Why Plants Need Zinc ?

Ismail Cakmak

Sabanci University, Istanbul

Zinc Deficiency: a Global Micronutrient Deficiency in Human Populations

2 BILLION

People worldwide who don't get enough zinc

1.5 MILLION

Children who die each year from diarrhea

800,000

People at risk of dying each year from zinc deficiency

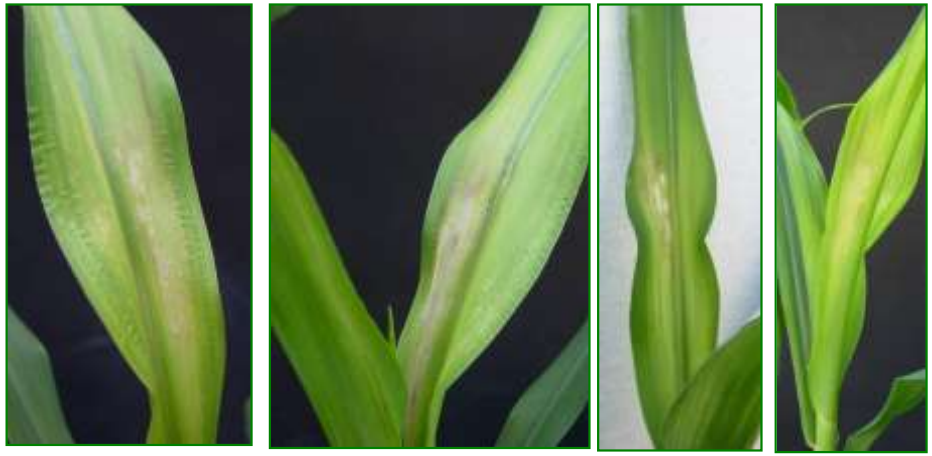
450,000

Children at risk of dying every year due to zinc deficiency

Source: A. Green: http://www.zinc.org/crops

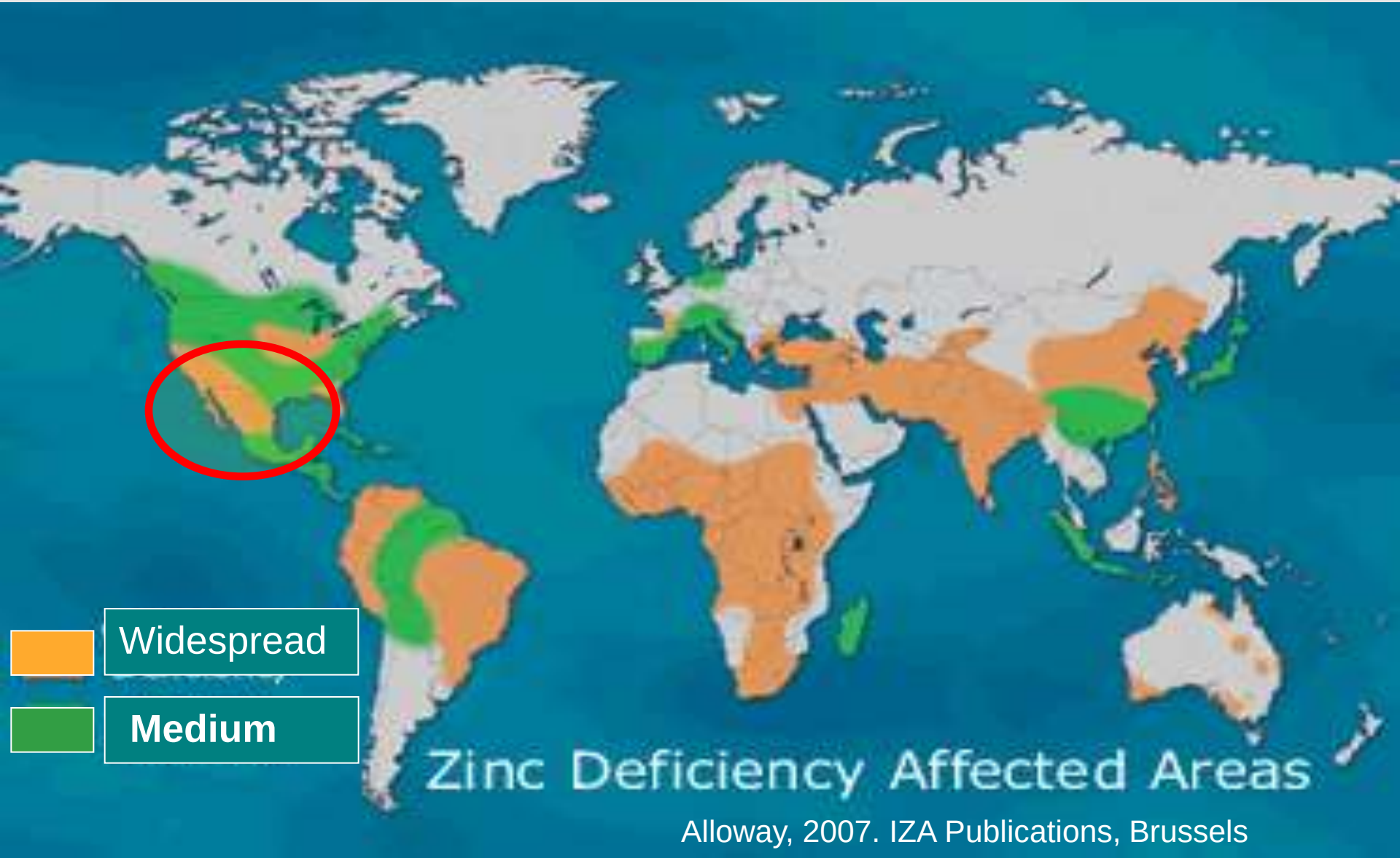
Zinc Deficiency: a global soil micronutrient deficiency. Around 1/3 of soils are deficient in available Zn

Australia	: >10 mio ha
Turkey	: 14 mio ha
Bangladesh	: 2 mio ha
China	: 30 mio ha
India	: 90 mio ha

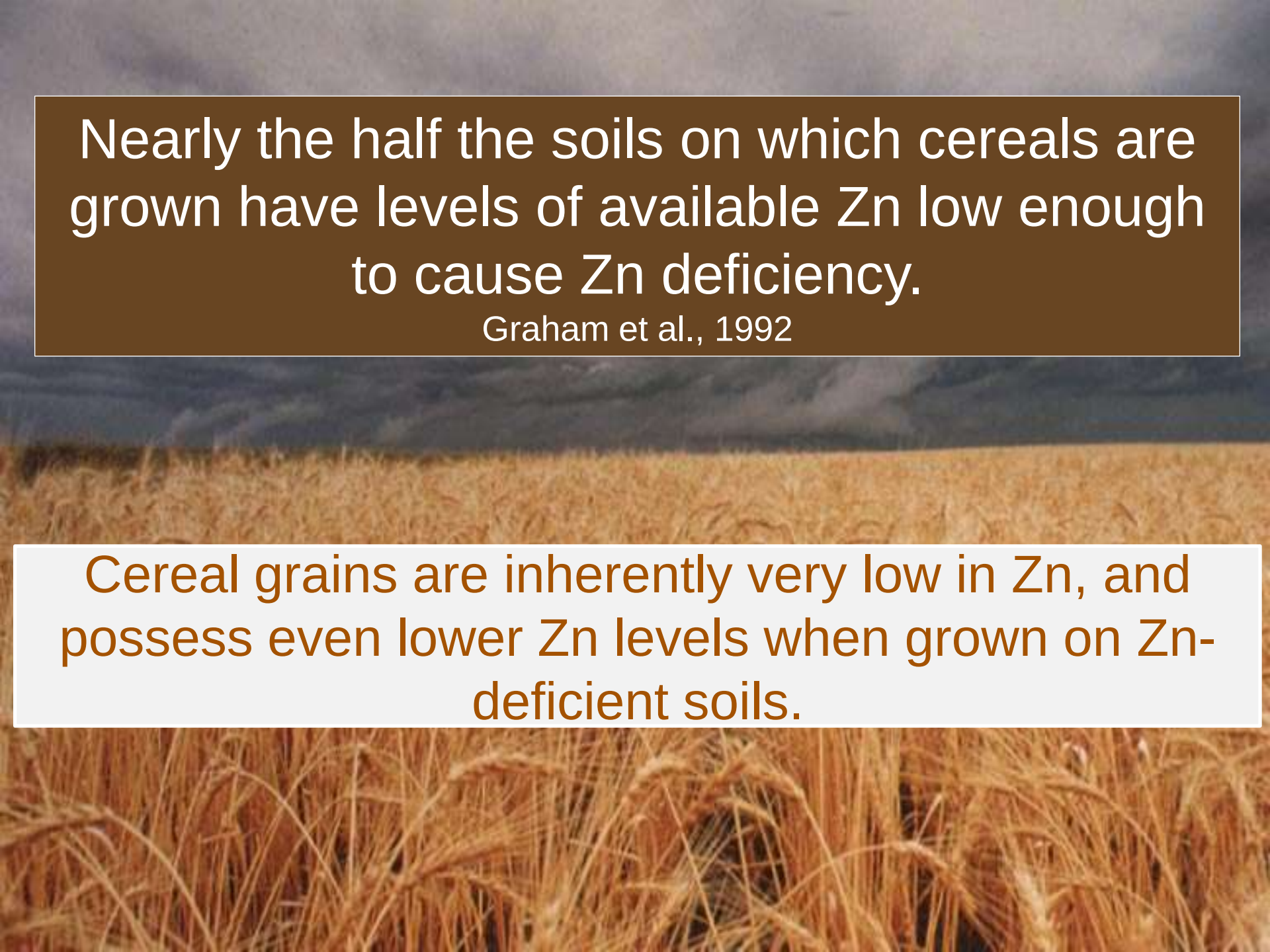


White and Zasoski, 1999; Field Crops Res., 60:11-26

Zn Deficiency:
Global Micronutrient Deficiency in Soils



Alloway, 2007. IZA Publications, Brussels

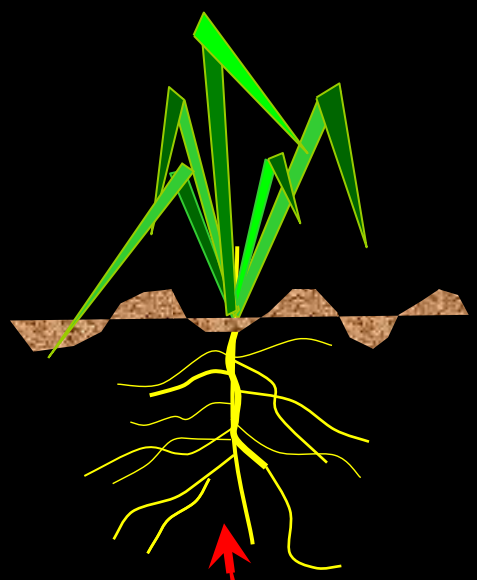


Nearly the half the soils on which cereals are grown have levels of available Zn low enough to cause Zn deficiency.

Graham et al., 1992

Cereal grains are inherently very low in Zn, and possess even lower Zn levels when grown on Zn-deficient soils.

Soil factors affecting availability of Zn to roots



- high $CaCO_3$
- high pH
- clay soils
- low organic matter
- low soil moisture
- high Fe and Al oxides

SOIL

Zn

Zn

Zn

Zn

Zn

Zn

Enhanced Zn adsorption and precipitation

Zn

Decreased Zn desorption

Zn

Limited Zn uptake

Additional Cause of Zn Deficiency: Intensification of Farming

Zinc Depletion in Soil and Zinc Dilution in the Harvested Products

Increasing grain yield potential of new varieties results in rapid **depletion** of soil-Zn and **dilution** of seed-Zn

Functions of Zinc in Plant Systems

Why Plants Need Zinc

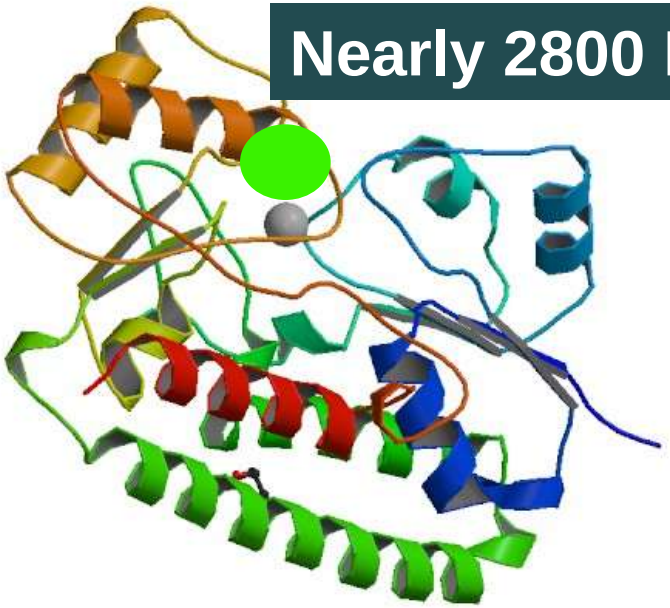
Basic Roles of Zinc in Biological Systems

- nearly 10 % of proteins needs Zn for their function and structure
- structural and functional integrity of biological membranes depends on adequate amount of Zn
- Zinc is a major actor of cellular defense systems against highly toxic oxygen free radicals (better tolerance to environmental stress factors, e.g., drought stress)
- Zinc is required for protection of IAA from oxidation
- Zinc is required for better pollination

Marschner, 1995; Cakmak, 2000, New Phytol.

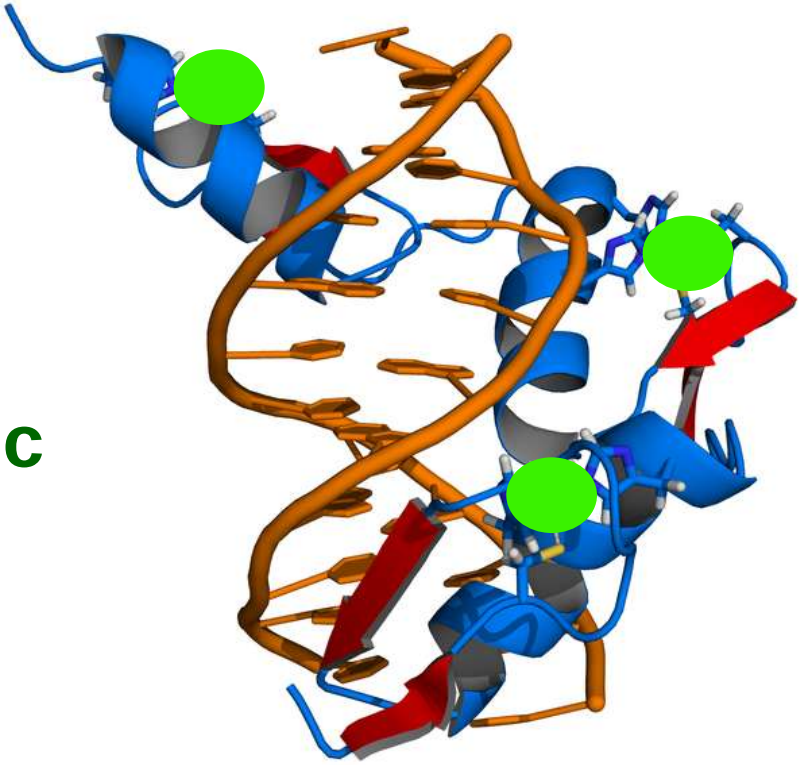
Zinc Binding Proteins

Nearly 2800 Proteins are Zn-dependent

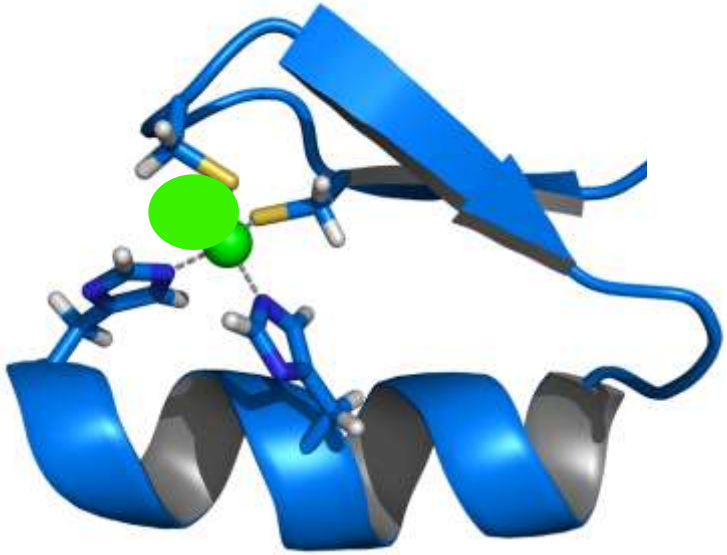


: Zinc

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



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



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Marschner, 1995; Cakmak, 2000, New Phytol.

Zinc : An important micronutrient controlling membrane stability

Zn has a key role in maintaining structural integrity of plasma membranes of root cells.

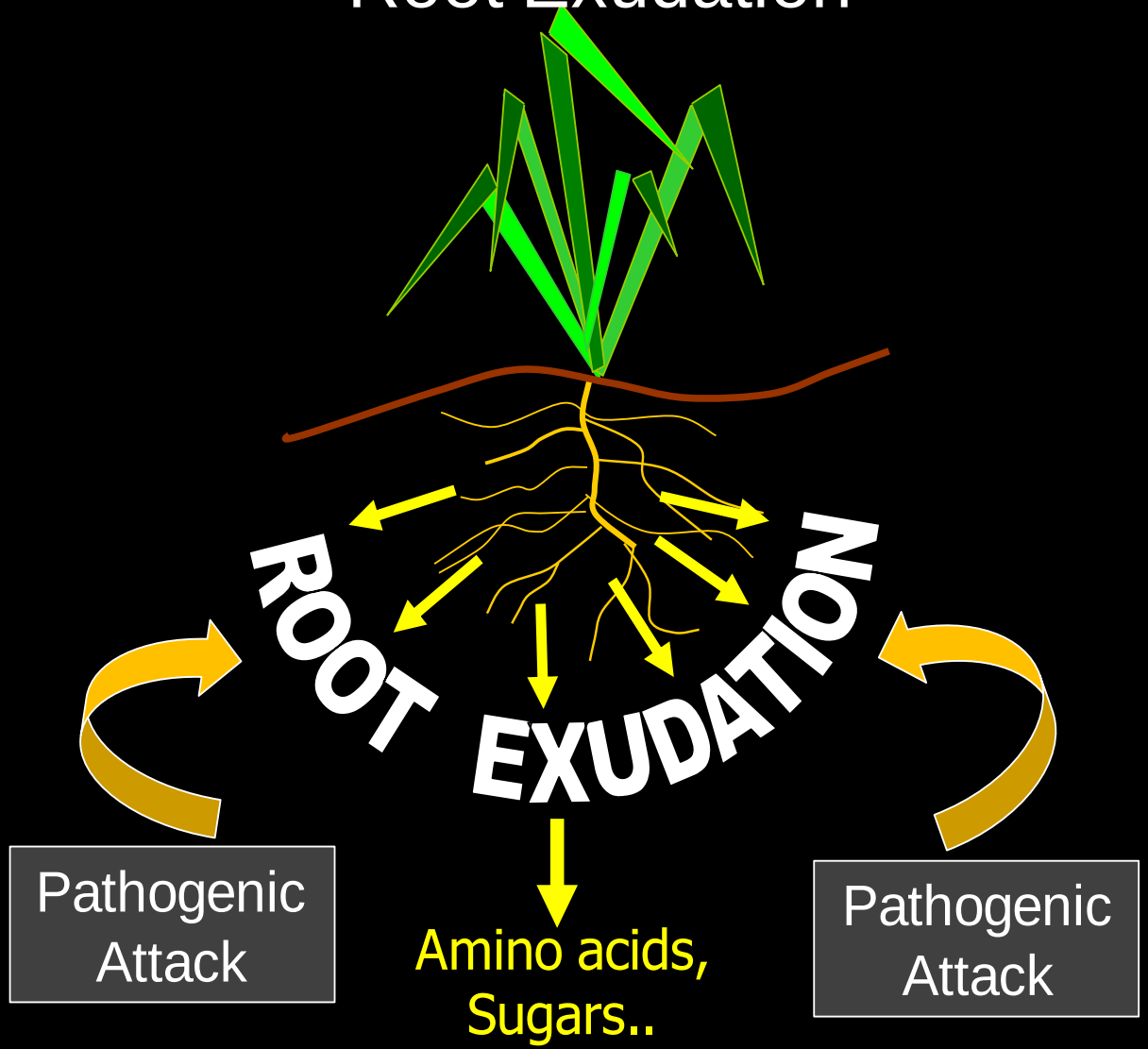
Continues presence of chemically available Zn in root environment during the plant growth is of great importance for fulfilling the membrane function of Zn; otherwise, root cell membranes lose their stability and become leaky.

Consequence of structural impairments in cell membranes under Zn deficiency:

Zn deficient roots are leaky and exude various carbon-containing compounds into the surrounding soil that is rich in fungal and bacterial populations

ROOT EXUDATES:
feeding substrates for pathogens

Zinc Deficiency-Induced Root Exudation

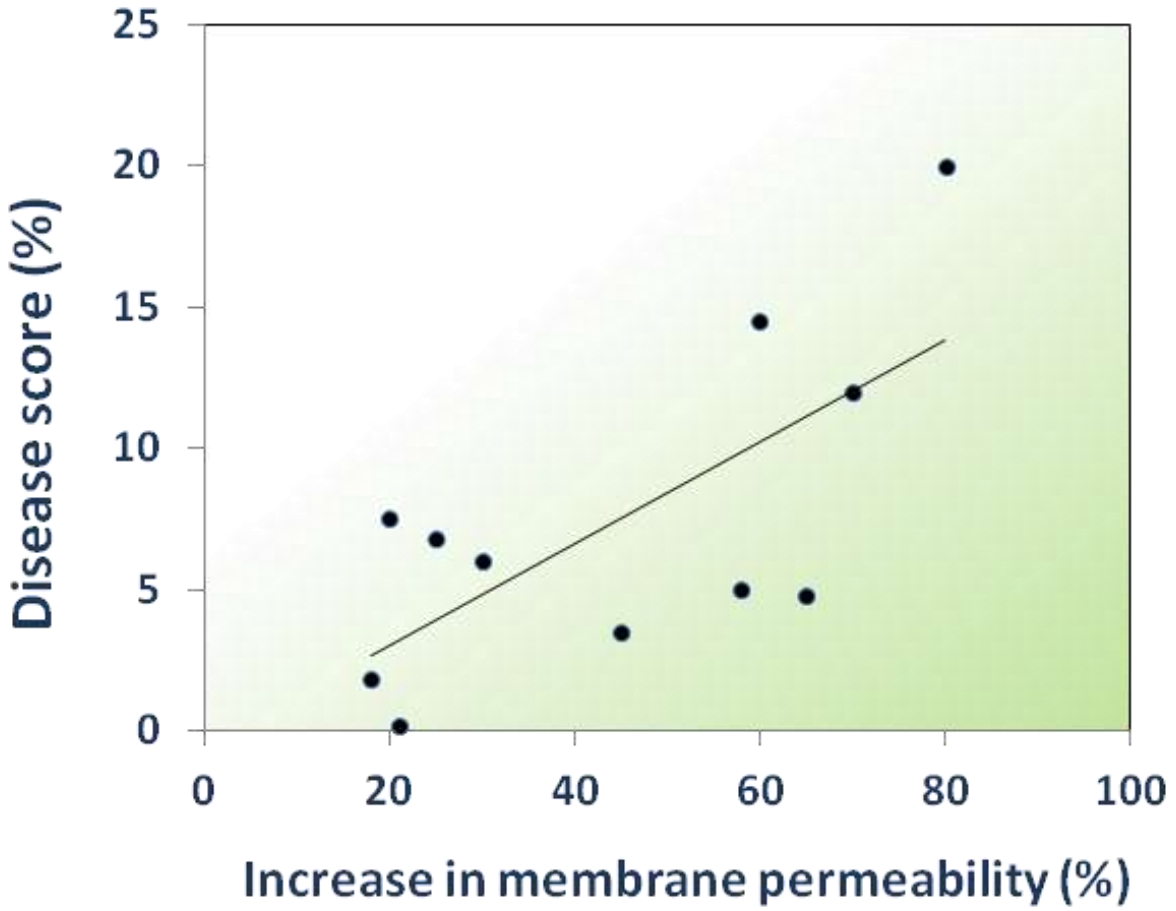


Root exudation of organic compounds in cotton, wheat and apple at low (-Zn) and adequate (+Zn) Zn supplies

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

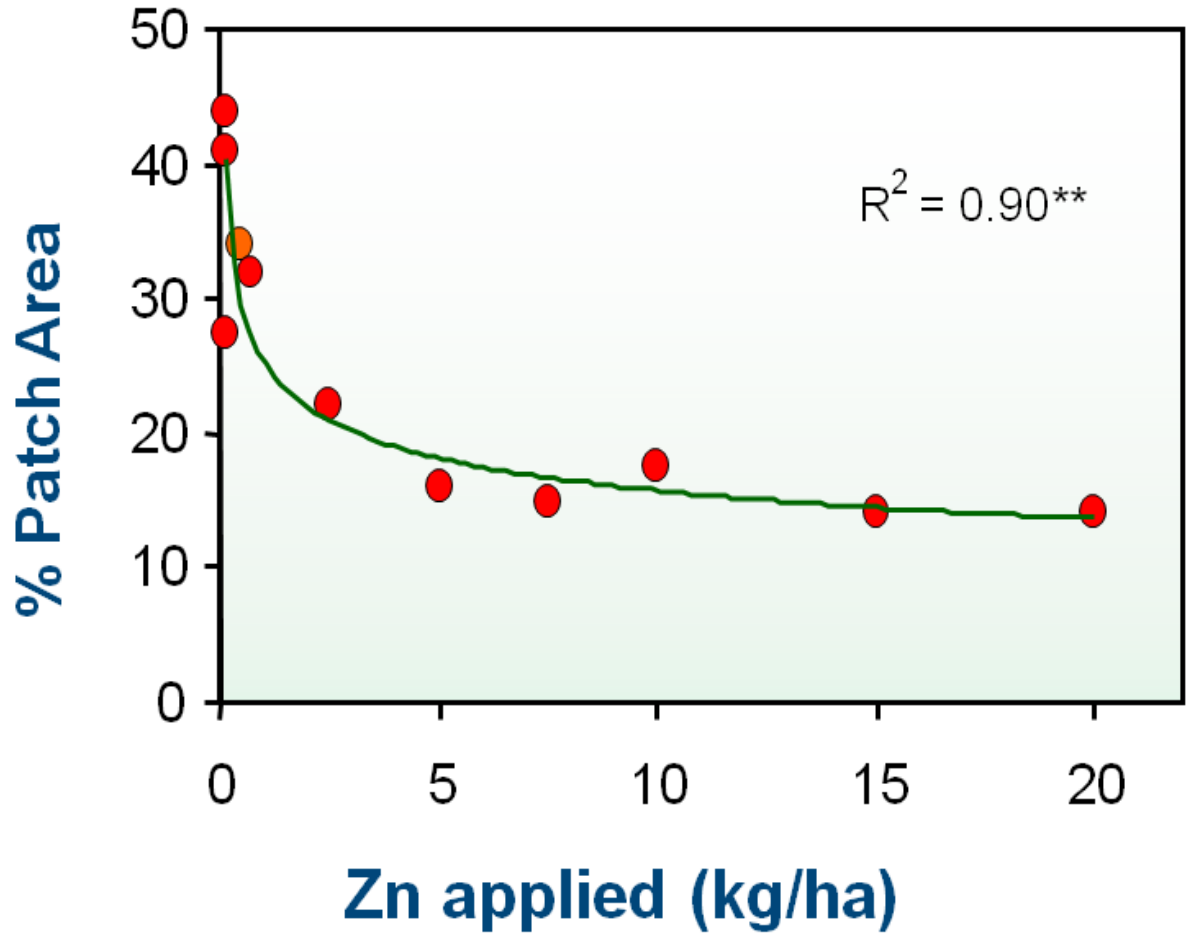
Cakmak and Marschner, 1988, J. Plant Physiol.

Relationship between root membrane permeability and severity of the Fusarium disease under different Zn treatments



(Khoshgoftarmanesh et al., 2010. Soil Sci. Plant Nutr. 56:234-243).

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



Thongbai et al., 1993, Plant and Soil

Effect of Zn application on phytophtora zoospores on roots of two different Eucalyptus

Zn supply	Species	
	E. marginata	*E. sieberi*
	(No./mm^2 root)	
+Zn	4±1	89±13
-Zn	44±8	489±48

Graham and Webb, 1991

Adequate Zn supply is also effective in reducing growth and sporulation of various fungal pathogens

Basic Roles of Zinc in Biological Systems

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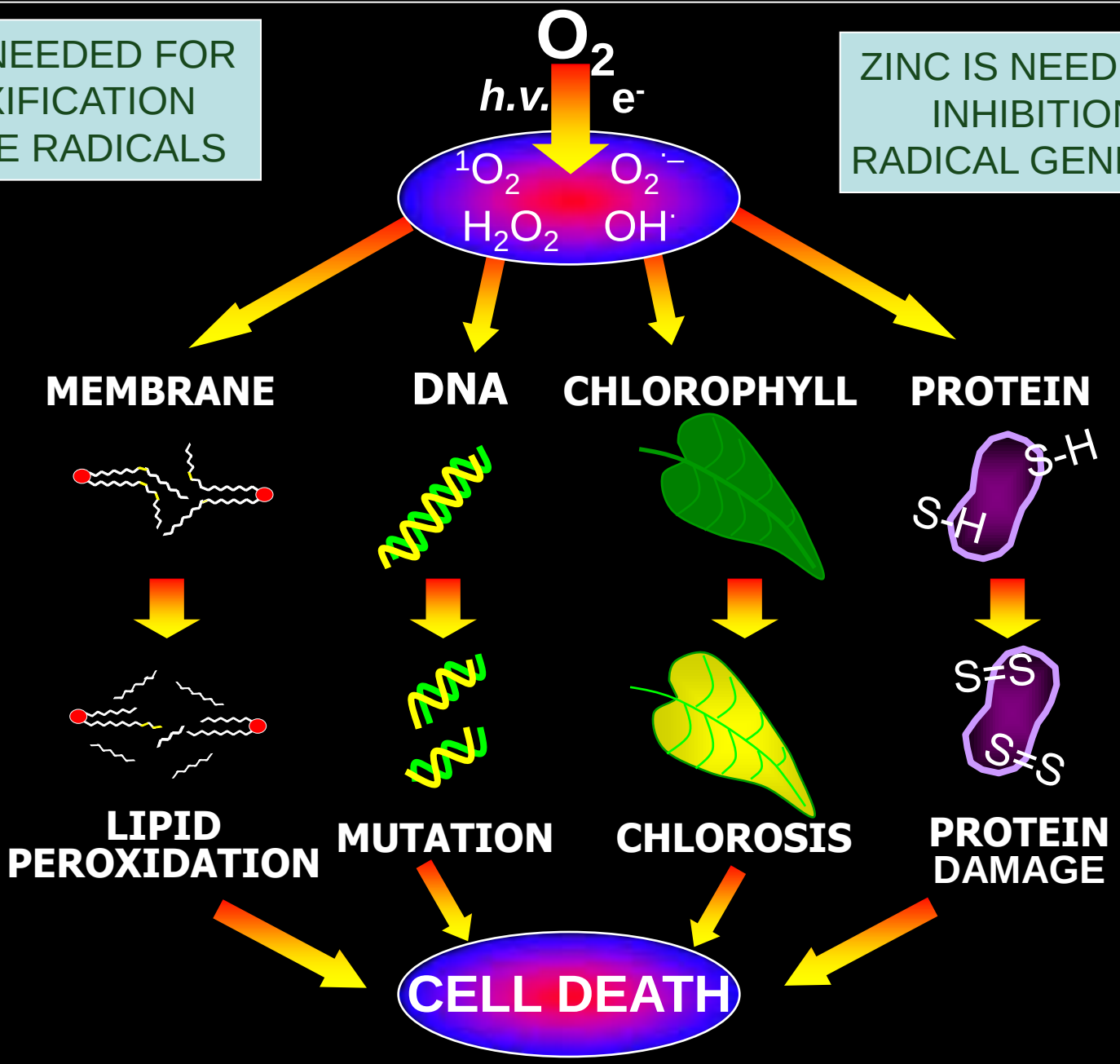
- Zinc is required for protection of IAA from oxidation
- Zinc is required for better pollination

Marschner, 1995; Cakmak, 2000, New Phytol.

ZINC PROVIDES DEFENSE AGAINST FREE RADICAL DAMAGE IN CELLS

ZINC IS NEEDED FOR DETOXIFICATION OF FREE RADICALS

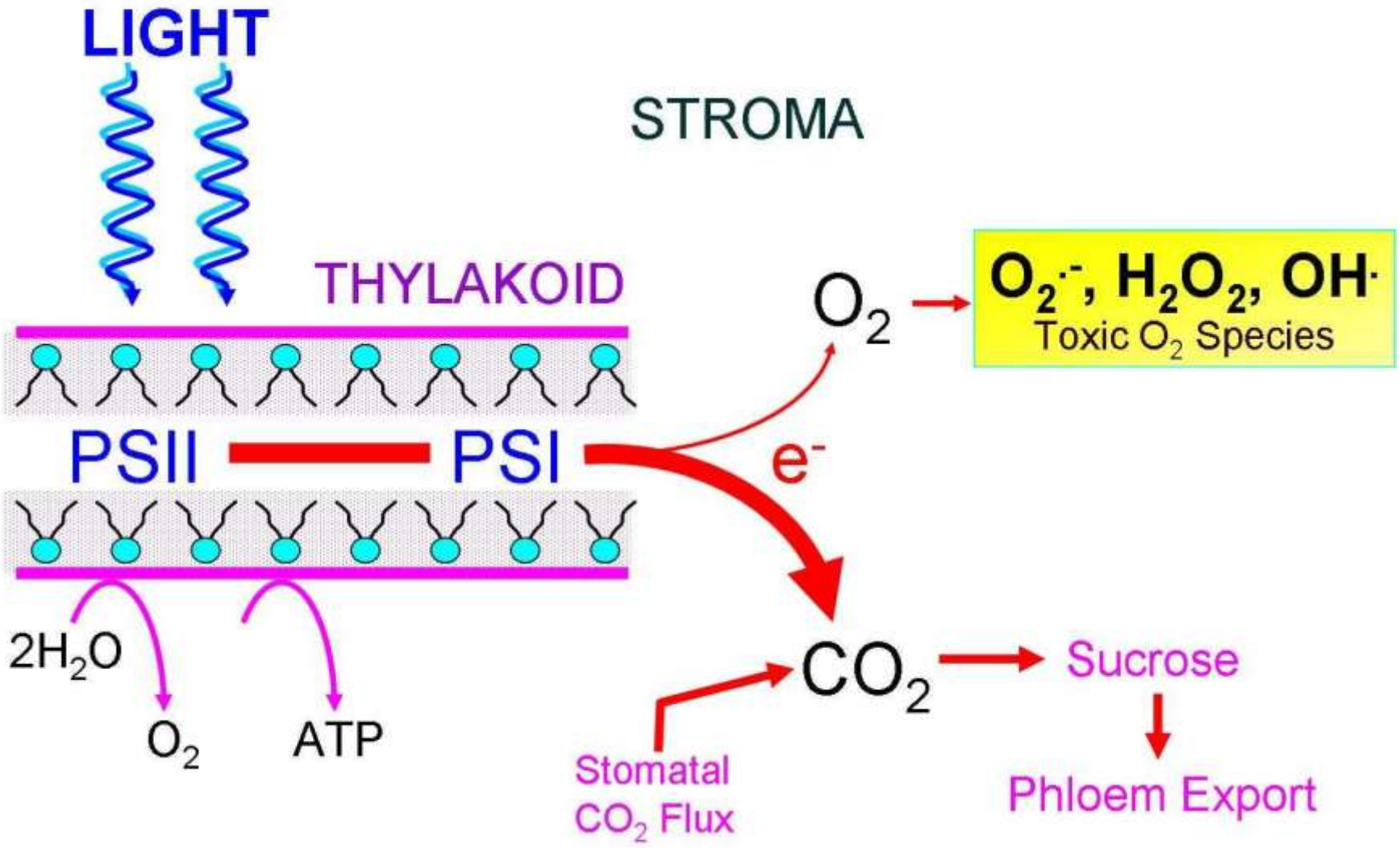
ZINC IS NEEDED FOR INHIBITION OF RADICAL GENERATION



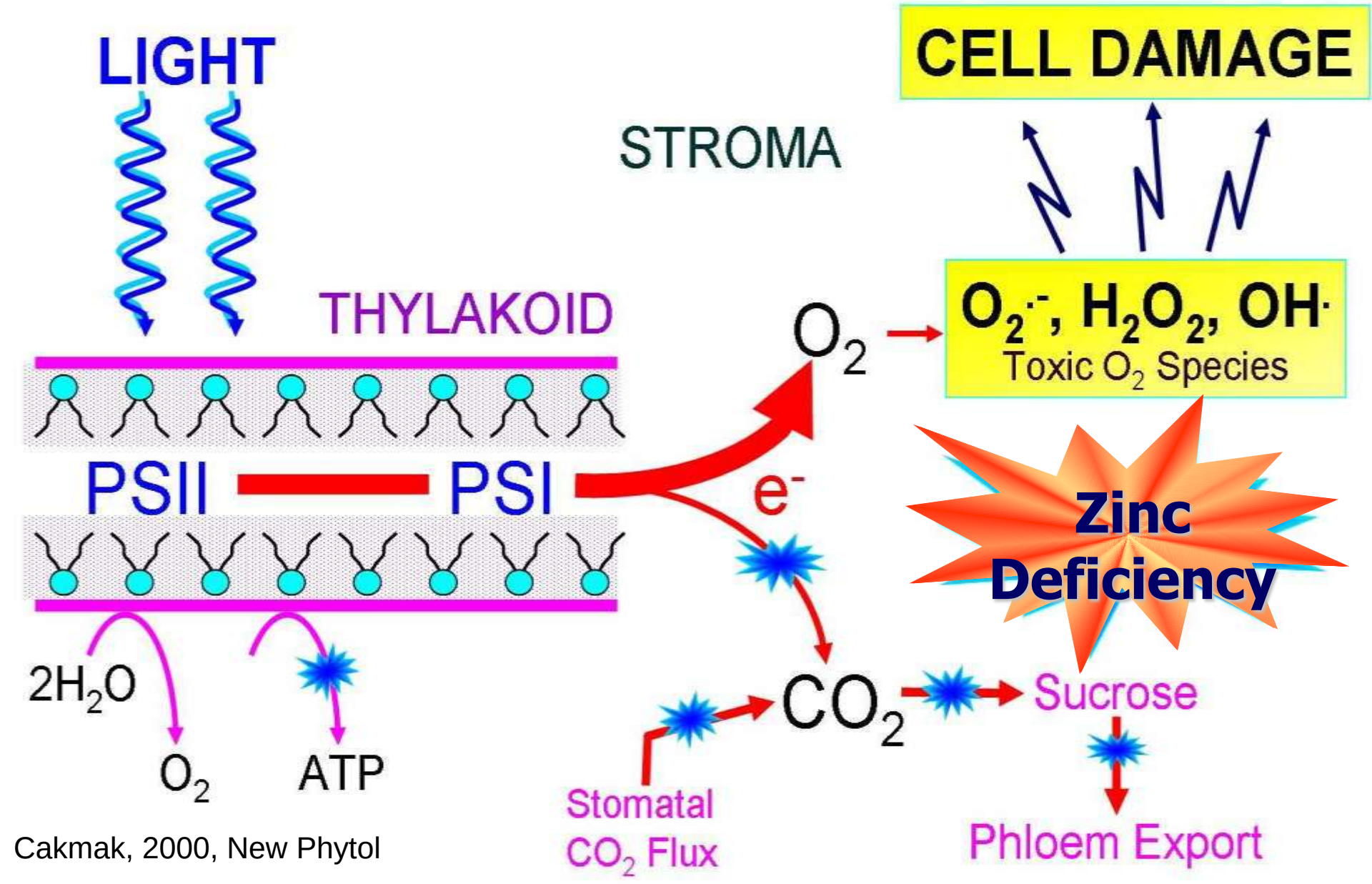
Photooxidative (Light) Damage in Zn-Deficient Plants

REMEMBER:

Photosynthetic Electron Transport and Superoxide Radical Generation



Photosynthetic Electron Transport and Superoxide Radical Generation



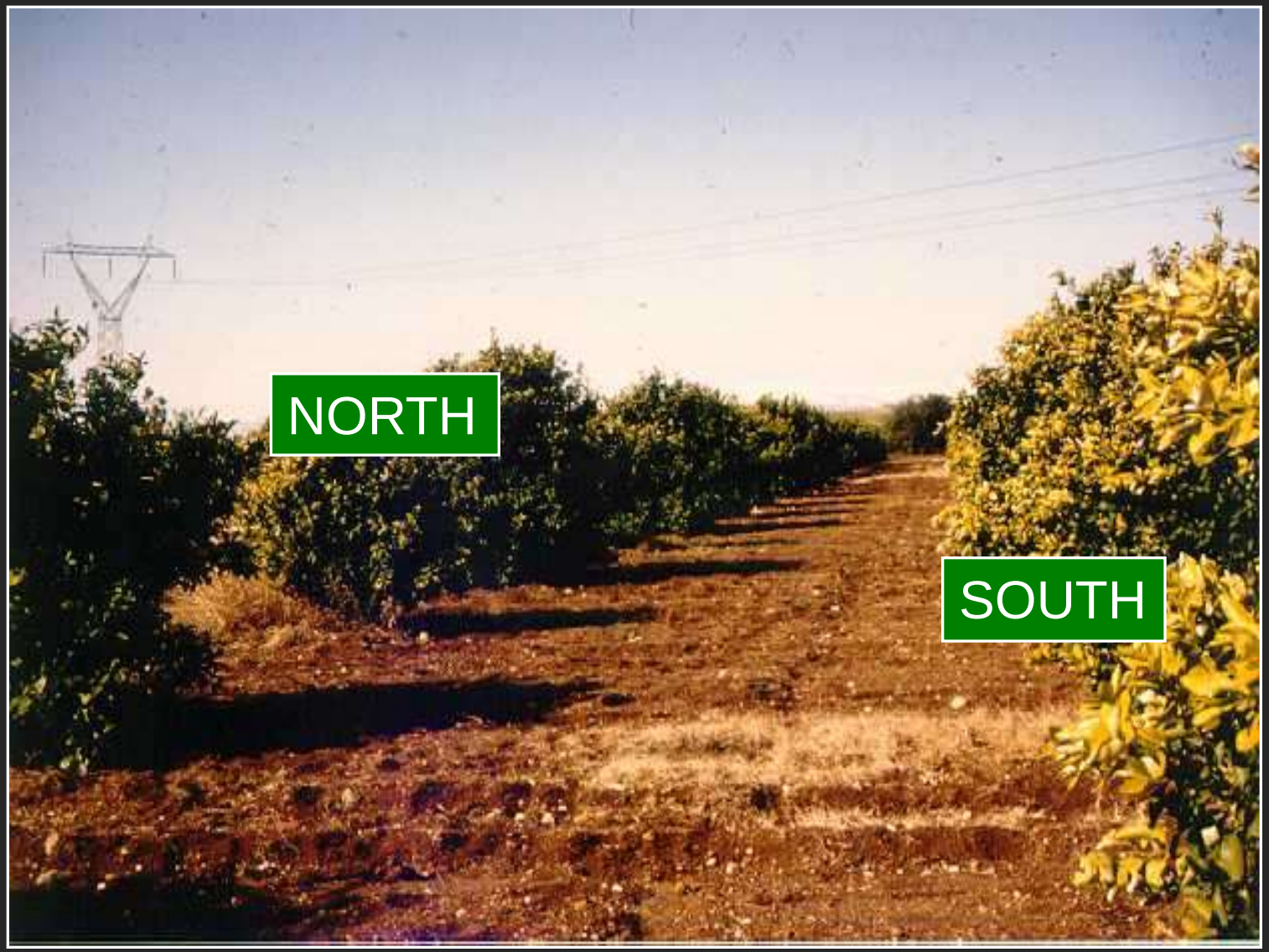
Cakmak, 2000, New Phytol

Zinc Protects Plants from High Light and Heat Stress

Zn Deficiency Makes Plants Highly Sensitive to High Light and Heat

Cakmak, 2000, New Phytol

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



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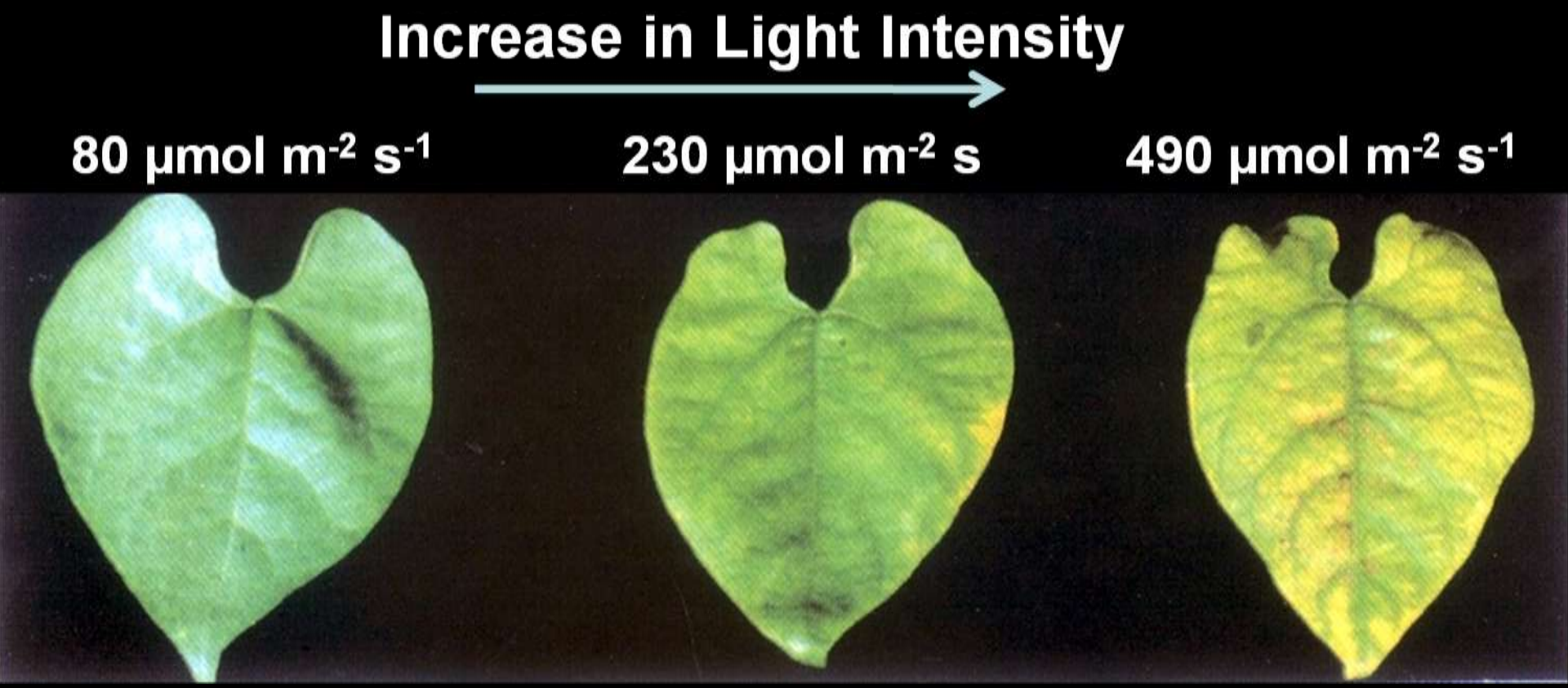
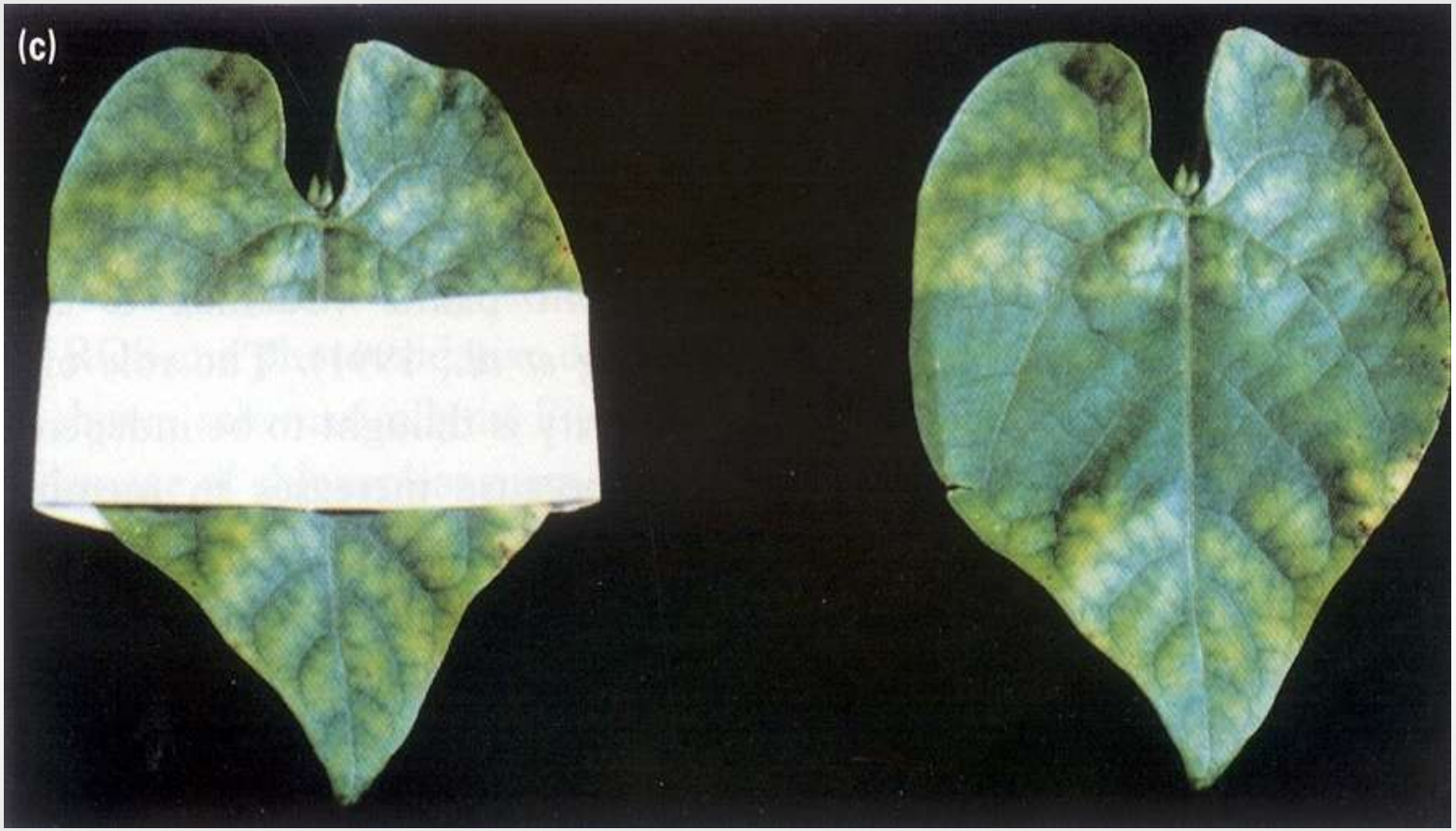


Cakmak, 2000; New Phytologist, 146: 185-205

Partial shading of primary leaves of Zn-deficient bean plants



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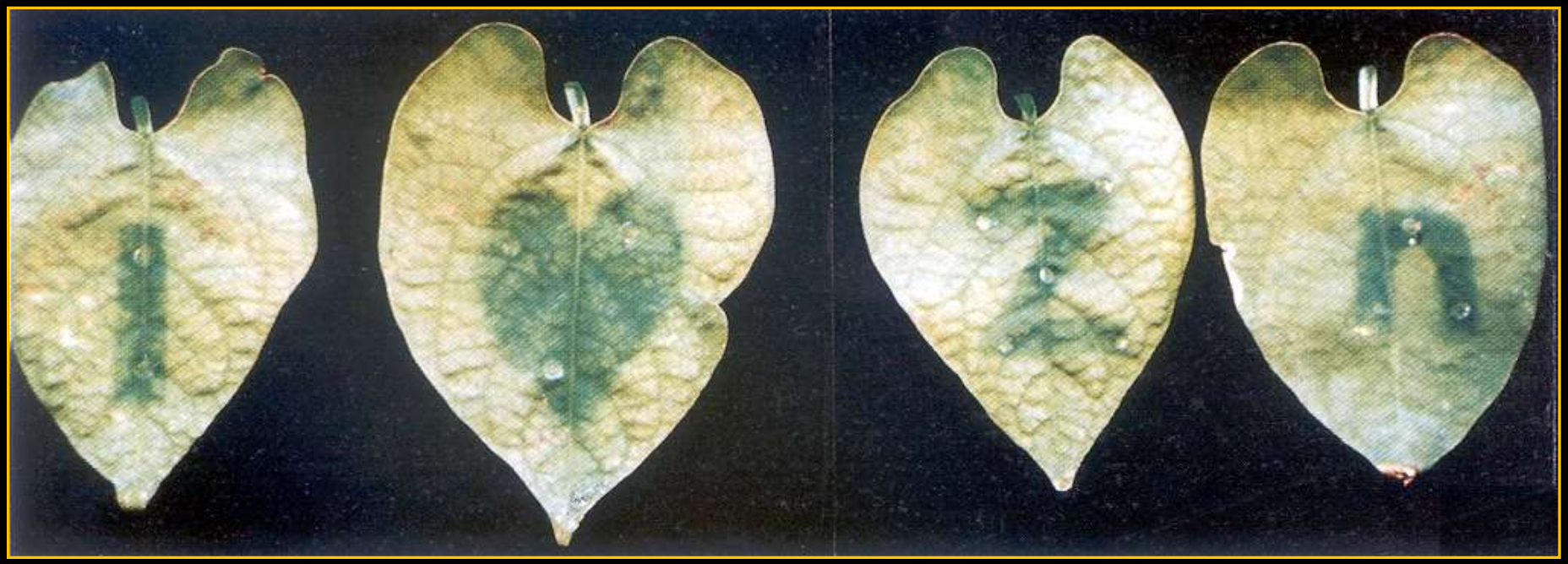

High Light-Induced Zn deficiency

Marschner and Cakmak, 1989; J. Plant Physiology

Average **spike sterility** (%) in 20 wheat genotypes grown in field conditions in Central Anatolia with (+Zn) and without (-Zn) Zn fertilization under rainfed and irrigated conditions.

	Rainfed		Irrigated	
	-Zn	+Zn	-Zn	+Zn
Spike Sterility (%)	37	17	15	4

Bagci et al., 2007

Spike sterility index was estimated by multiplying the percentage of stress-affected spikes in 1 m^2 with the percent spike sterility as the average of 20 stress-affected spikes.

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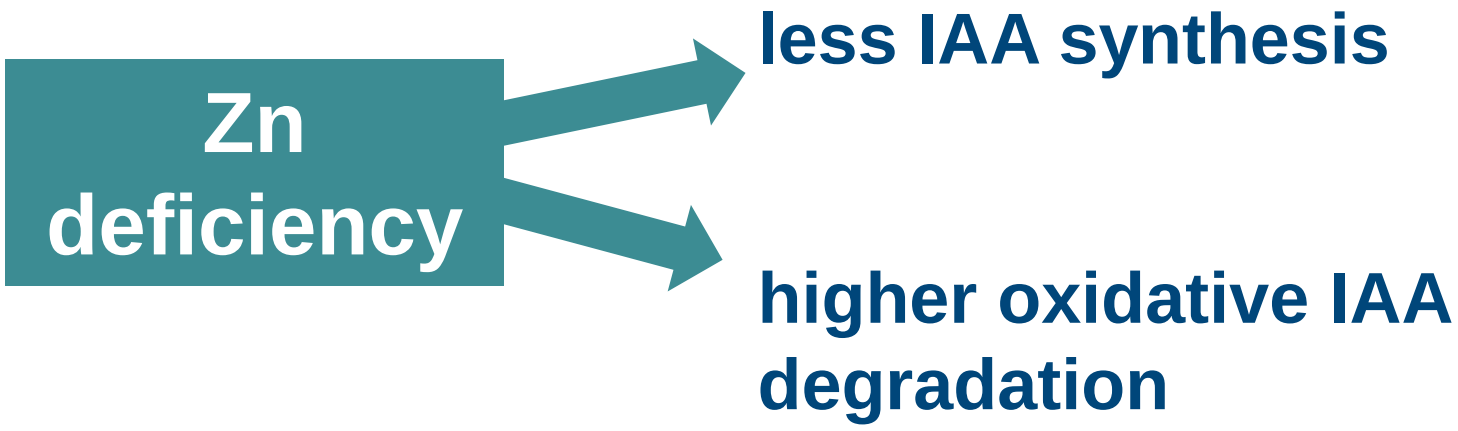
Marschner, 1995; Cakmak, 2000, New Phytol.

Importance of Zinc for Auxin (IAA) Hormone

Evidence is available showing that Zn is involved in both biosytnhesis of IAA and also protection of IAA from oxidative attack by free radicals



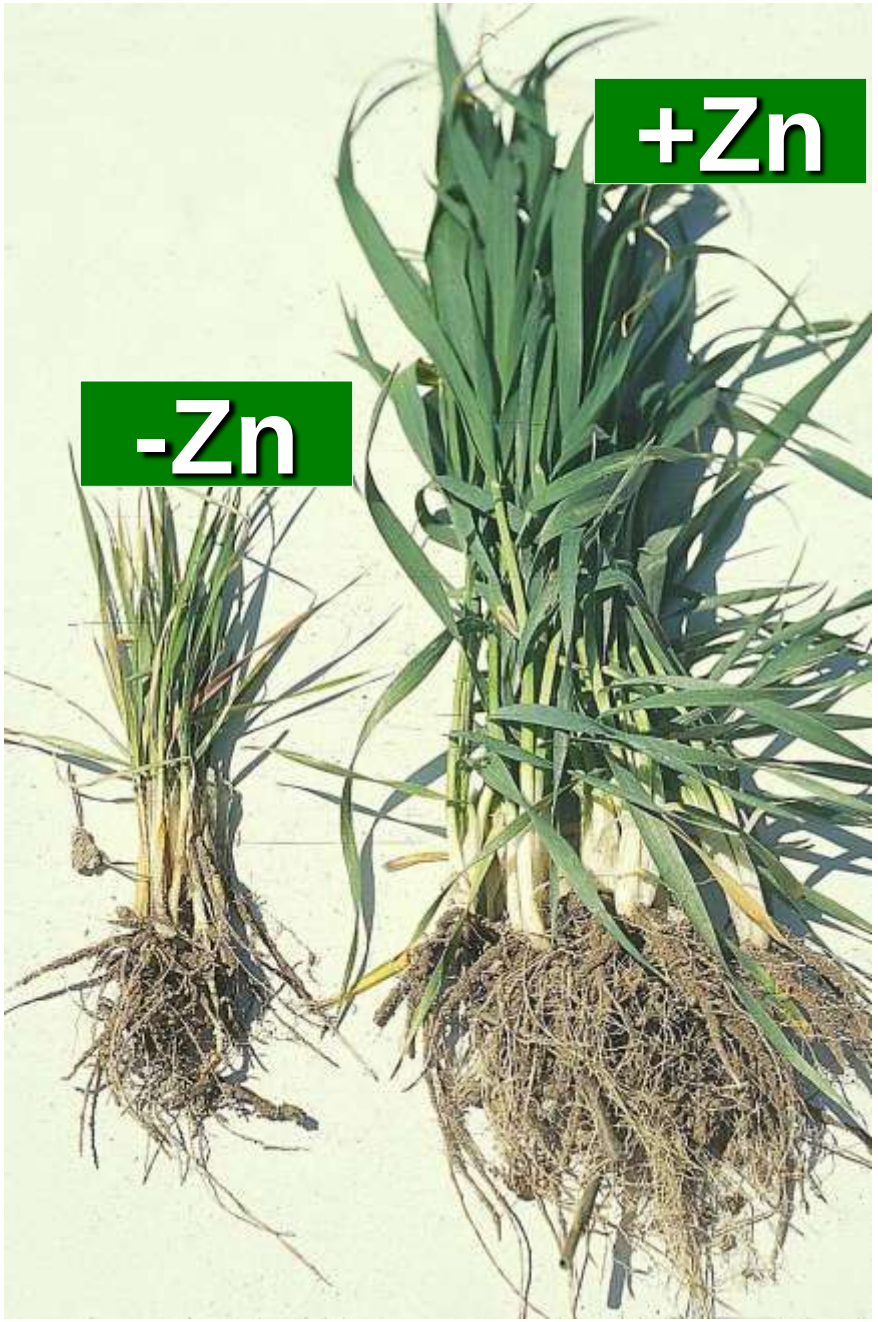
Under Zn deficiency IAA is Reduced

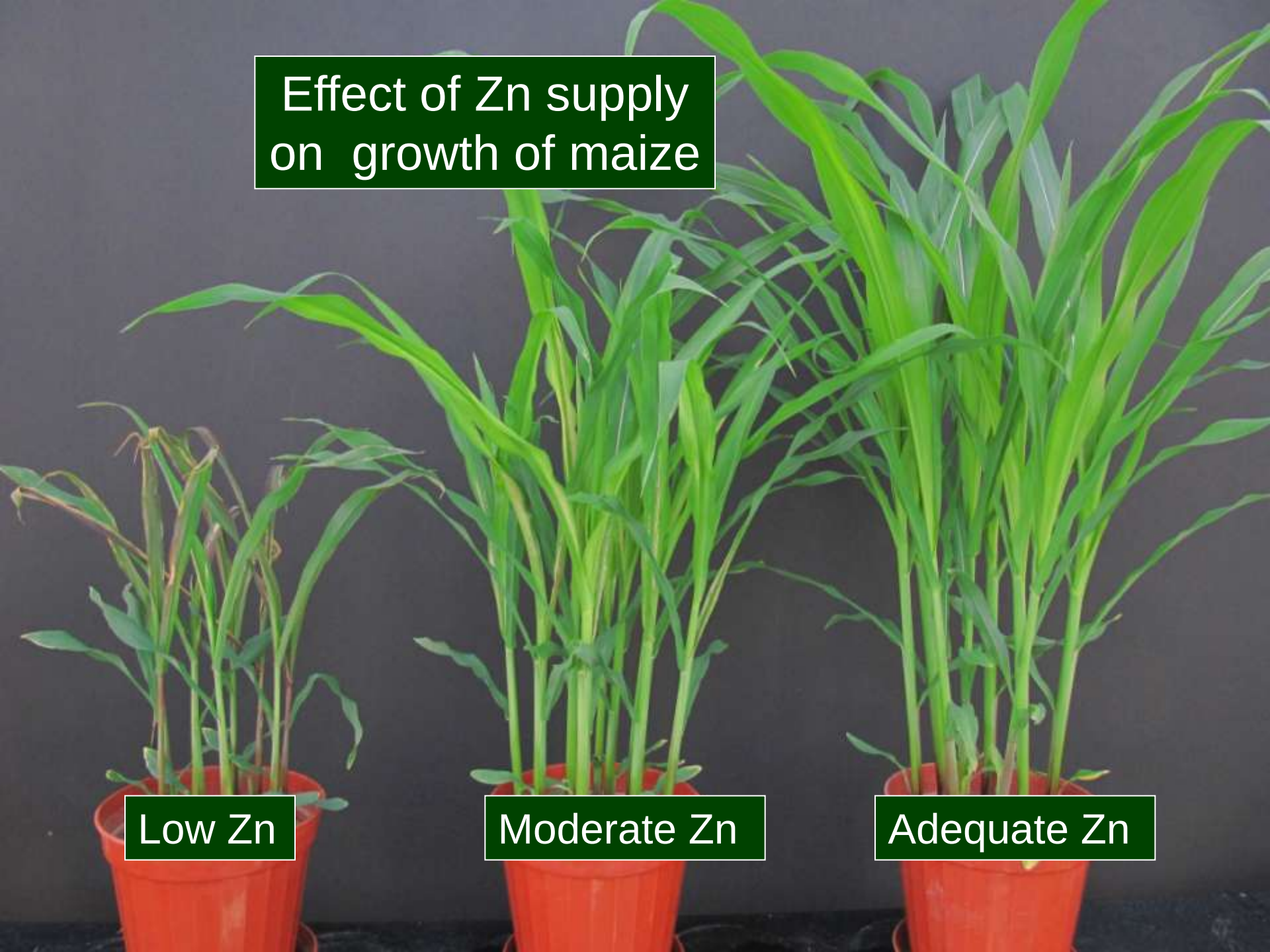
Effect of Zn supply on shoot dry weight and composition of young leaves and shoot tips of bean plants.

Zn supply M	Shoot dry wt.	Concentrations in young leaves and shoot tips		
		Zn	Free amino acids	IAA
	g/plant	mg kg^{-1}	µmol g^{-1} dry wt.	µg kg^{-1} fresh wt.
+Zn (10^{-6})	8.24	52	82	240
- Zn	3.66	13	533	122
Zn-Resupply	4.53	141	118	180

Cakmak et al., 1989, J. Experimental Botany, 40:405

Reduced Shoot Elongation and Little Leaf Formation are very Characteristic for Zn deficiency




Effect of Zn supply on growth of maize
Low Zn
Moderate Zn
Adequate Zn

Little Leaf Formation

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Marschner, 1995; Cakmak, 2000, New Phytol.

High Zn demand for pollination

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

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

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

Zinc Deficiency Symptoms

ZINC DEFICIENCY SYMPTOMS IN WHEAT


Zn-adequate
wheat leaf
HarvestZinc
exploring fertilizer use to increase zinc in cereals


Development of Zn deficieny in wheat
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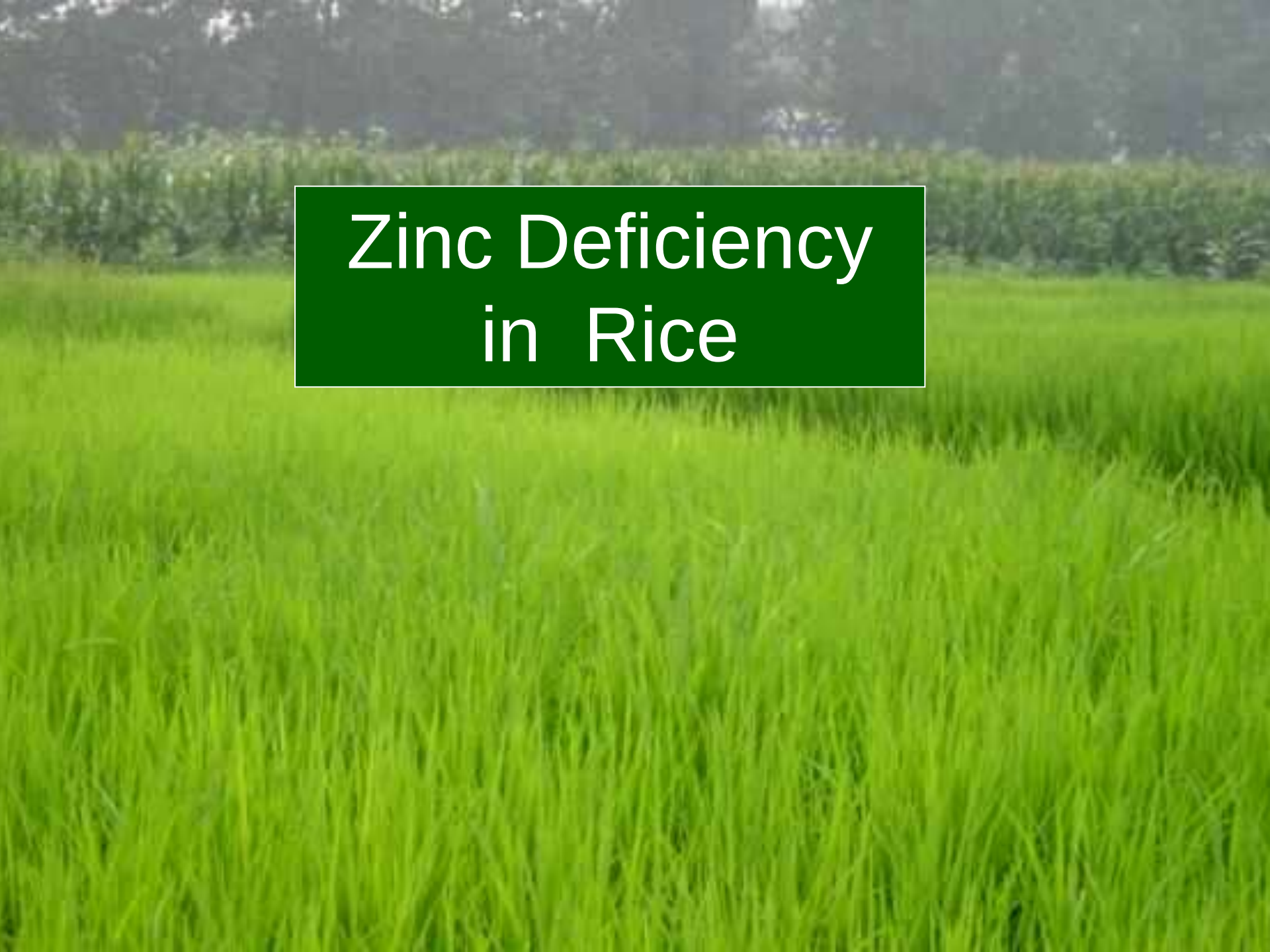

Zinc Deficiency
in Rice

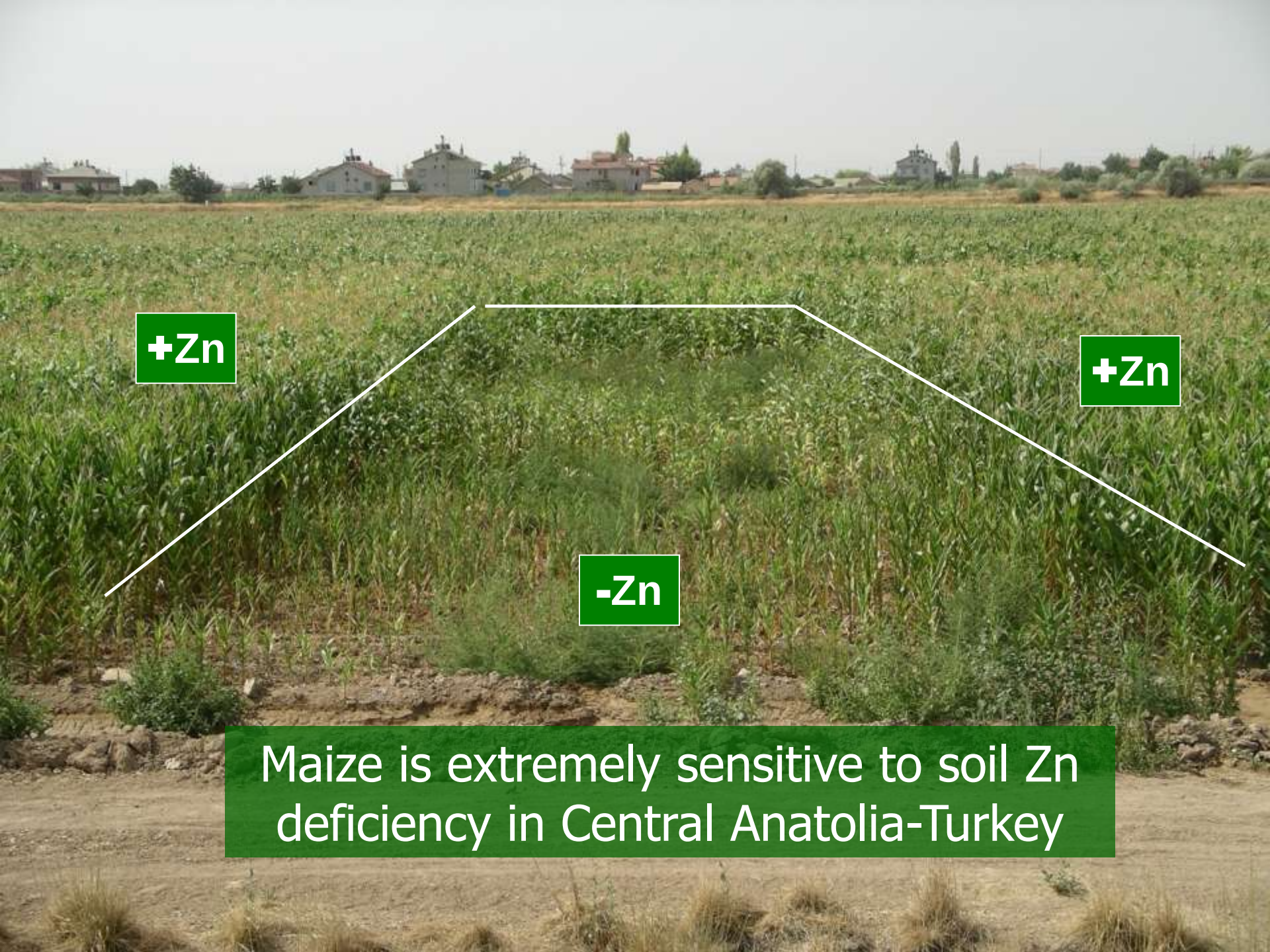

Zn-adequate
rice leaf

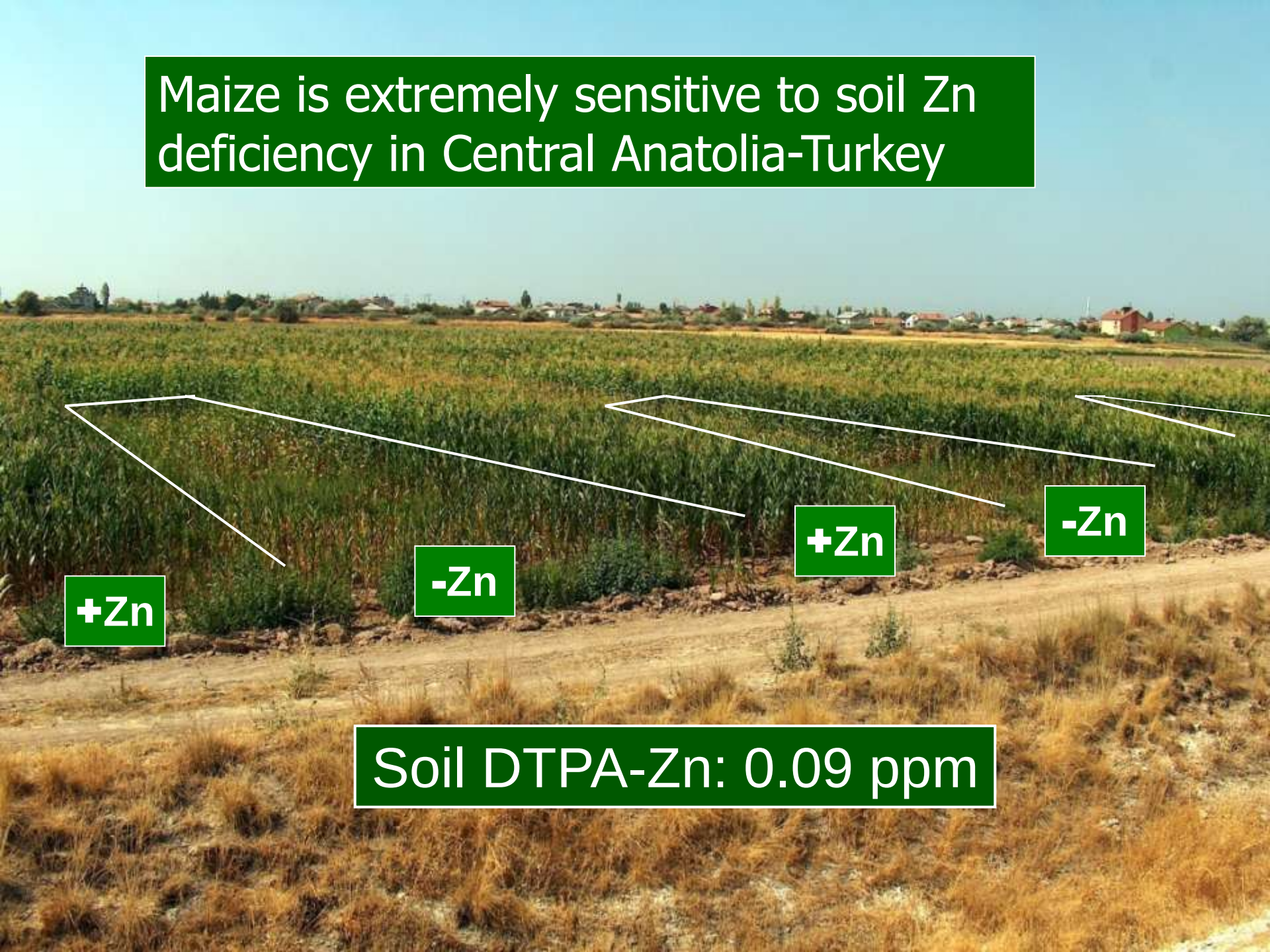

Development of Zn
deficieny in rice

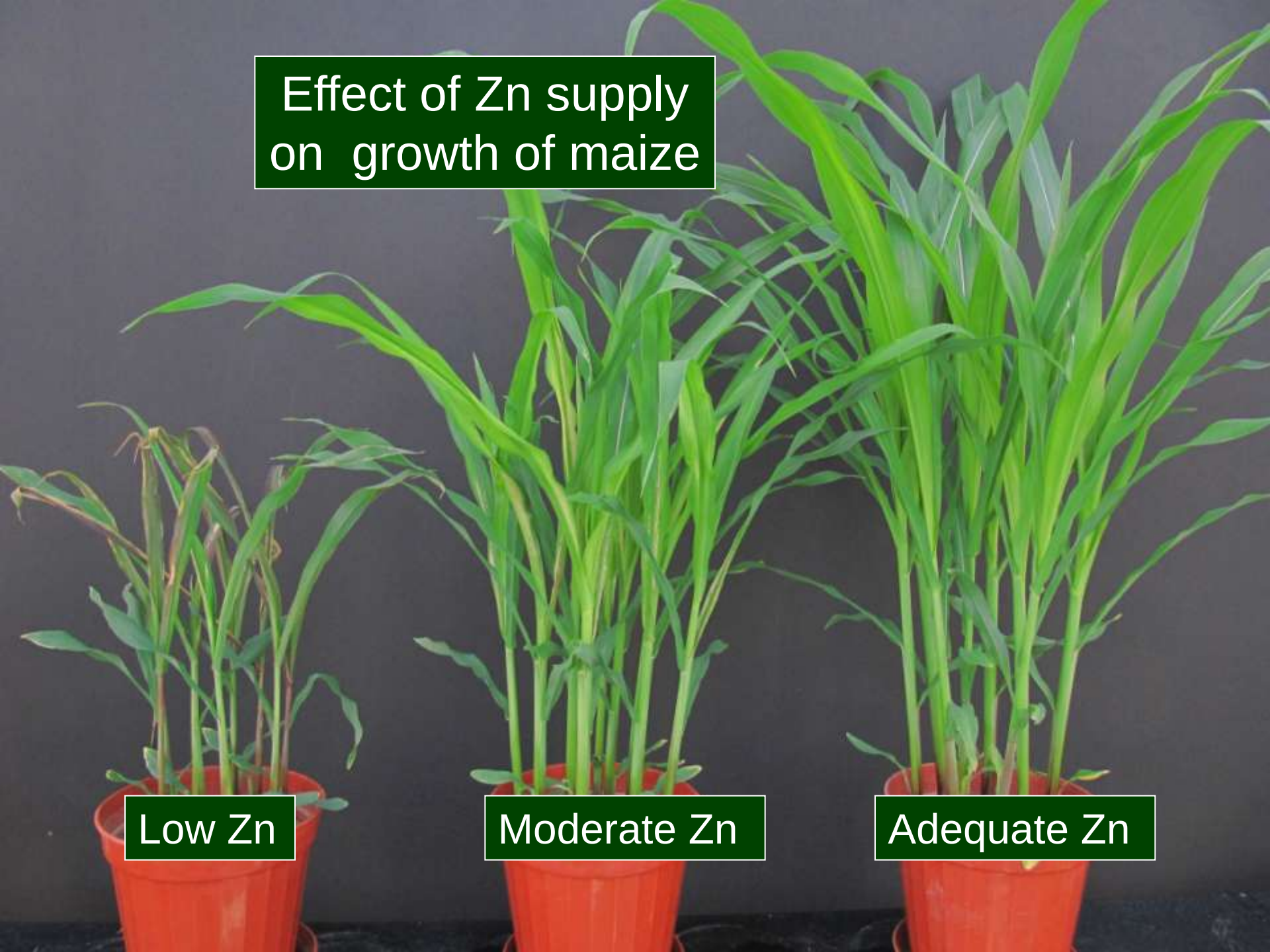

Development of Zn
deficieny in rice


Severe Zn
deficieny in rice

ZINC DEFICIENCY SYMPTOMS IN MAIZE


+Zn
+Zn
-Zn
Maize is extremely sensitive to soil Zn deficiency in Central Anatolia-Turkey


Maize is extremely sensitive to soil Zn deficiency in Central Anatolia-Turkey
+Zn
-Zn
+Zn
-Zn
Soil DTPA-Zn: 0.09 ppm


Effect of Zn supply on growth of maize
Low Zn
Moderate Zn
Adequate Zn


Development of Zn deficiency in maize


Zn deficiency in maize


Zn deficiency in maize

Video:
Growth of Corn Plants on a Zn-Deficient Soil

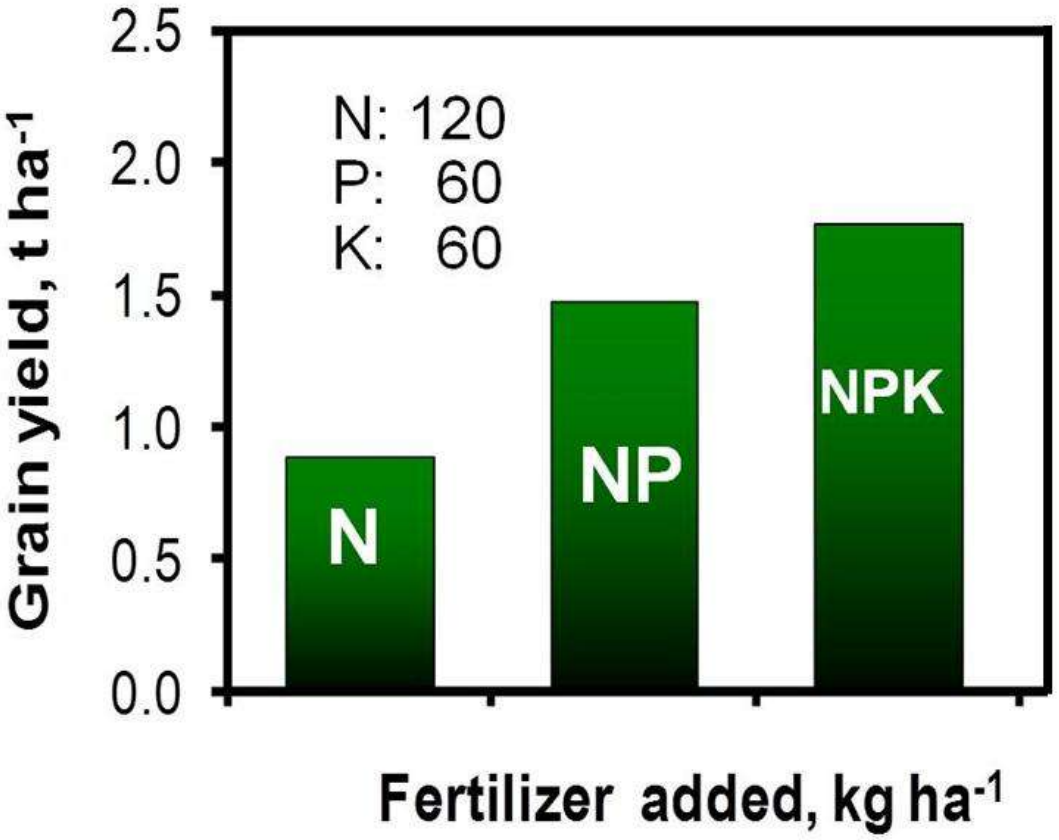
Balanced Crop Nutrition (Zn)

Cultivation of high yielding cultivars under continuous monoculture or intensive cropping systems leads to **depletion of nutrients in soils**.

The nutrients depleted should be replenished to sustain high yields under continuous cropping systems.

Deficiencies of Zn and S are particular examples occurring in various cropping systems; for example in India

Wheat Grain Yield Based on **Long-term Multi Location Experiments** in India



Source: Tandon, 1995

In: Proceedings of the IFPRI/FAO Workshop on Soil Fertility, Plant Nutrient Management, and Sustainable Agriculture: The future Through 2020. Eds. P Gruhn, et al,

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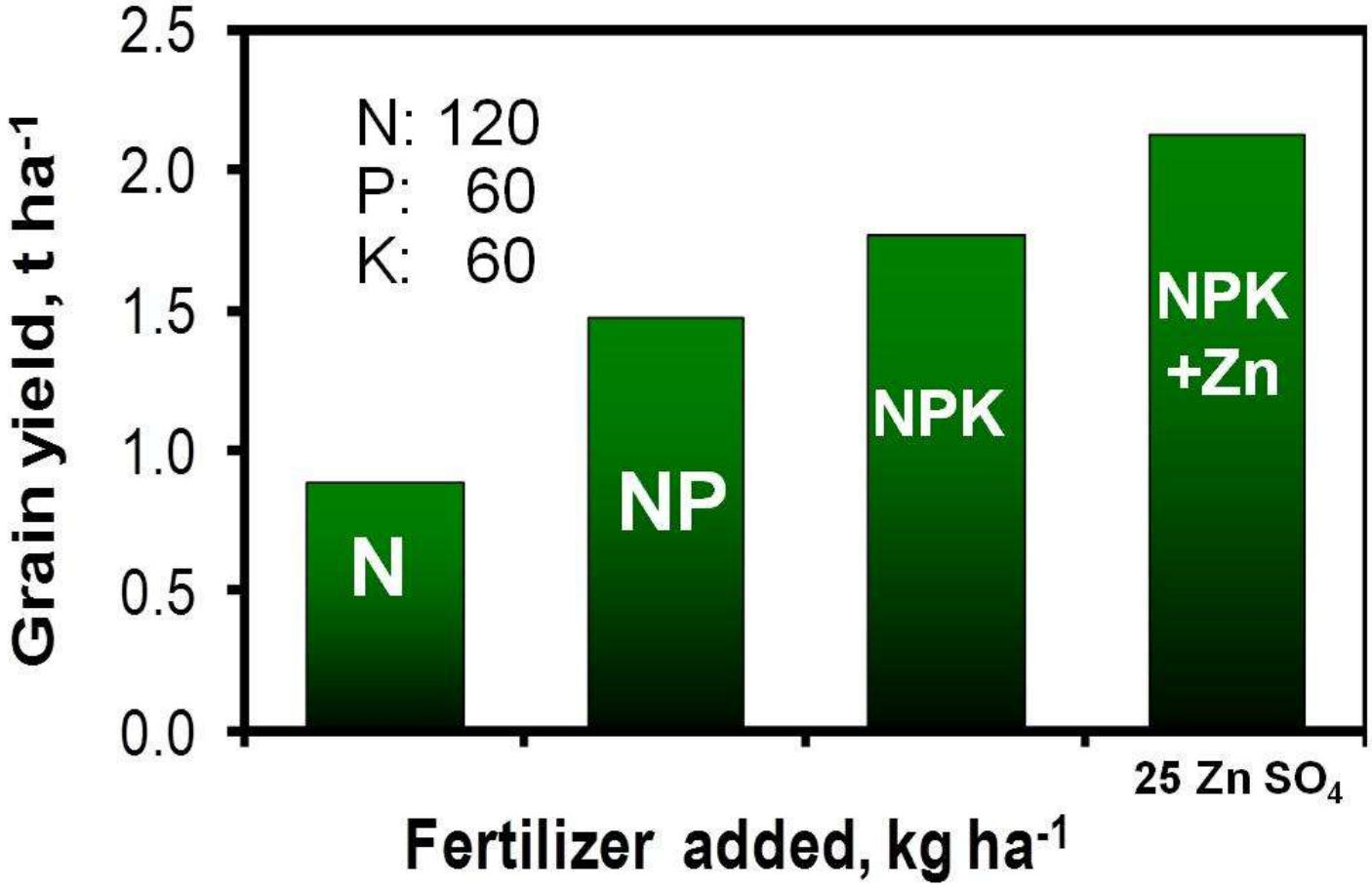
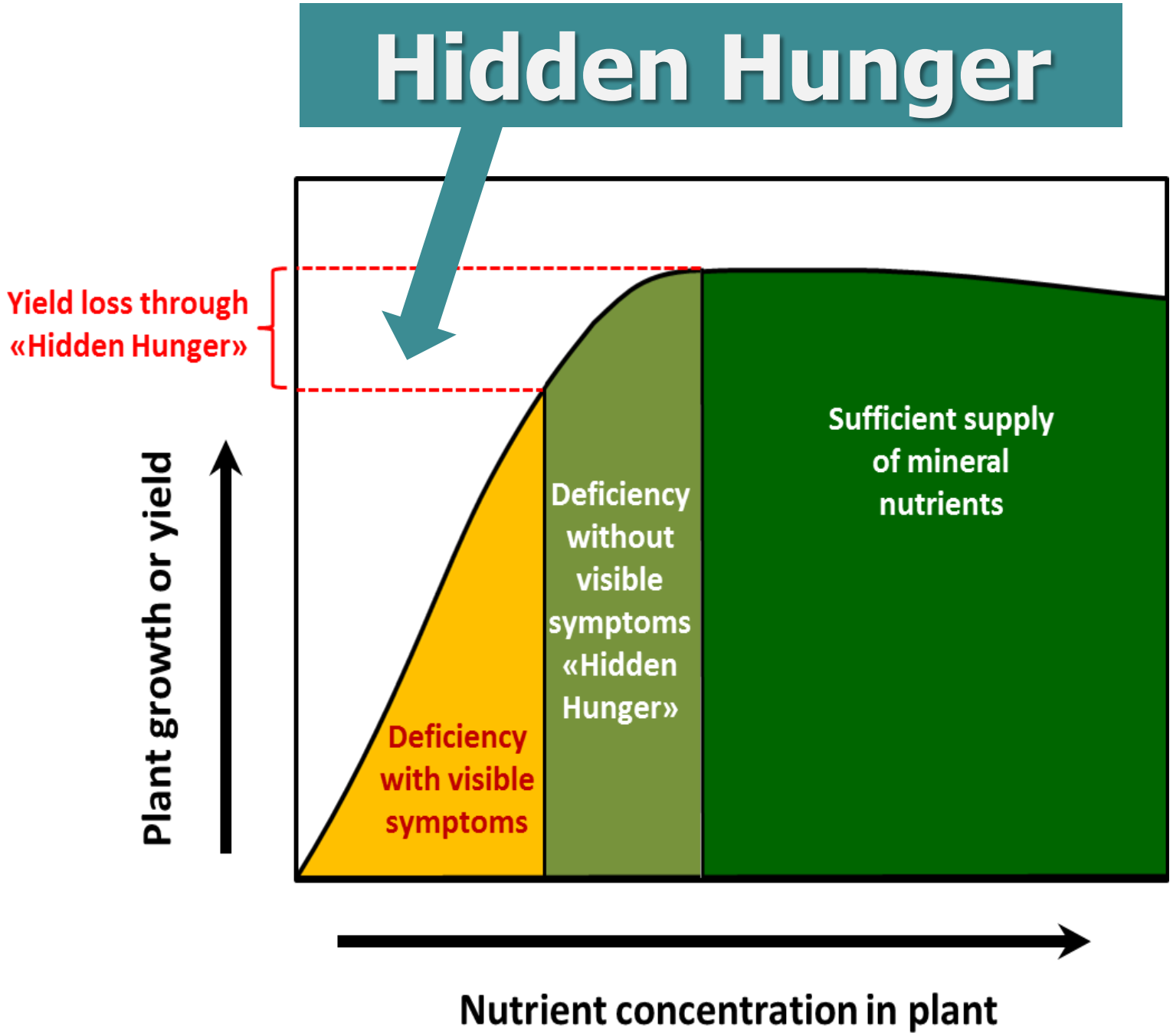


Tandon, 1995; In: Proceedings of the IFPRI/FAO Workshop on Soil Fertility, Plant Nutrient Management, and Sustainable Agriculture: The future Through 2020. Eds. P Gruhn, et al,

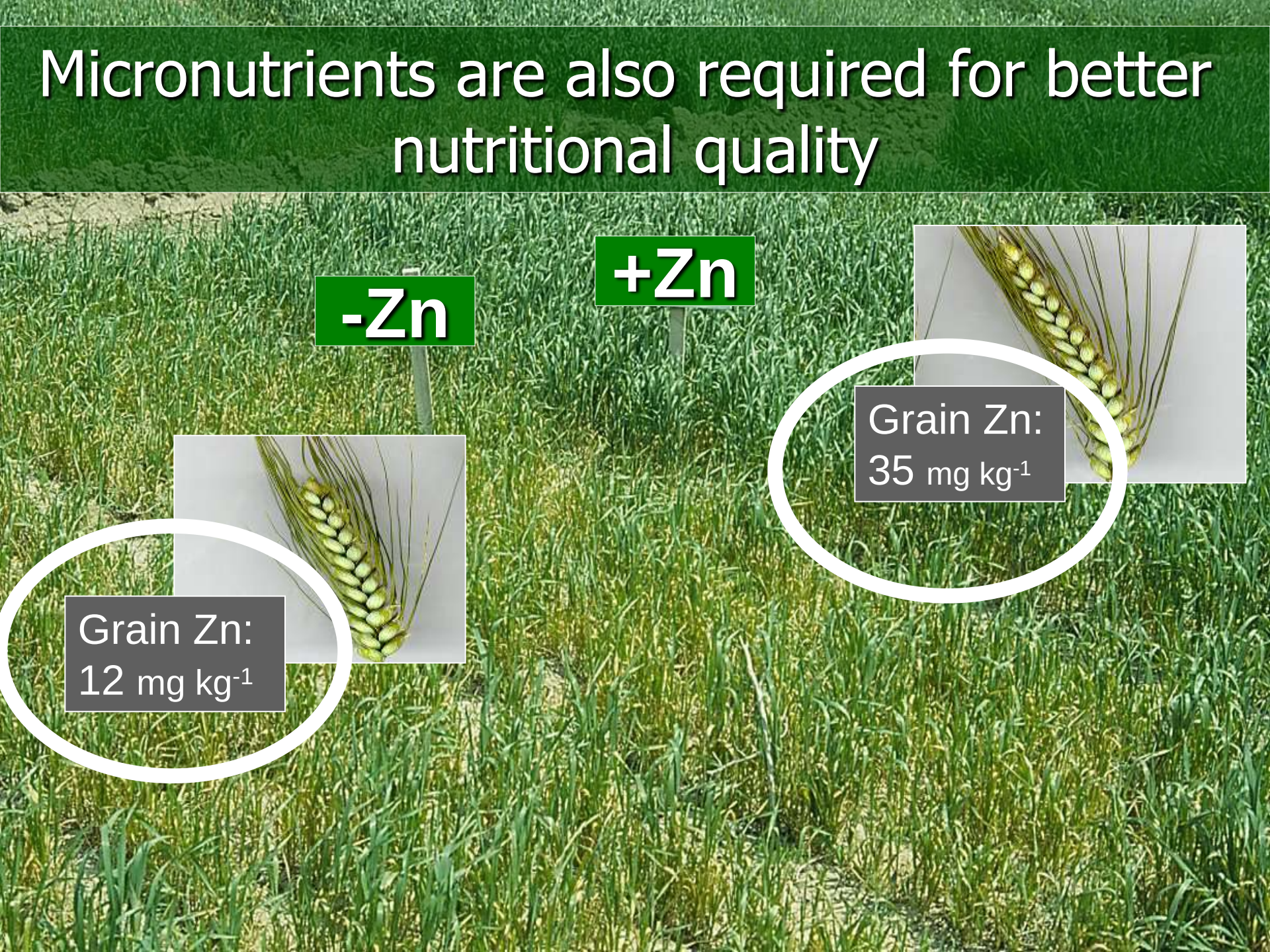
Hidden zinc deficiency

In many crop plants **hidden zinc deficiency** has been well documented that may be responsible for reductions in yield up to 20 % without appearance of distinct leaf symptoms.

It is, therefore, important to include zinc in the commonly applied NP fertilizers and/or spray foliar Zn-fertilizers to plants to ensure that plants don't suffer from Zn deficiency stress.


Hidden Hunger
Yield loss through «Hidden Hunger»
Plant growth or yield
Deficiency with visible symptoms
Deficiency without visible symptoms «Hidden Hunger»
Sufficient supply of mineral nutrients
Nutrient concentration in plant

Micronutrients are also required for better nutritional quality



Further benefit achieved by adequate micronutrient nutrition of crop plants is related to quality of food crops and better nutritional diet.

Micronutrient Deficiencies: Global Malnutrition Problem

Iron Estimated 2 billion

Zinc Estimated 2 billion

www.harvestplus.org

Zinc deficiency impairs range of functions:

- Immunity
- Growth; physical development
- Brain function and development
- Reproduction
- ….

Children particularly sensitive to Zn deficiency

> 450,000 deaths/year children under 5 years-old

Black et al. 2008

The Lancet Maternal and

Child Undernutrition Series

ZINC SAVES KIDS

Intl' Zinc Assoc.

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

www.ZincSavesKids.org

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.

For a better Zn nutrition of human beings, cereal grains should contain around

40-60 mg Zn kg^{-1}

Current Situation:

10-30 mg kg^{-1}

The Underlying Cause of Malnutrition

- **Agriculture is the primary source of all nutrients entering human food systems**

- **Therefore, agriculture must play an important role in fighting malnutrition**

Health comes from the farm, not from the pharmacy.

Solutions to Micronutrient Deficiencies

- Supplementation
- Food Fortification

(not affordable in rural regions)

Golden Wheat Fortfied with Zn

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

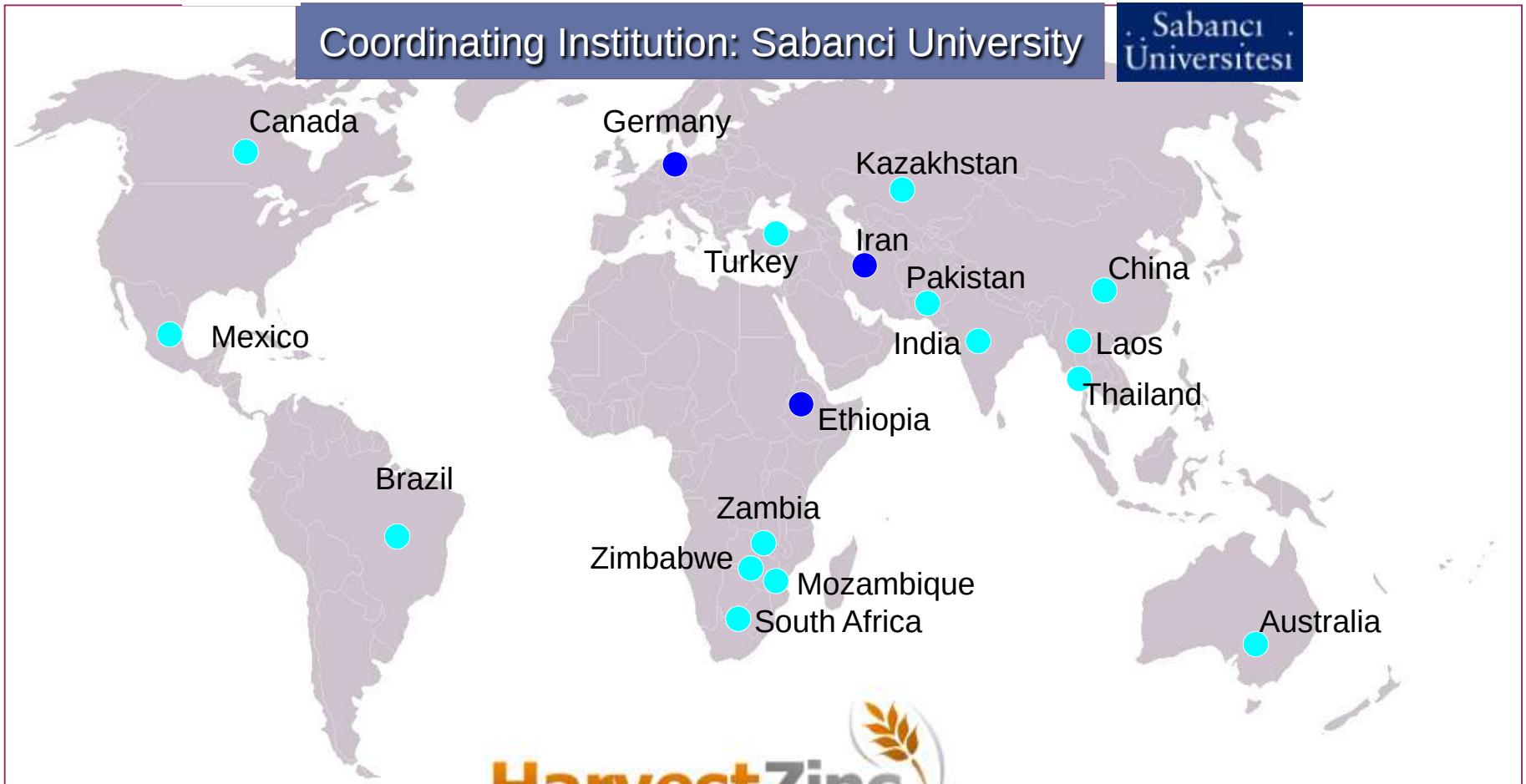
HarvestPlus
Breeding Crops for Better Nutrition

HarvestZinc
exploring fertilizer use to increase zinc in cereals

Mosaic · KALI · Zinc essential for life · OMEX · ifa · IPNI · BAYER · ADOB · Valagro · fbsciences · ATP NUTRITION Powering Growth with Science™

Coordinating Institution: Sabanci University

Sabancı Üniversitesi



HarvestZinc
exploring fertilizer use to increase zinc in cereals

HarvestPlus
Breeding Crops for Better Nutrition

Global Zinc Fertilizer Project
II. Phase

HarvestZinc
exploring fertilizer use to increase zinc in cereals

2011 June- 2014 May

Mosaic · KALI · Zinc essential for life

OMEX · ifa · Bayer CropScience

ADOB · Valagro · fbsciences · IPNI · ATP NUTRITION Powering Growth with Science ™

Sabancı Üniversitesi

For a better Zn and Fe nutrition of human beings, cereal grains should contain around **40-60 mg Zn or Fe kg^{-1}**

Current Situation:
10-30 mg kg^{-1}

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 +Z

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

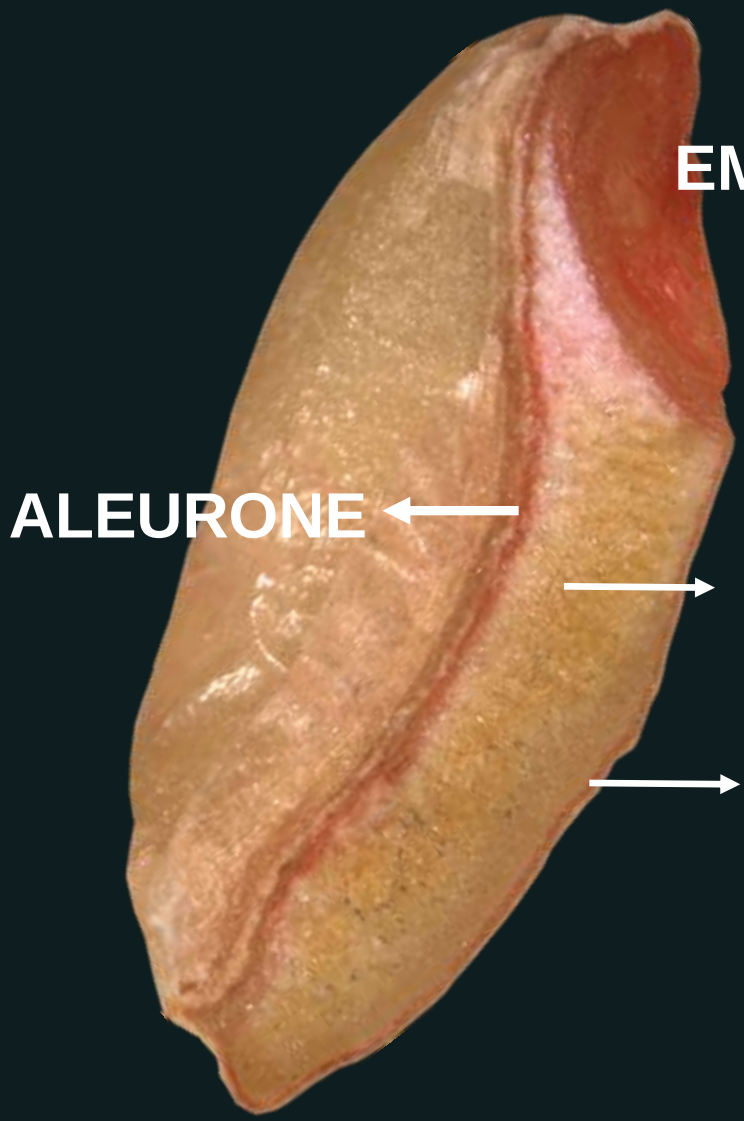
(10 Countries with 32 locations)

-Zn: 26 ppm

+Zn: 50 ppm

Zou et al., 2012, Plant and Soil

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

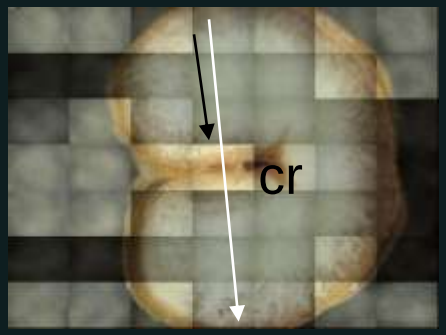


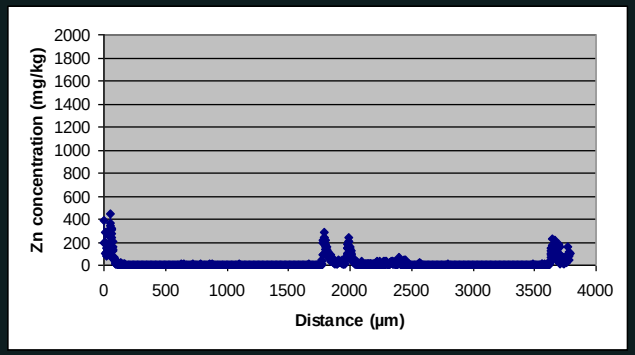
Cakmak et al., 2010

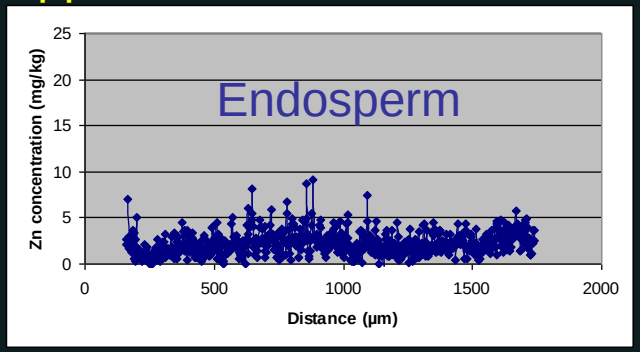
Cereal Chemistry, 77: 10-20

LA-ICP-MS Tests

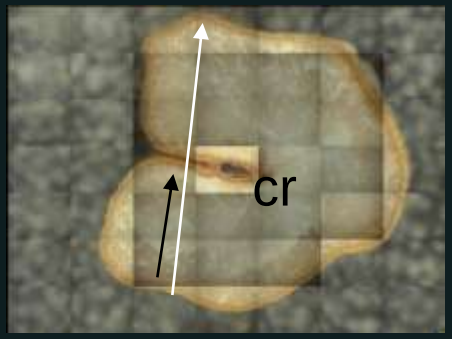
No Foliar Zn Application

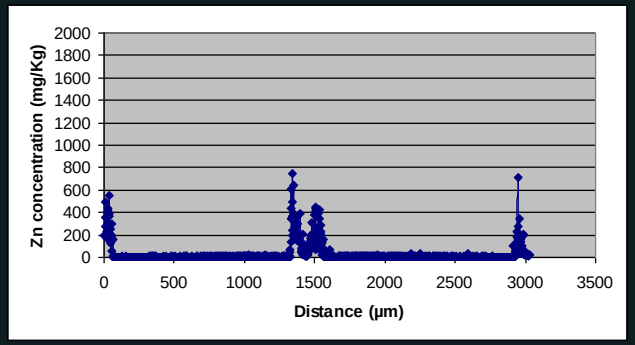


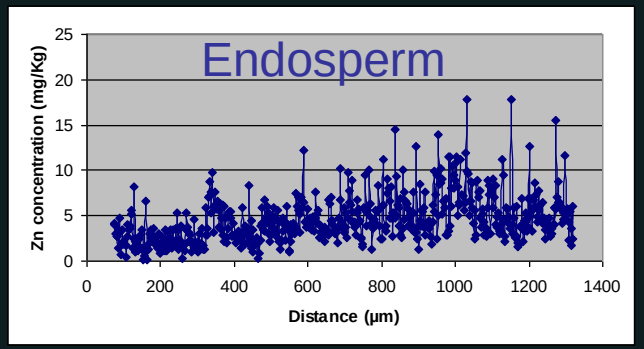




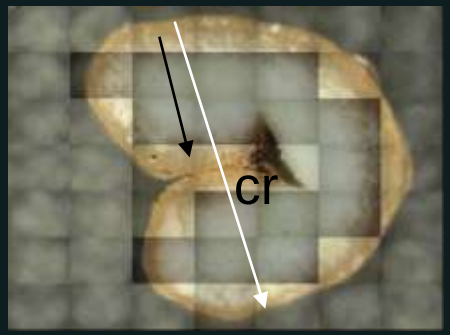
Foliar Zn Application at Stem Elongation and Booting Stages

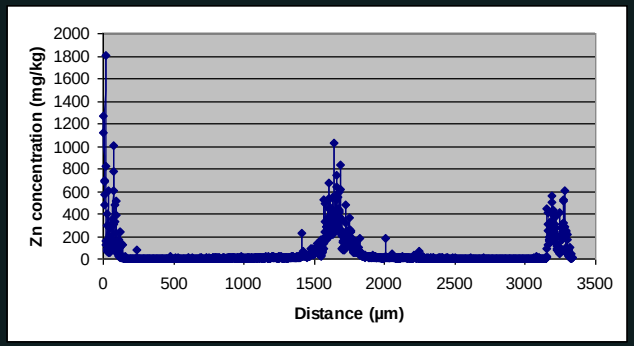


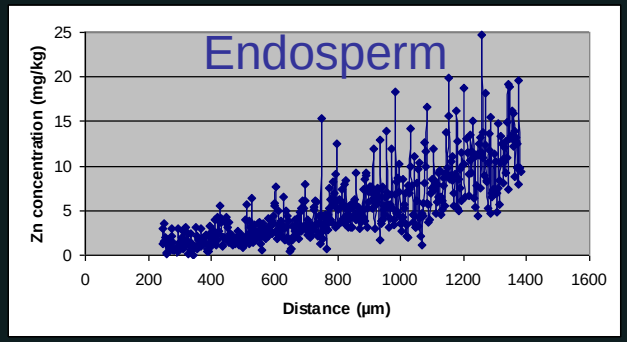




Foliar Zn Application at Milk and Dough Stages

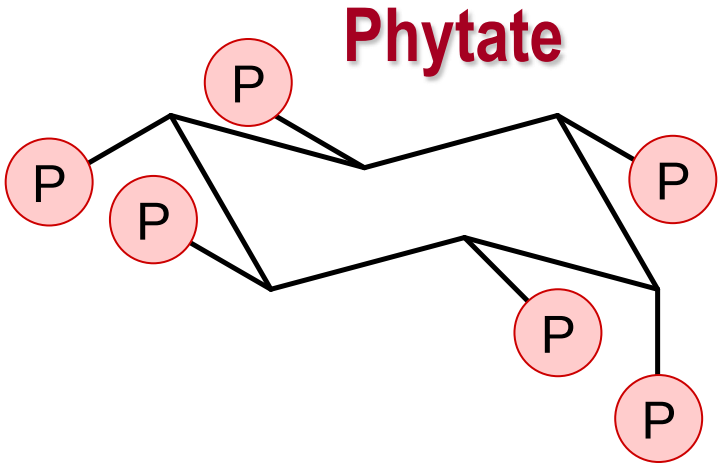






Cakmak et al., 2010, J. Agric. Food. Chem. 58:9092-9102

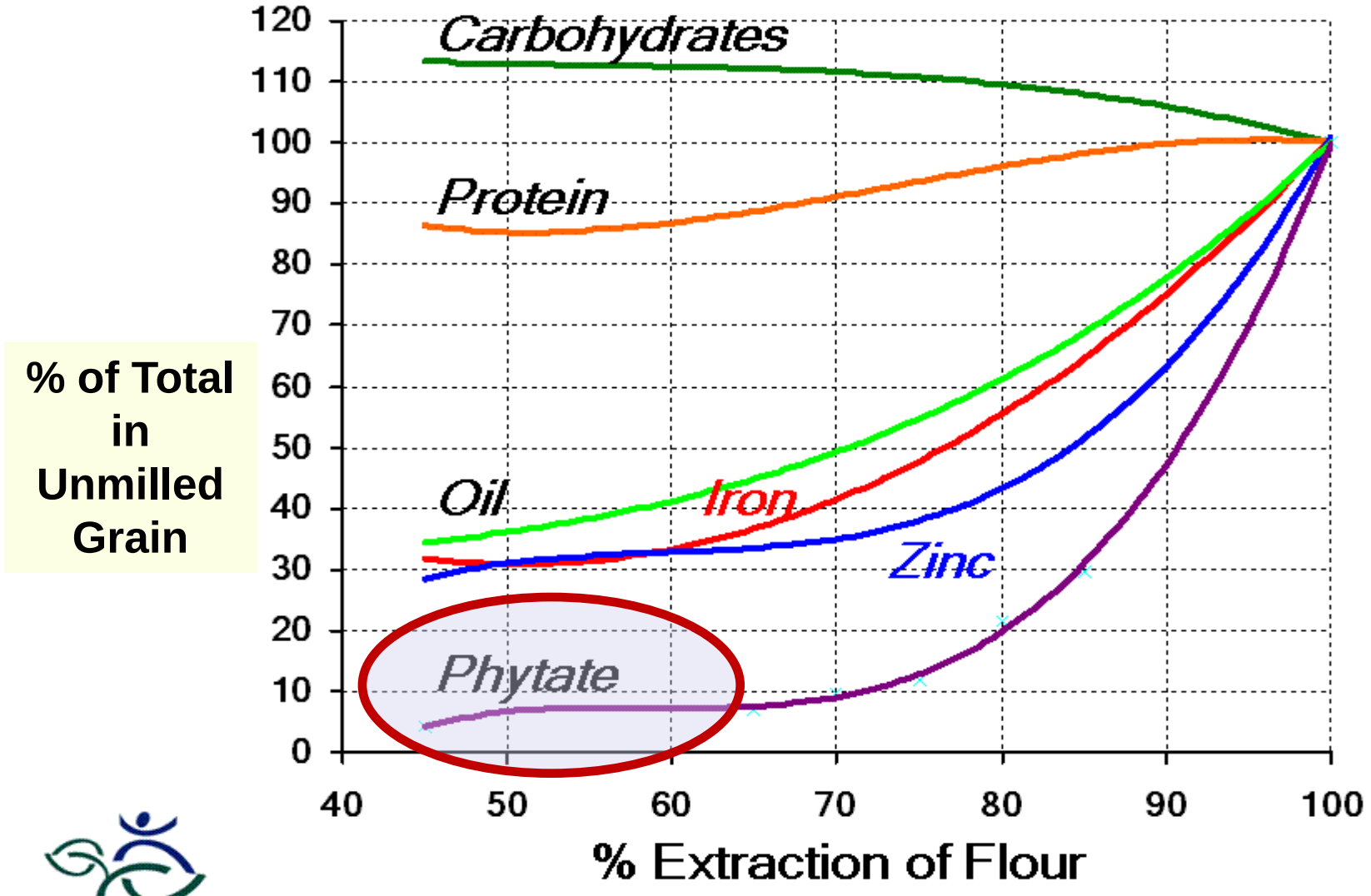
Phytate is belived to impair Zn bioavailability



P : Phosphate group

- Cereal grains are rich in phytate
- Phytate forms insoluble complexes with Zn2+
- Phytate concentration is very low in endosperm

Change in Nutrient Composition With Milling Affects Bioavailability & Warrants Consideration in Breeding



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Breeding Crops for Better Nutrition
Wolfgang HFREIFFER

Data source: Y. Pomeranz, 1978, Wheat: Chemistry and Technology, AACC.

Thank you...