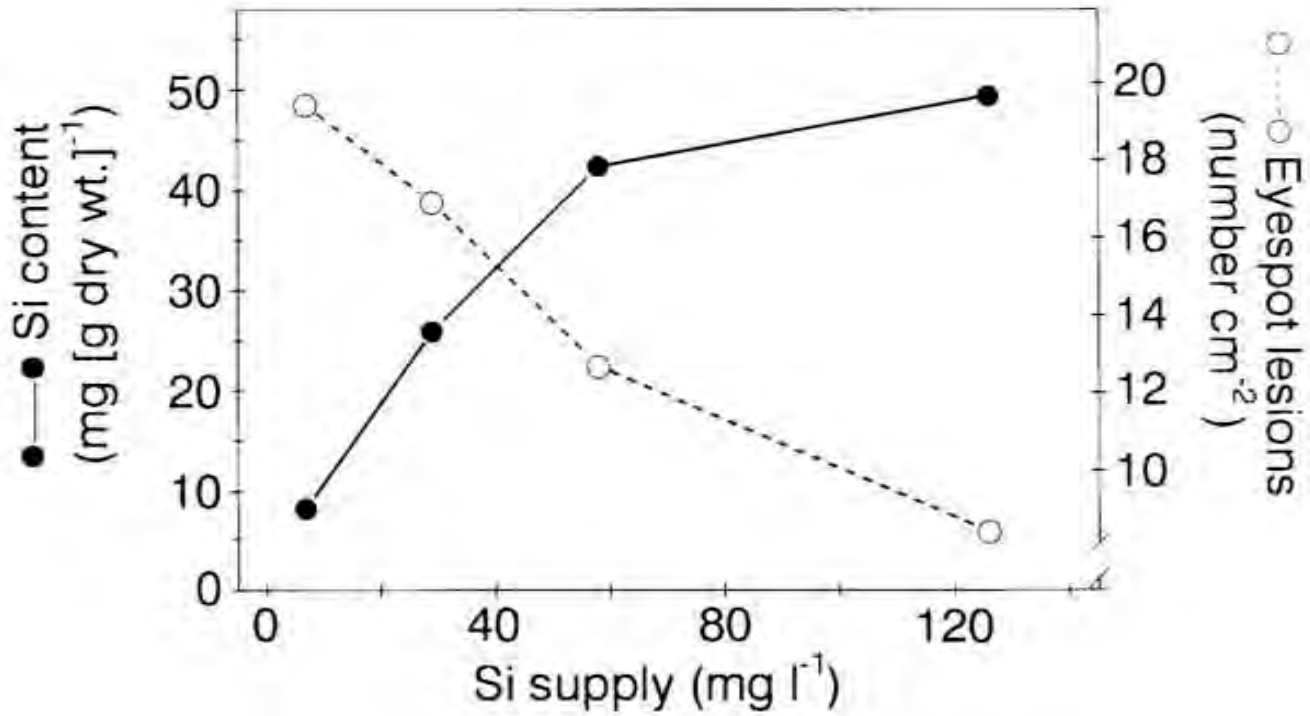
Nutritional status of plants affects tolerance against pathogens through different mechanisms

For example

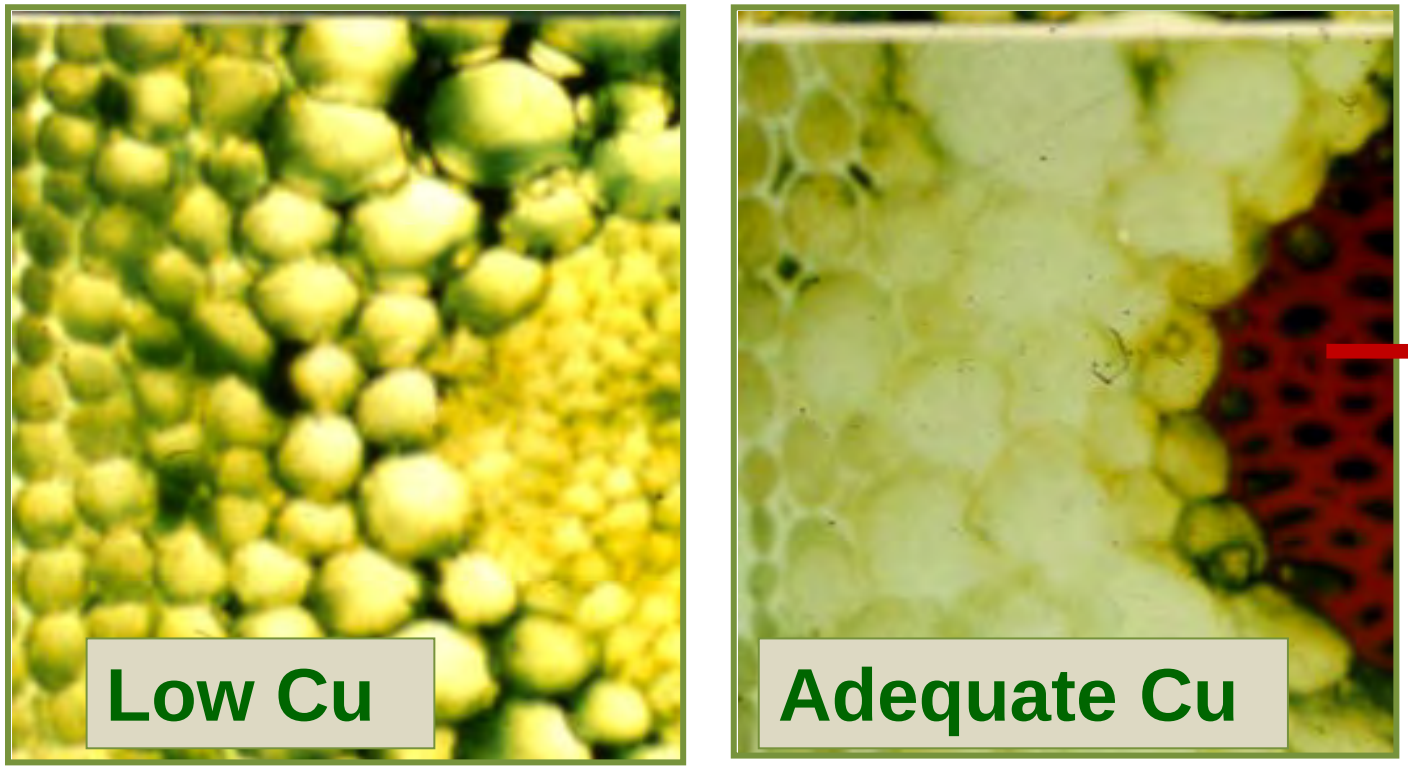
- Enhanced germination/infection of pathogen spores through exudation of sugars and amio acids from root or leaf cells caused by mineral deficiency (Ca, Zn, B deficiencies)
- Enhanced penetration of pathogens into cell walls due to instability or weakness of cell walls caused by nutrient deficiencies 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)

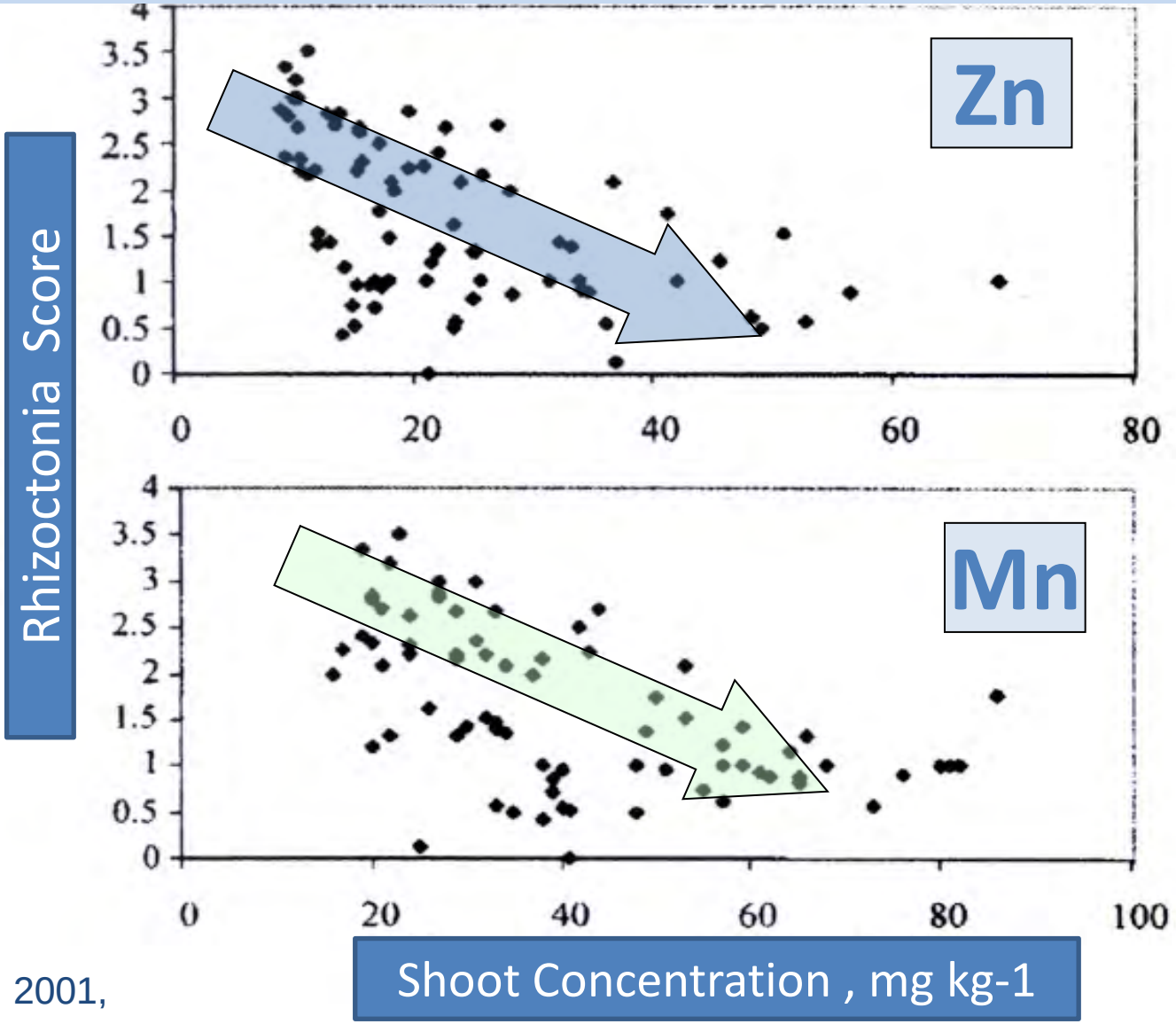
Root lesions (take all) and lignin content in root tissue of wheat at different Mn treatments

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

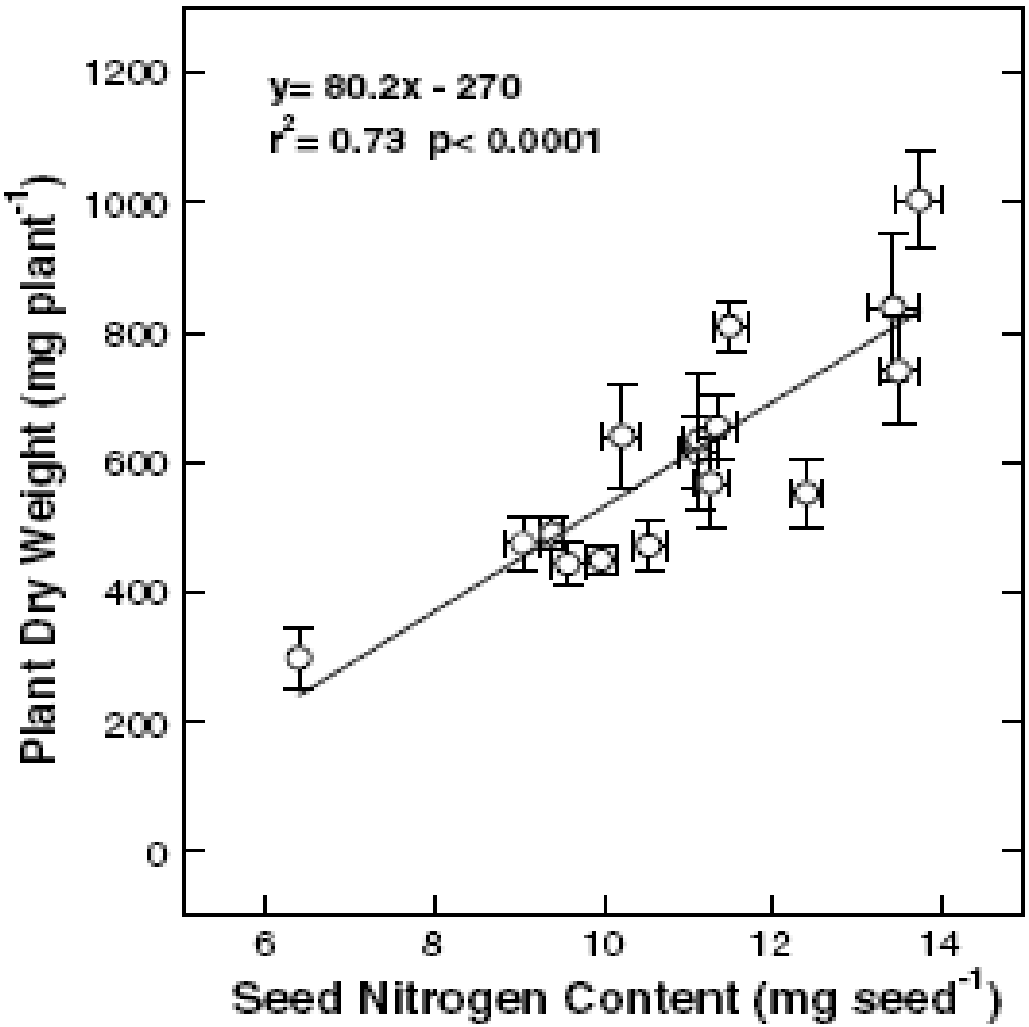


Steer et al., 2001, Plant Soil

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

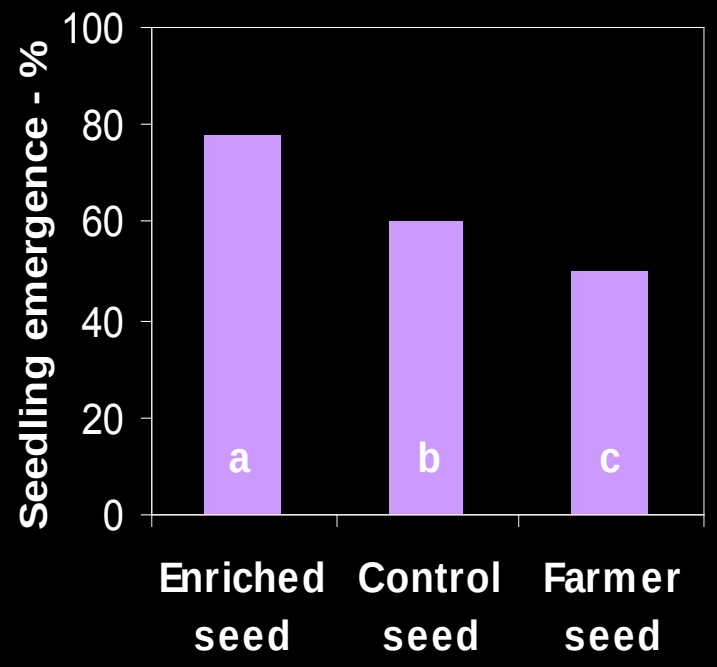
Data from Peltonen-Sainio (Agron. J. 2006; 98:206-211)

Impact of Micronutrient Dense Rice Seed in Bangladesh

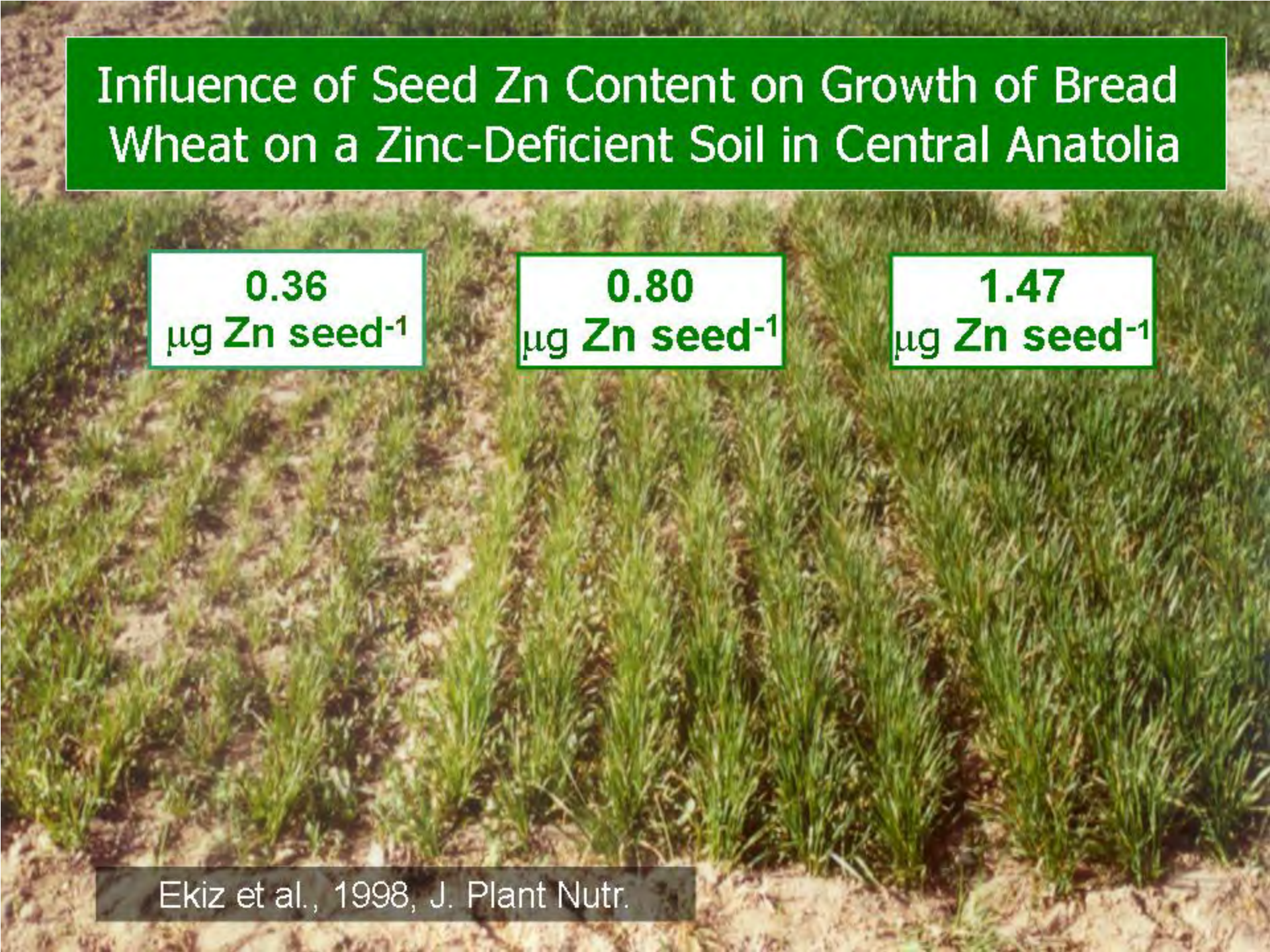
(data from J. Duxbury, 2002, Cornell Univ.)

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 $p < 0.1$



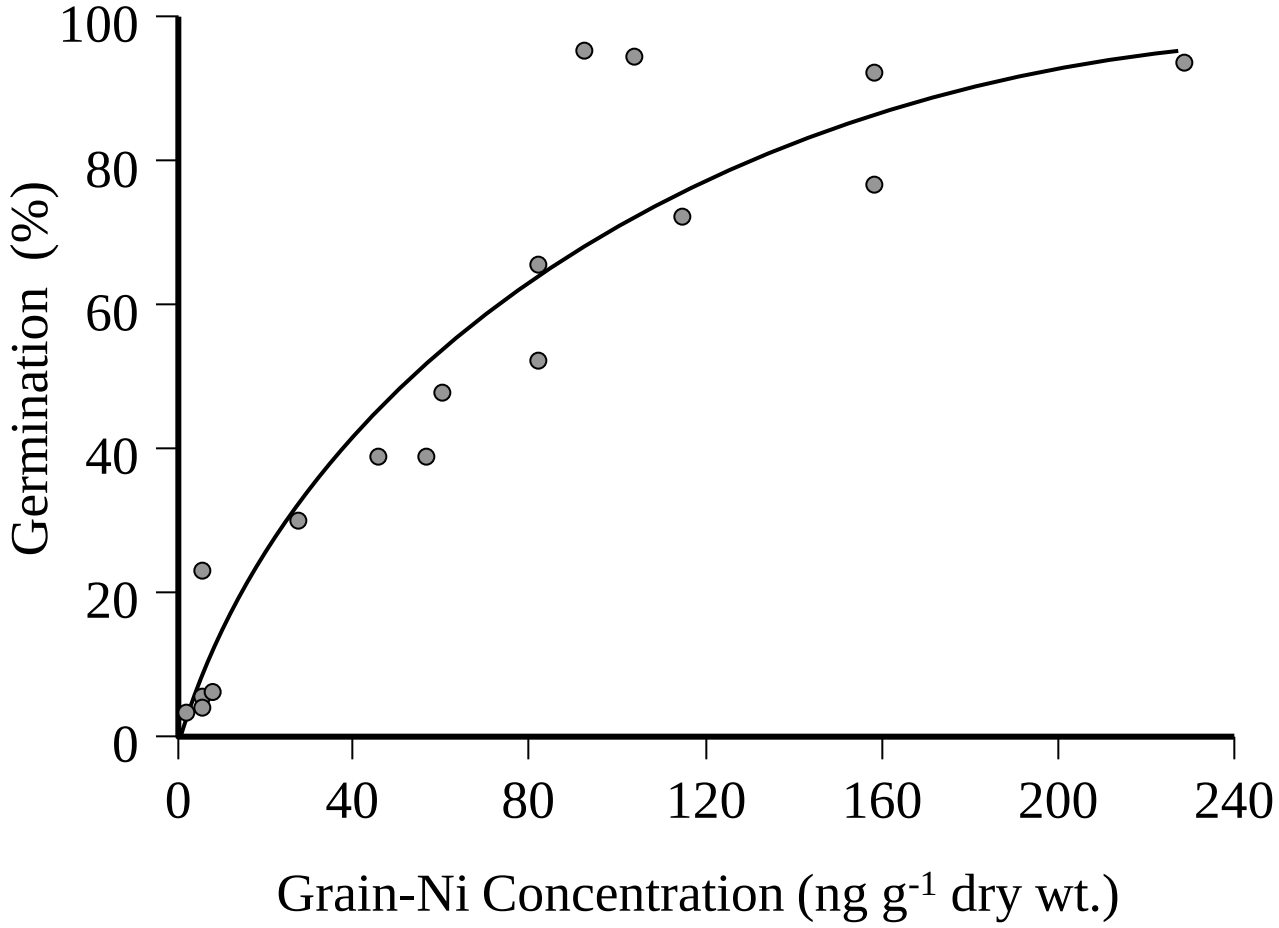
Influence of Seed Zn Content on Growth of Bread Wheat on a Zinc-Deficient Soil in Central Anatolia



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)



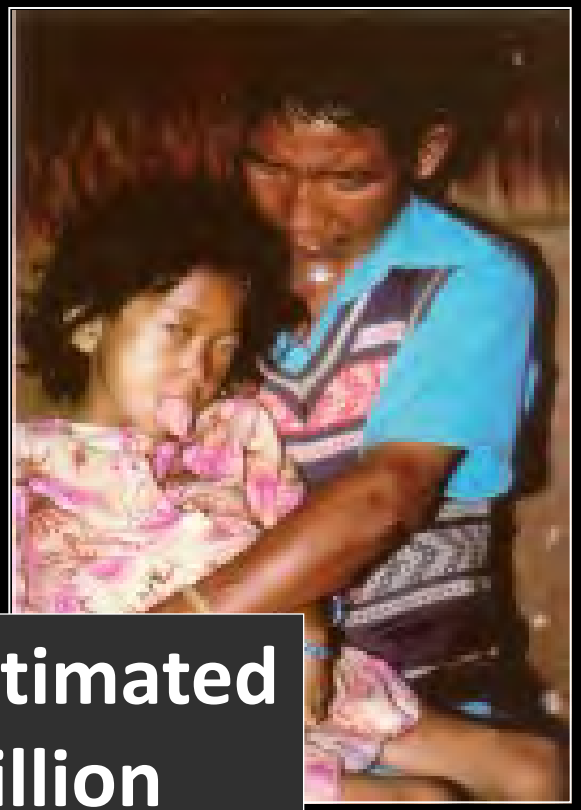
Agricultural solutions to global micronutrient malnutrition

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) 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

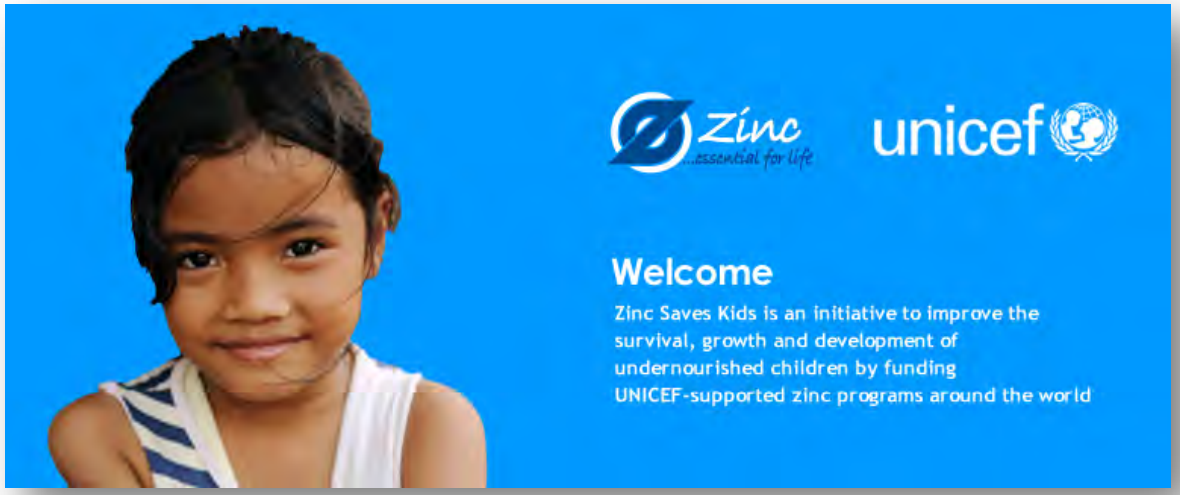
Underweight	14.9%
Unsafe sex	10.2%
Unsafe water	5.5%
Indoor smoke	3.7%
Zinc Deficiency	**3.2%**
Iron deficiency	**3.1%**
Vitamin A deficiency	3.0%
Blood pressure	2.5%
Tobacco	2.0%
Cholesterol	1.9%

ZINC SAVES KIDS

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.

Mosaic · KALI · OMEX · ifa · IPNI

Coordinating Institution: Sabanci University

Sabancı Üniversitesi

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 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	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
	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

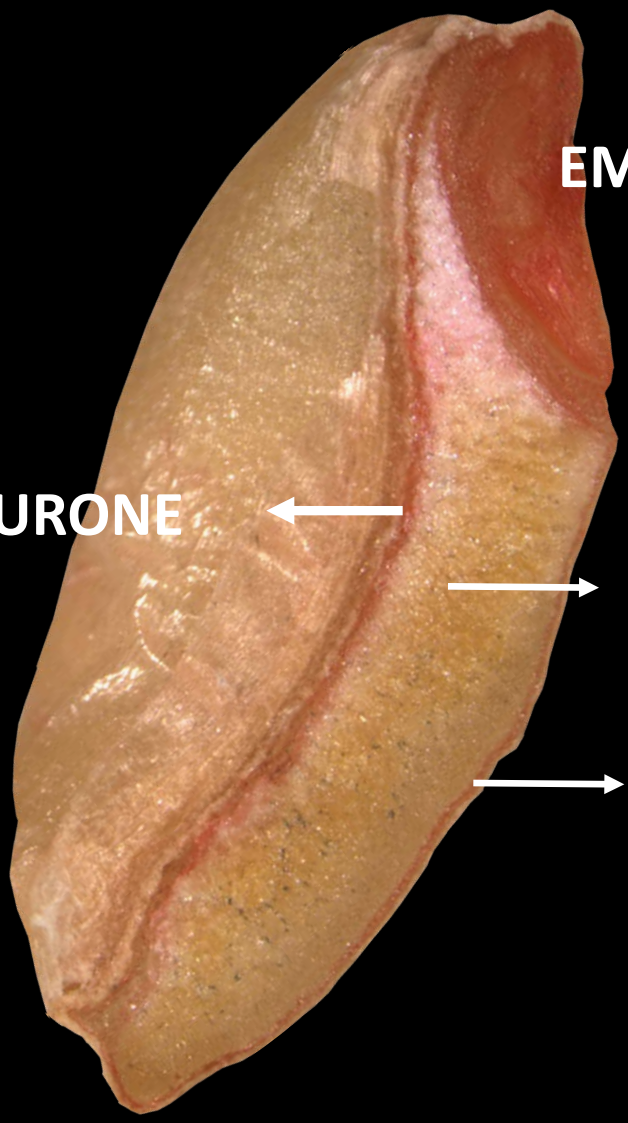
Average Concentrations of Grain Zn

(10 Countries with 32 locations)

-Zn: 26 ppm

+Zn: 50 ppm

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



Cakmak et al., 2010

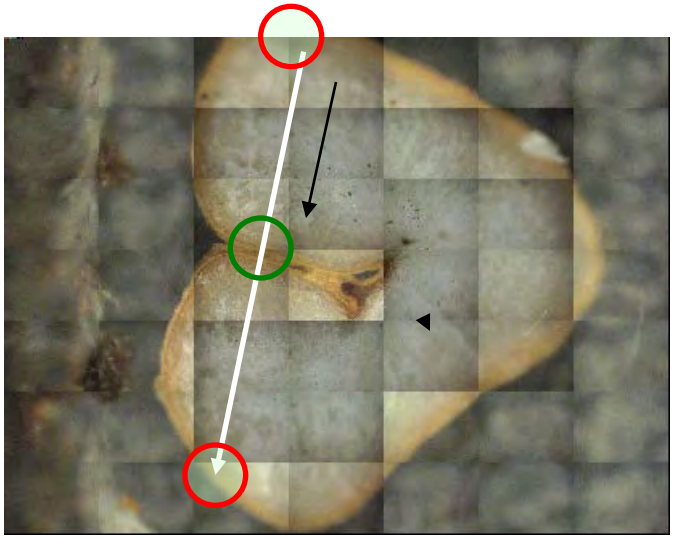
Cereal Chemistry, 77: 10-20

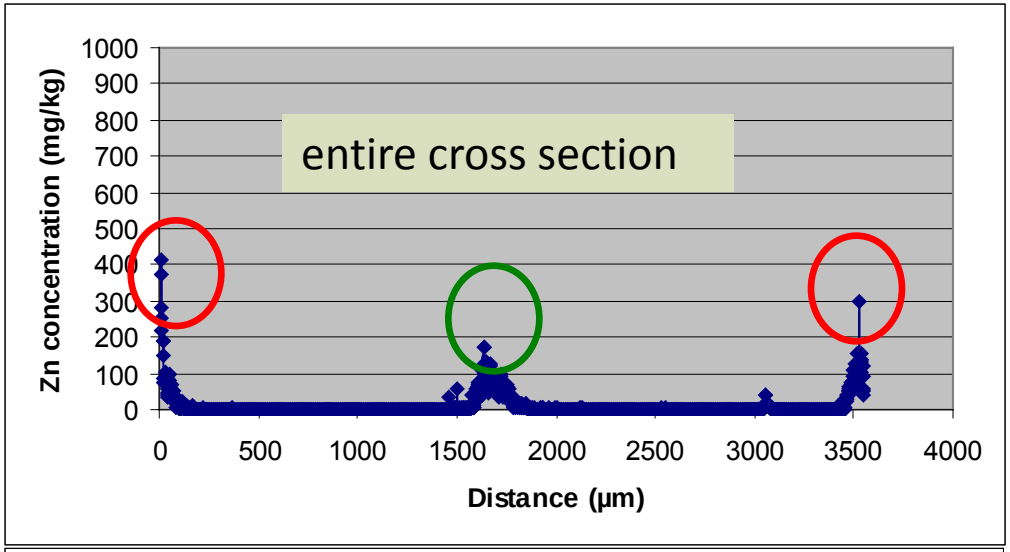
Localization of Zn in grain after foliar application?

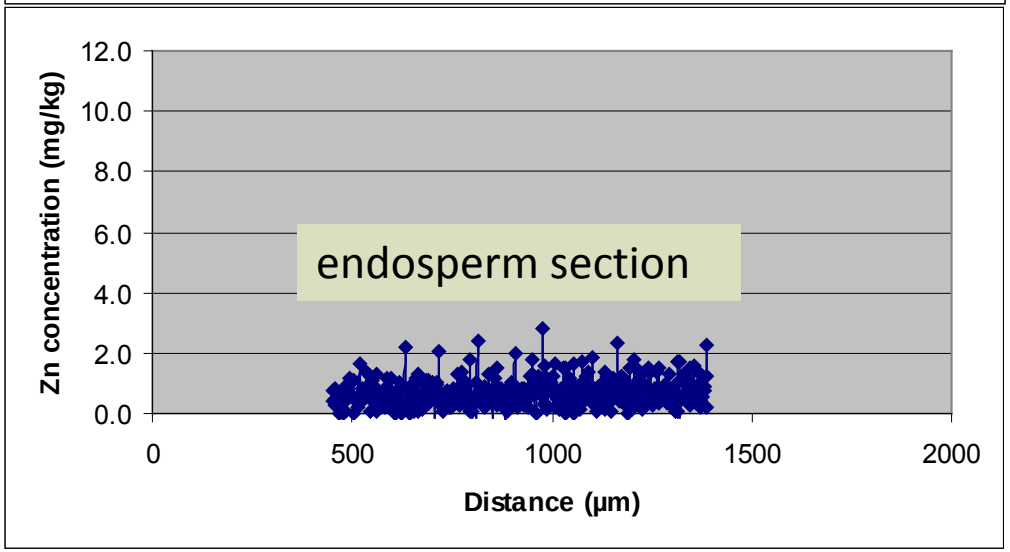
LA-ICP-MS Tests on Seeds

White arrow: Zn in entire cross section

Black arrow: Zn in endosperm section





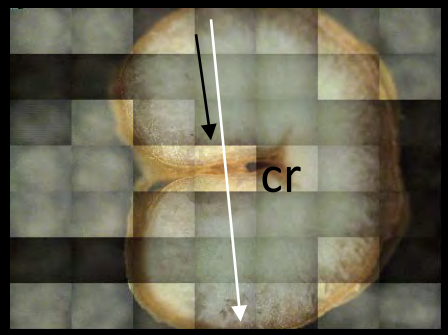


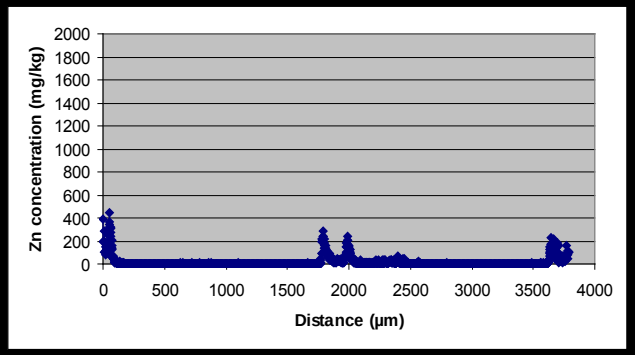
Cakmak et al., 2010,

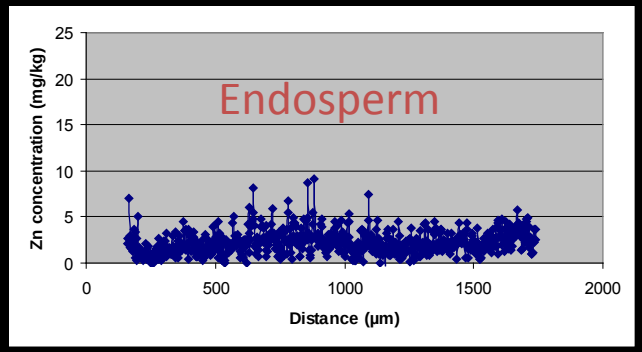
J. Agric. Food. Chem.

LA-ICP-MS Tests

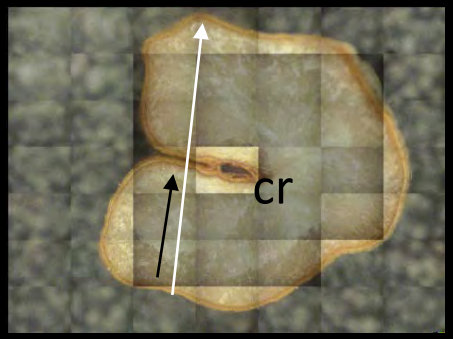
No Foliar Zn Application

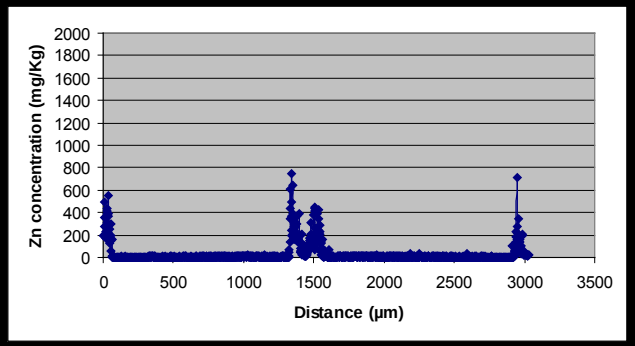


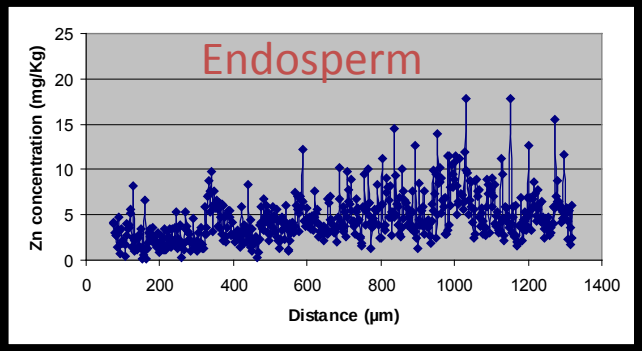




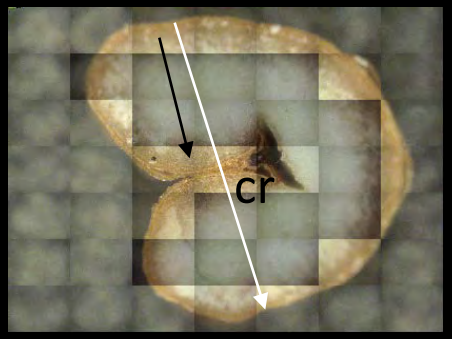
Foliar Zn Application at Stem Elongation and Booting Stages

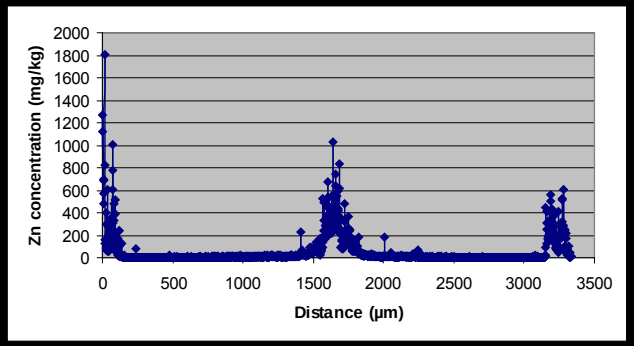


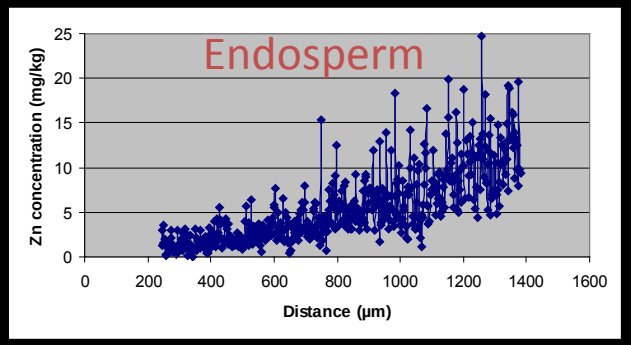




Foliar Zn Application at Milk and Dough Stages



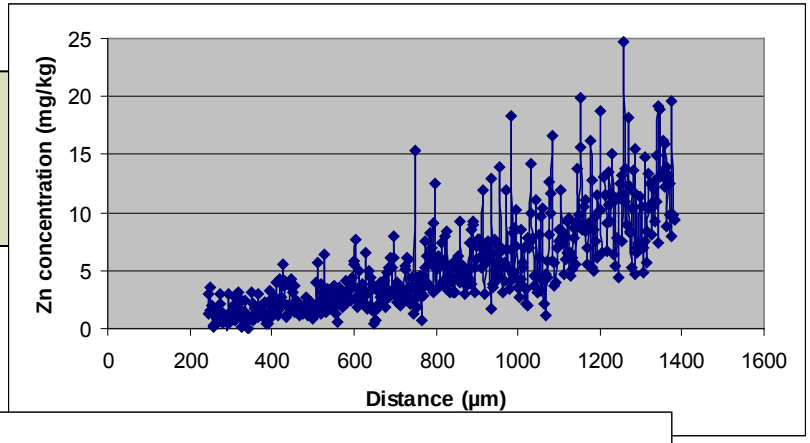




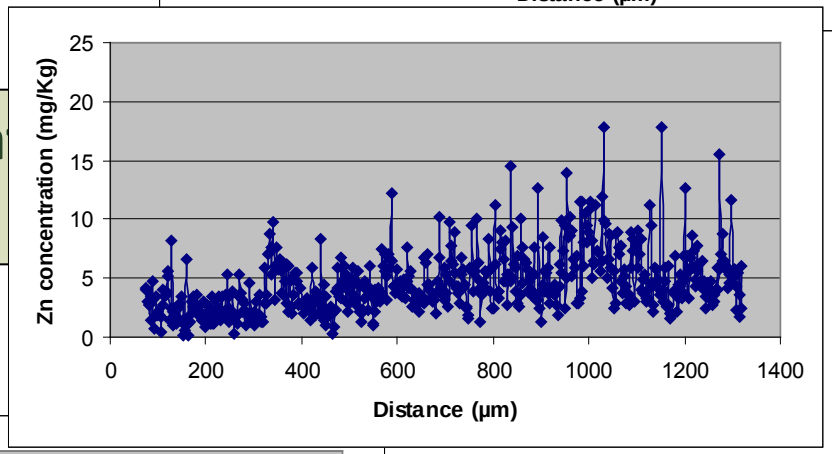
Cakmak et al., 2010, J. Agric. Food. Chem. 58:9092-9102

Changes in Endosperm Zinc Concentrations

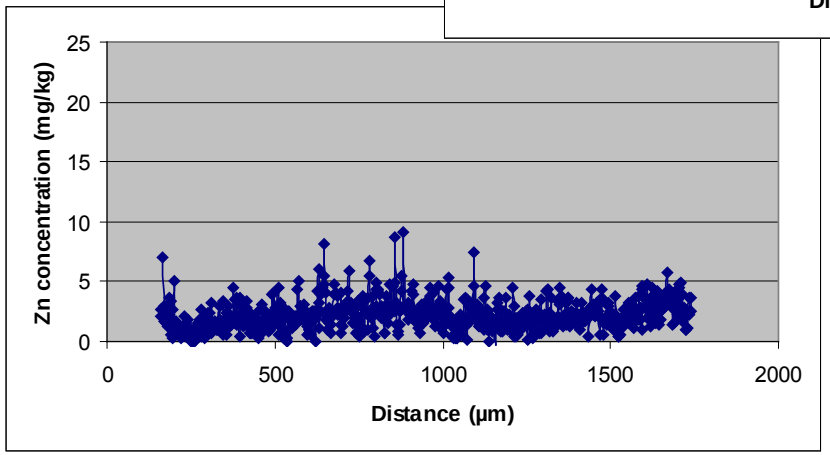
Zn applied at milk and and dough stages



Zn applied at stem elonga and boot

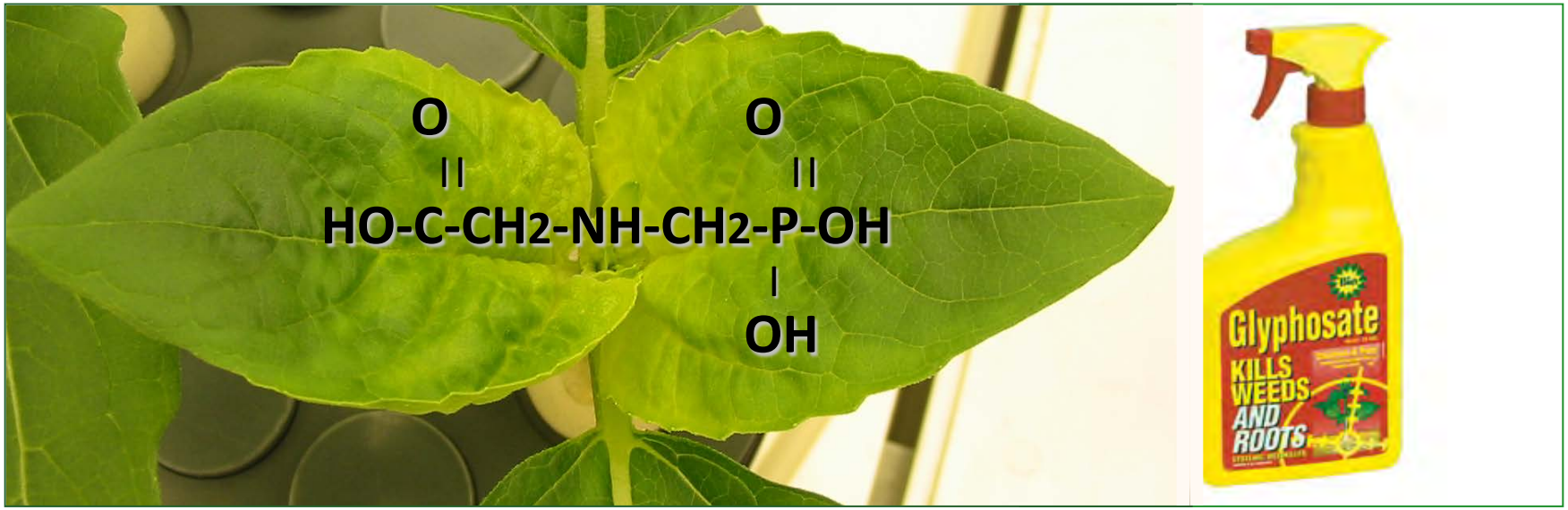


No Zn



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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FAX (204) 488-9599

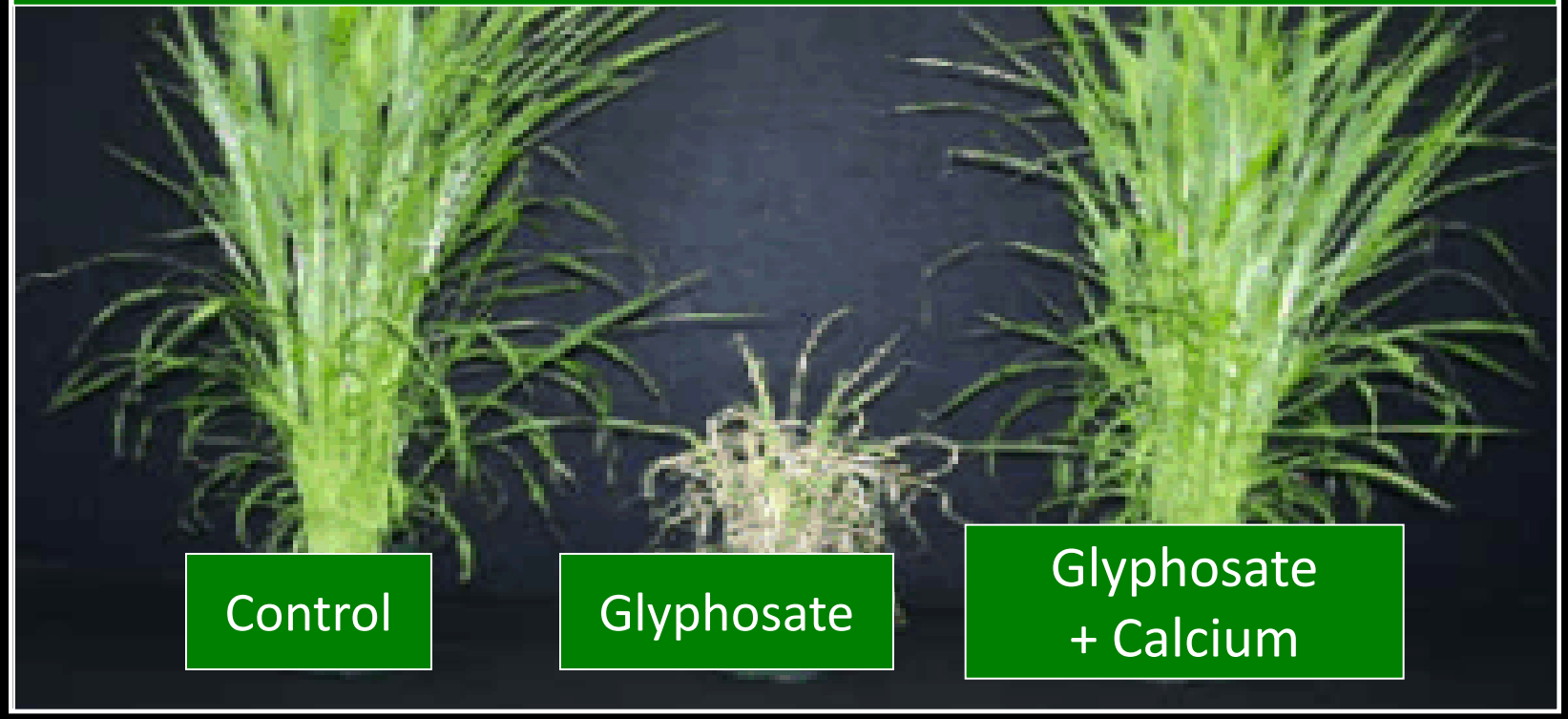
STAKHOLDER UPDATE
FOR INFORMATION ONLY
April 25, 2008

- ***"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 formation of poorly soluble glyphosate-metal complexes (??)

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

Thank You...

Sabanci University

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