Zinc Deficiency:

A Global Nutritional Problem in Crop Production and Human Nutrition

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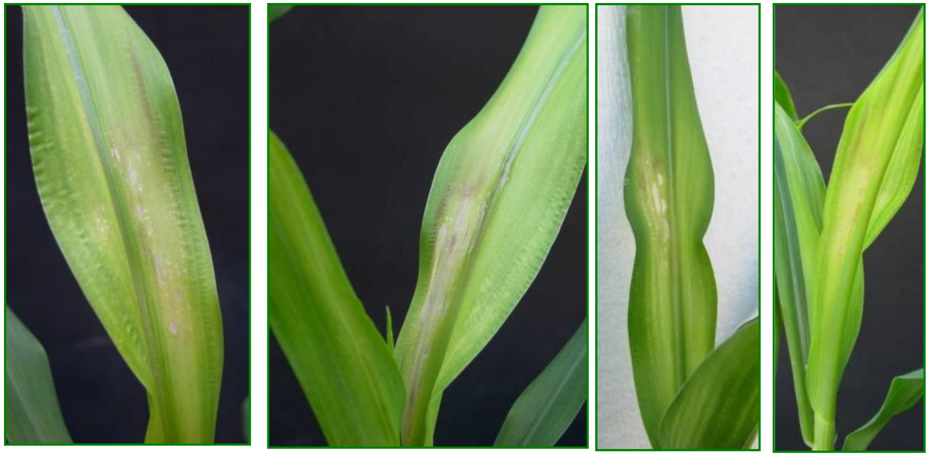
Zn Deficiency:
a global nutritional problem in cultivated soils

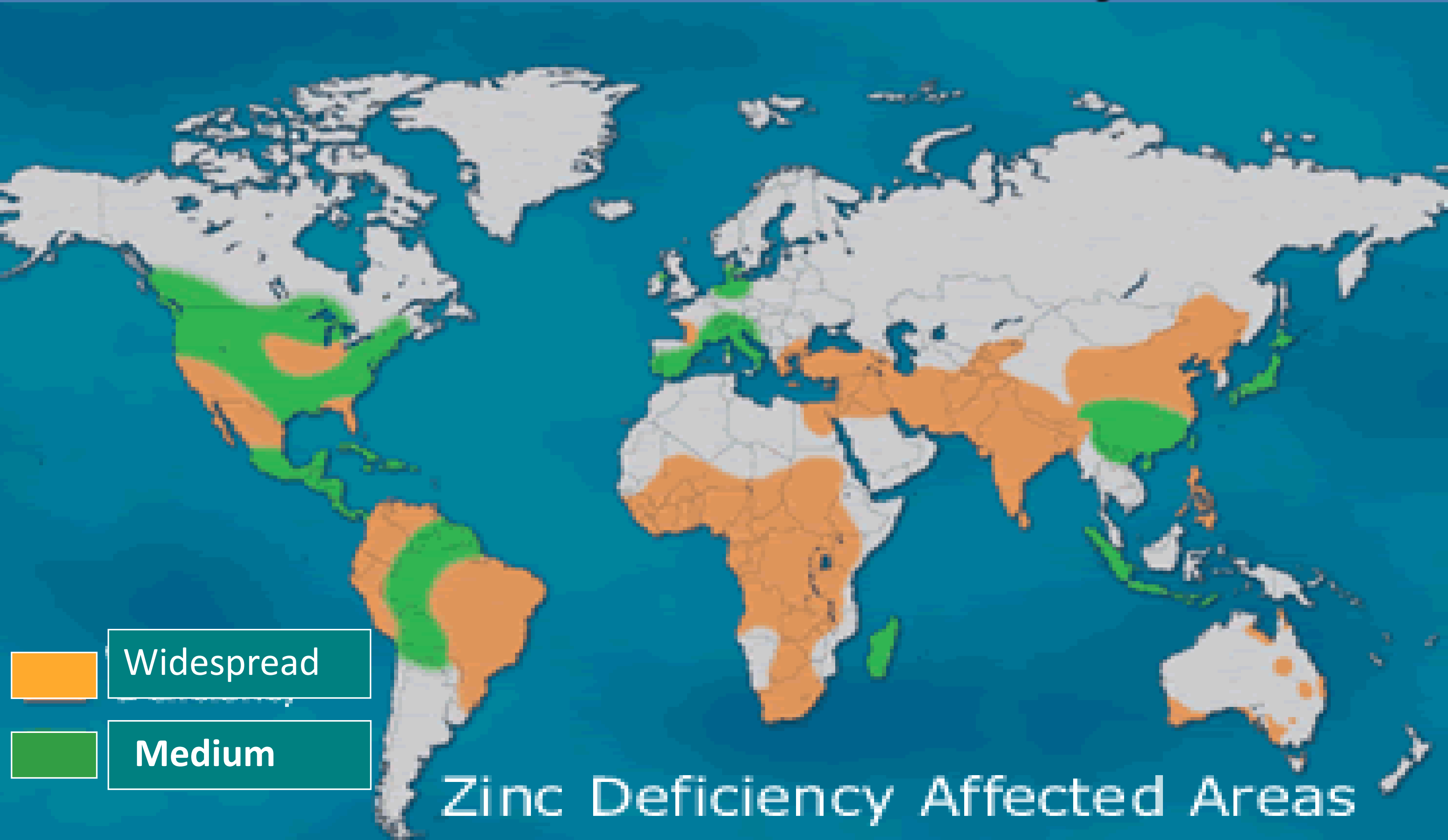
Australia	: >10 mio ha
Turkey	: 14 mio ha
Bangladesh	: 2 mio ha
China	:30 mio ha
India	: 90 mio ha

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



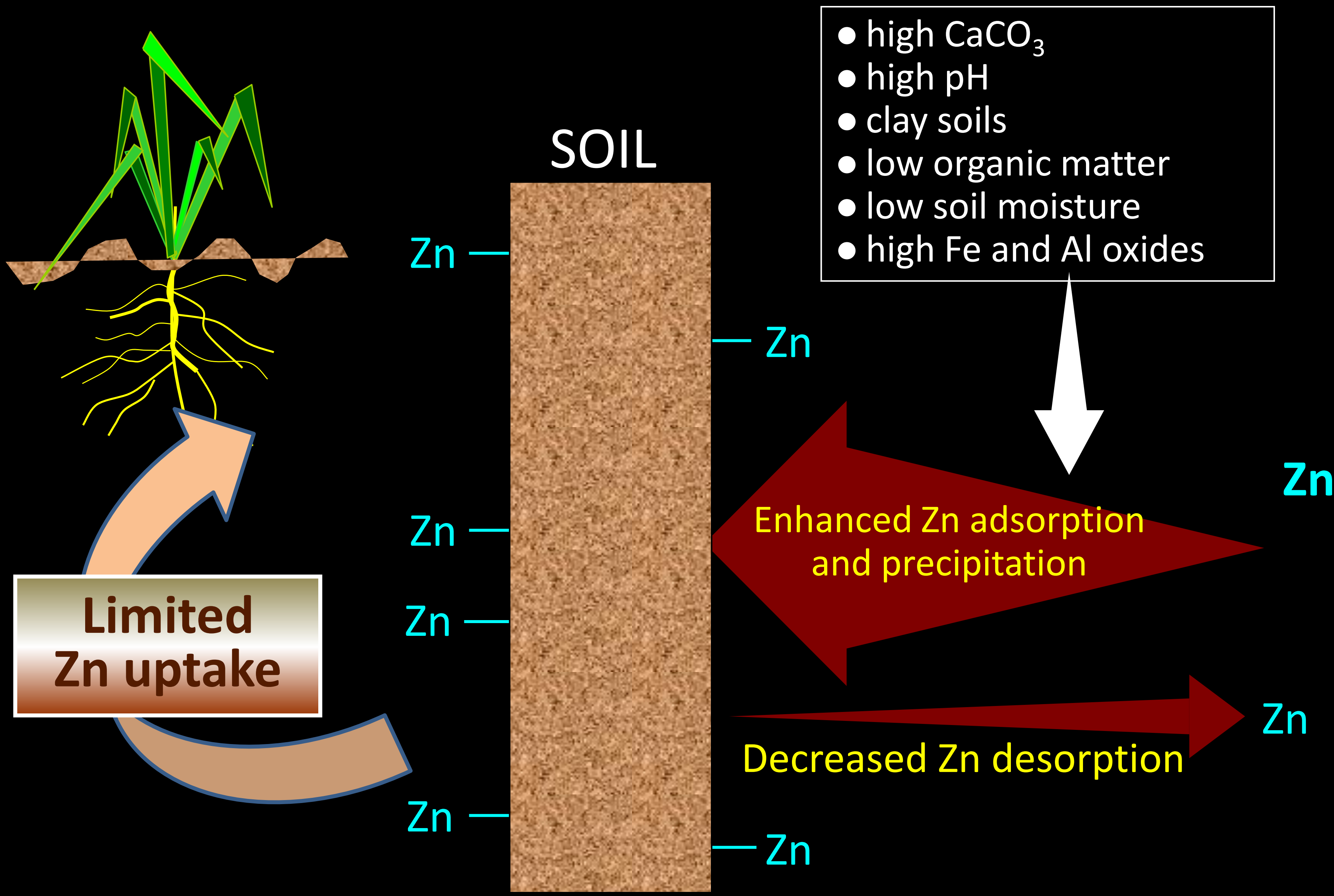
Zn Deficiency:

Global Micronutrient Deficiency in Soils

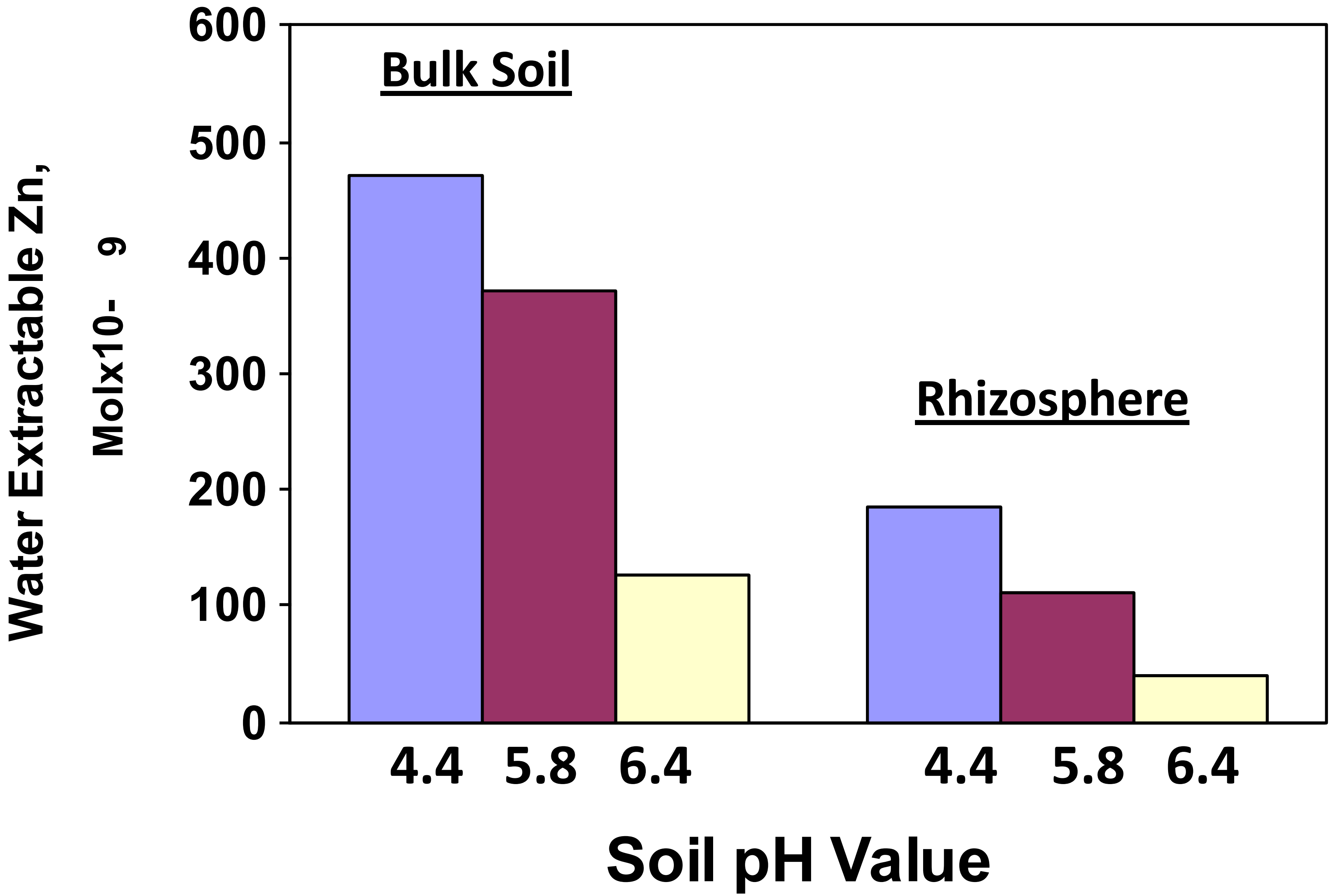


Alloway, 2007. IZA Publications, Brussels

Soil factors affecting availability of Zn to roots

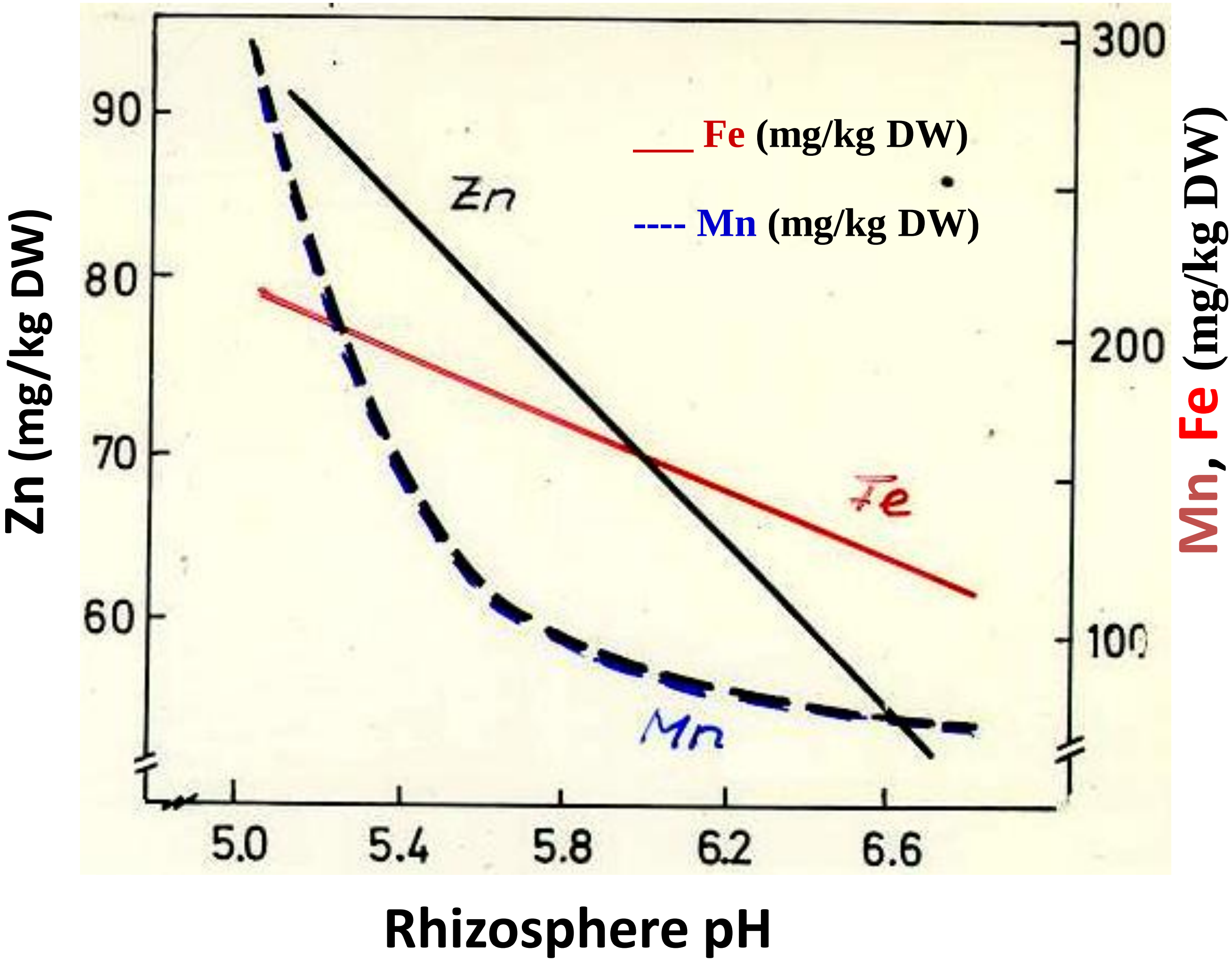


Soil pH: a critical factor reducing Zn solubility



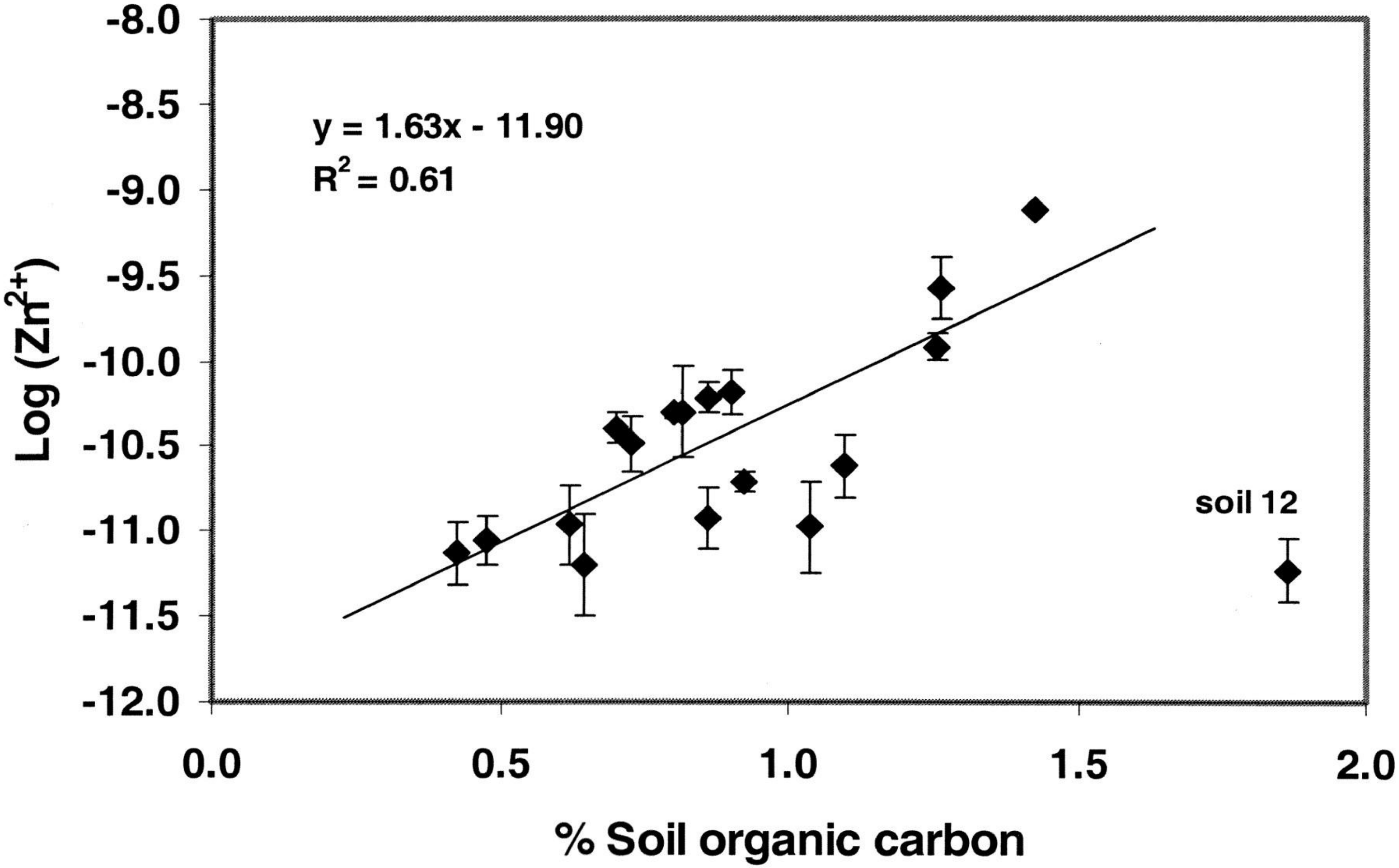
Saron et al., et al.,1989; Comm. Soil Sci. Plant Anal. 20: 271

Effect of Soil pH on Leaf Concenratation of Micronutrients in Bean Plants



(Sarkar and Wyn Jones, Plant Soil 66, 361, 1982)

Relationship between **free Zn Activity** and **soil organic carbon** for 18 Colorado Soils



Obrador et al., 2003, Soil Sci. Soc. Am. J. 67: 564.

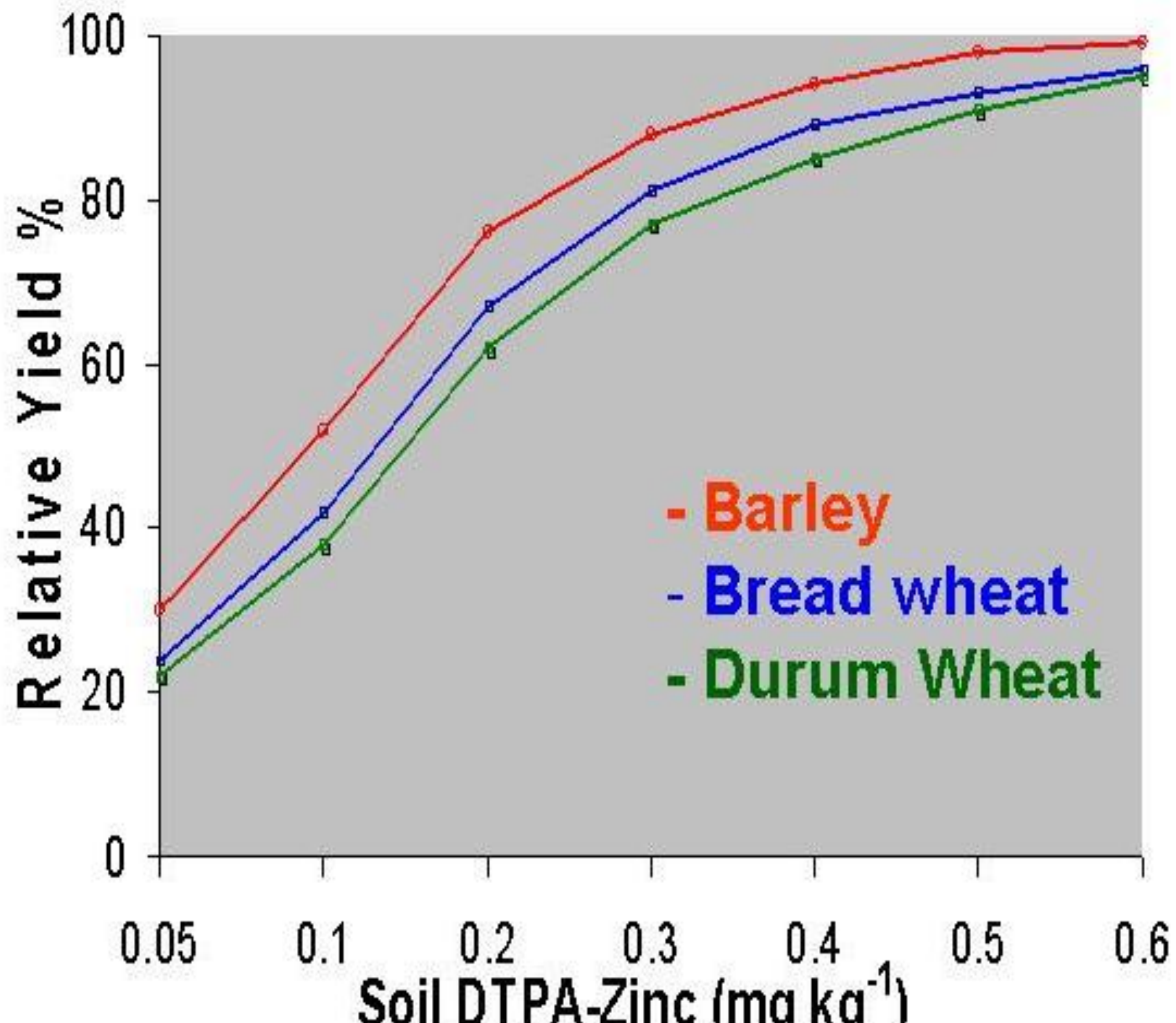
Soil Tests

Determination of DTPA-extractable zinc is the most widely used method for measurement of plant available Zn in soils.

Most commonly reported critical concentrations for the **DTPA-Zn is $\leq$0.5 ppm.**

Mehlich-3: 1.5-3.5 ppm depending on soil pH

Relationship between soil DTPA-Zn and Relative Yield of Cereal Crops Grown in Different Locations in Central Anatolia



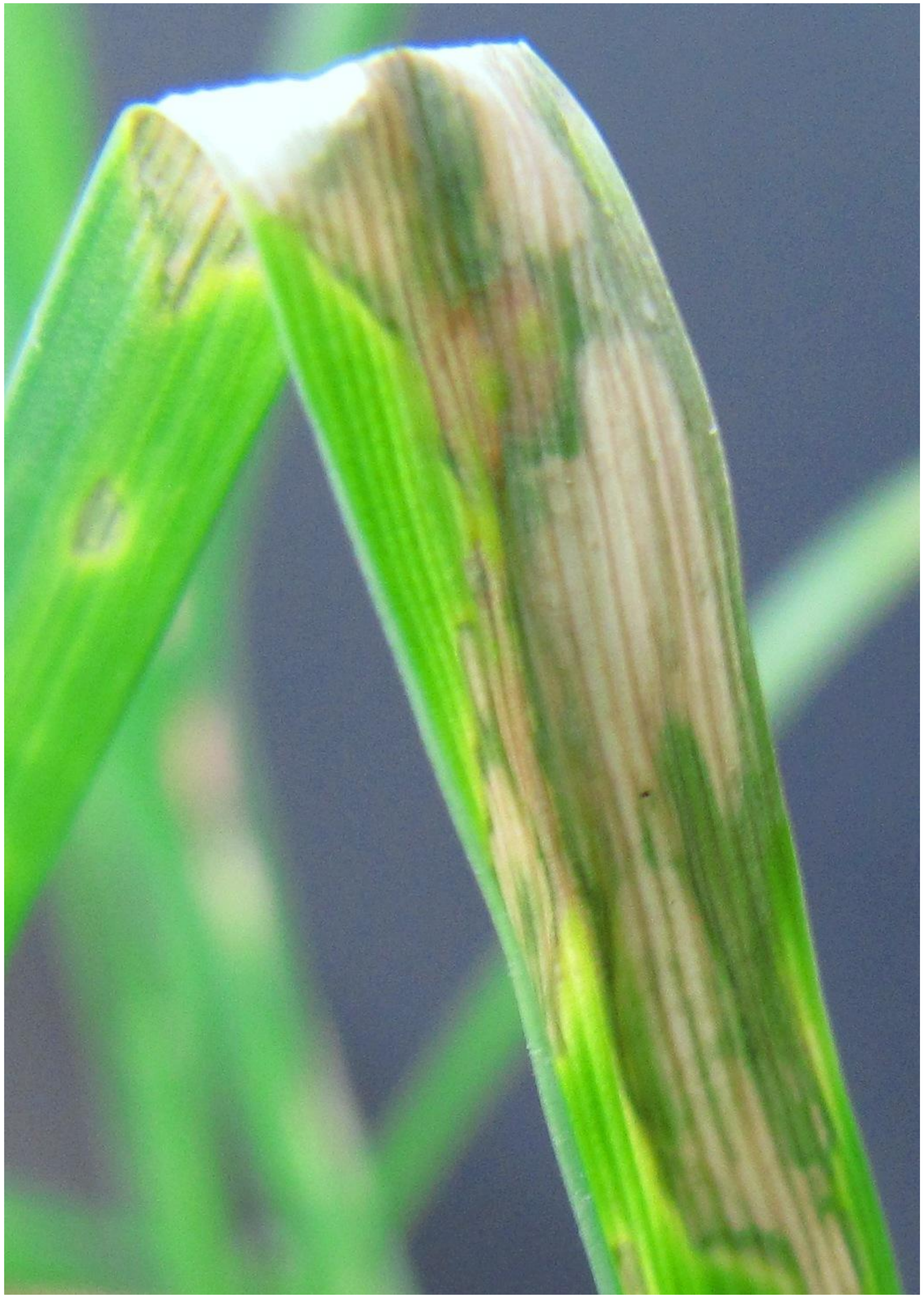
Gultekin et al., 1998

Zinc Deficiency Symptoms


Control
Increase in severity of Zinc Deficiency Symptoms in Wheat


Control
Increase in severity of Zinc Deficiency Symptoms in Wheat


Increase in severity
of Zinc Deficiency
Symptoms in Wheat



Final Stage of Leaf Zinc Deficiency in Wheat

Video:

Growth of Maize and Rice Plants on a Zn-Deficient Soil

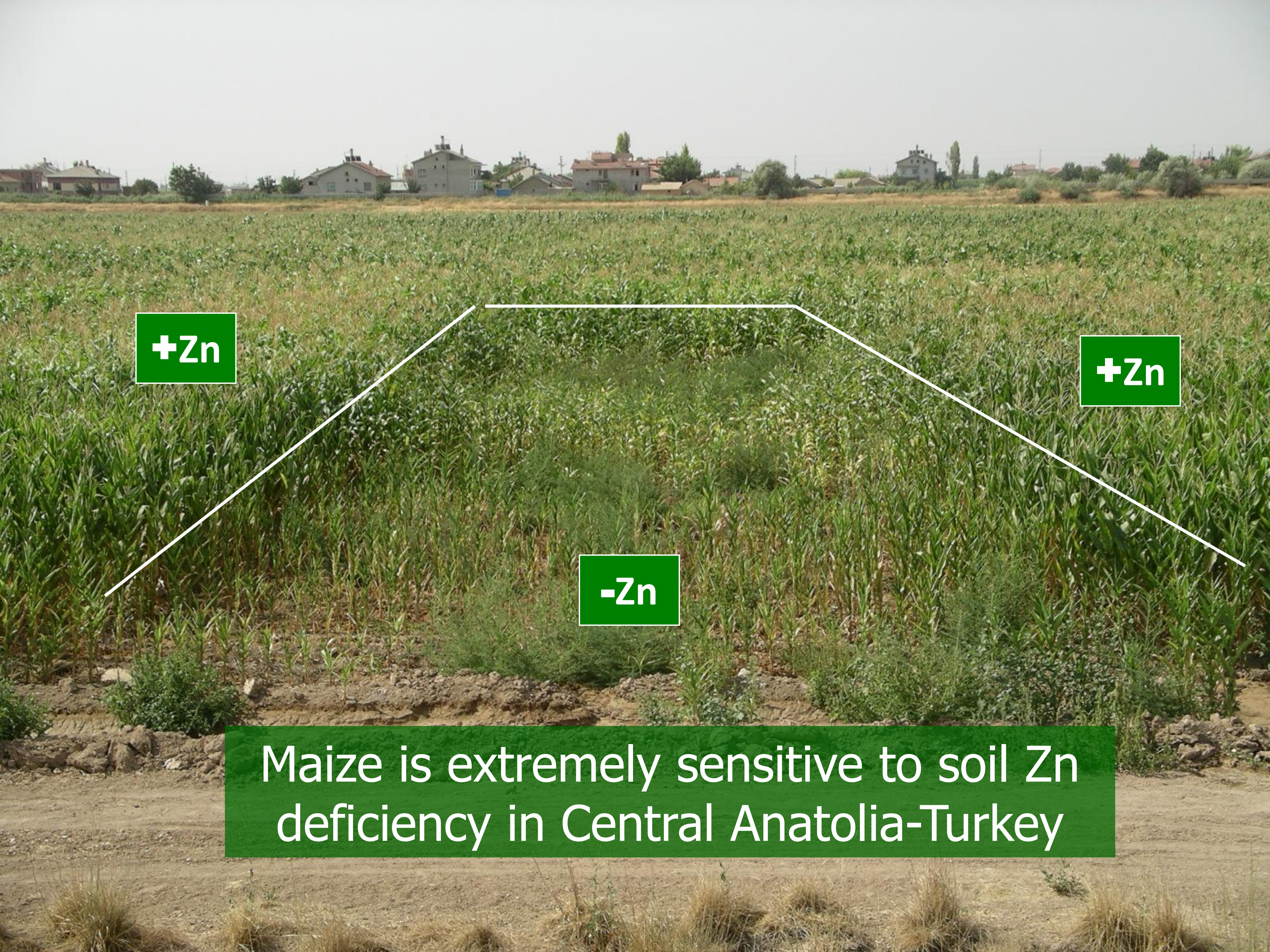
Zinc Deficiency in Maize

Leaf Symptoms

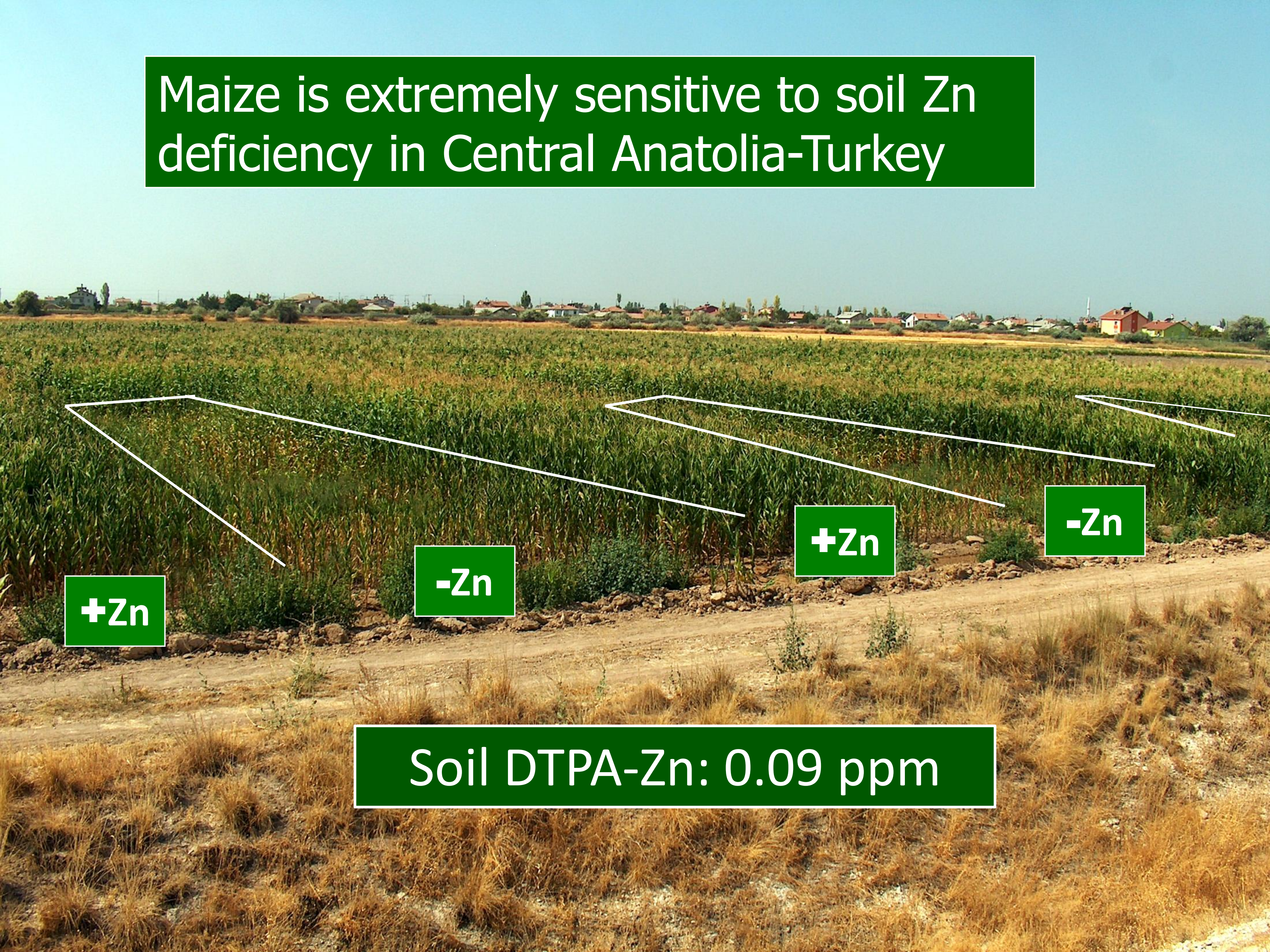
The most **characteristic symptoms** of zinc deficiency in maize include the development of whitish or yellowish stripes parallel to the midrib on the young leaves and stunting appearance







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

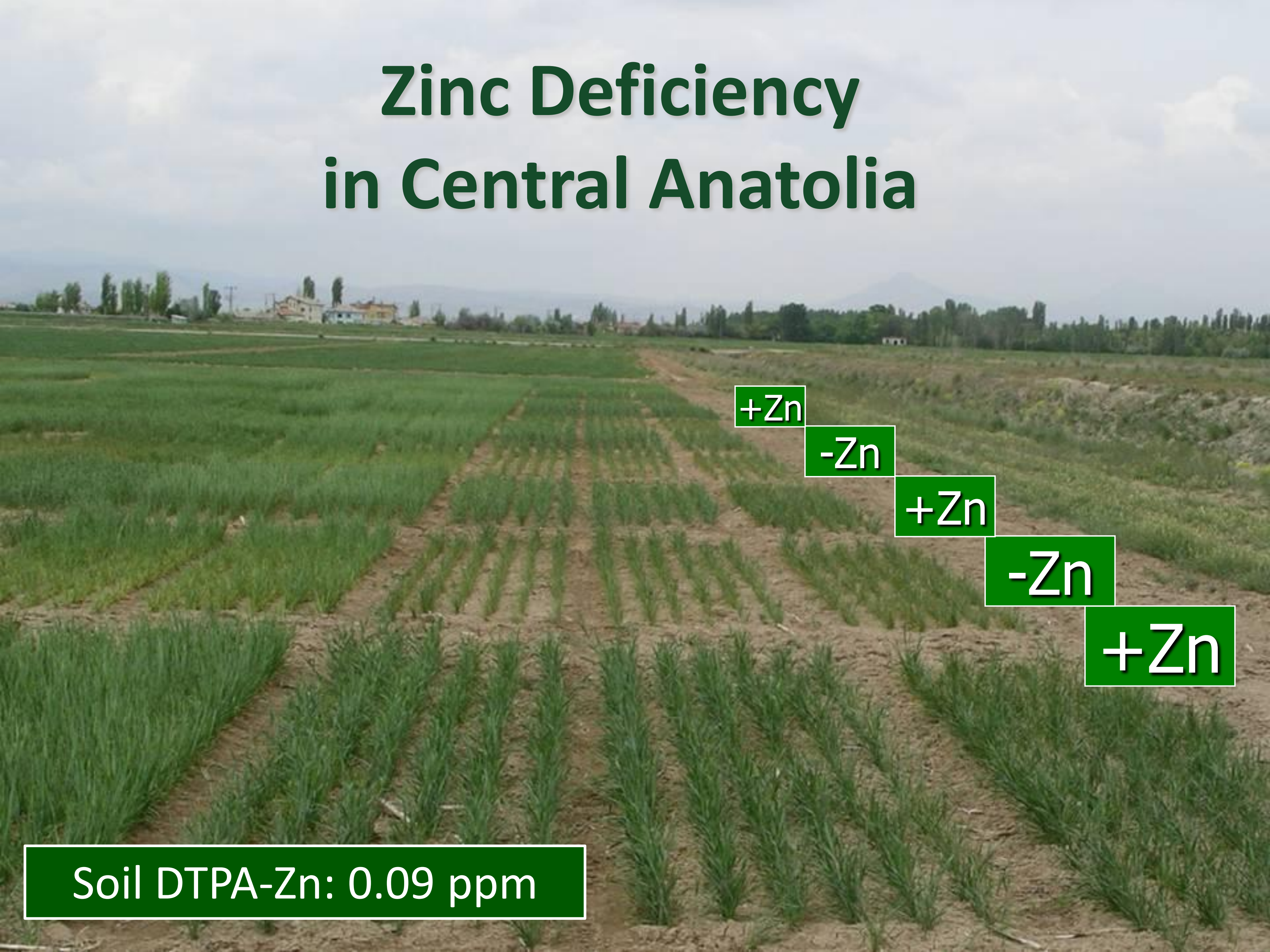

Maize is extremely sensitive to soil Zn deficiency in Central Anatolia-Turkey
+Zn
-Zn
+Zn
-Zn
Soil DTPA-Zn: 0.09 ppm

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 NPK fertilizers in order to ensure that plants don't suffer from Zn deficiency stress.

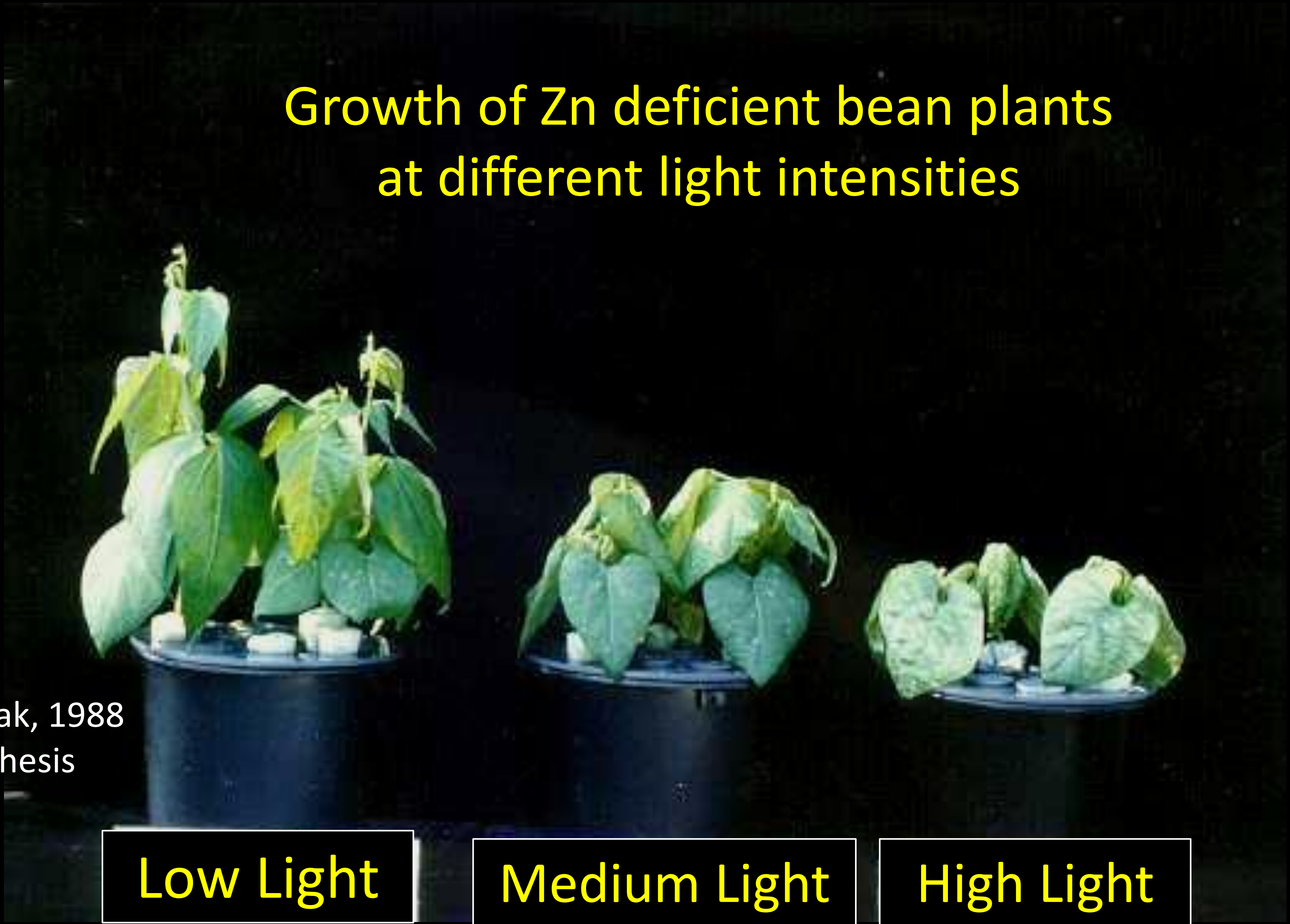
Zinc Deficiency in Central Anatolia



Foliar Application of Zn on Barley Field

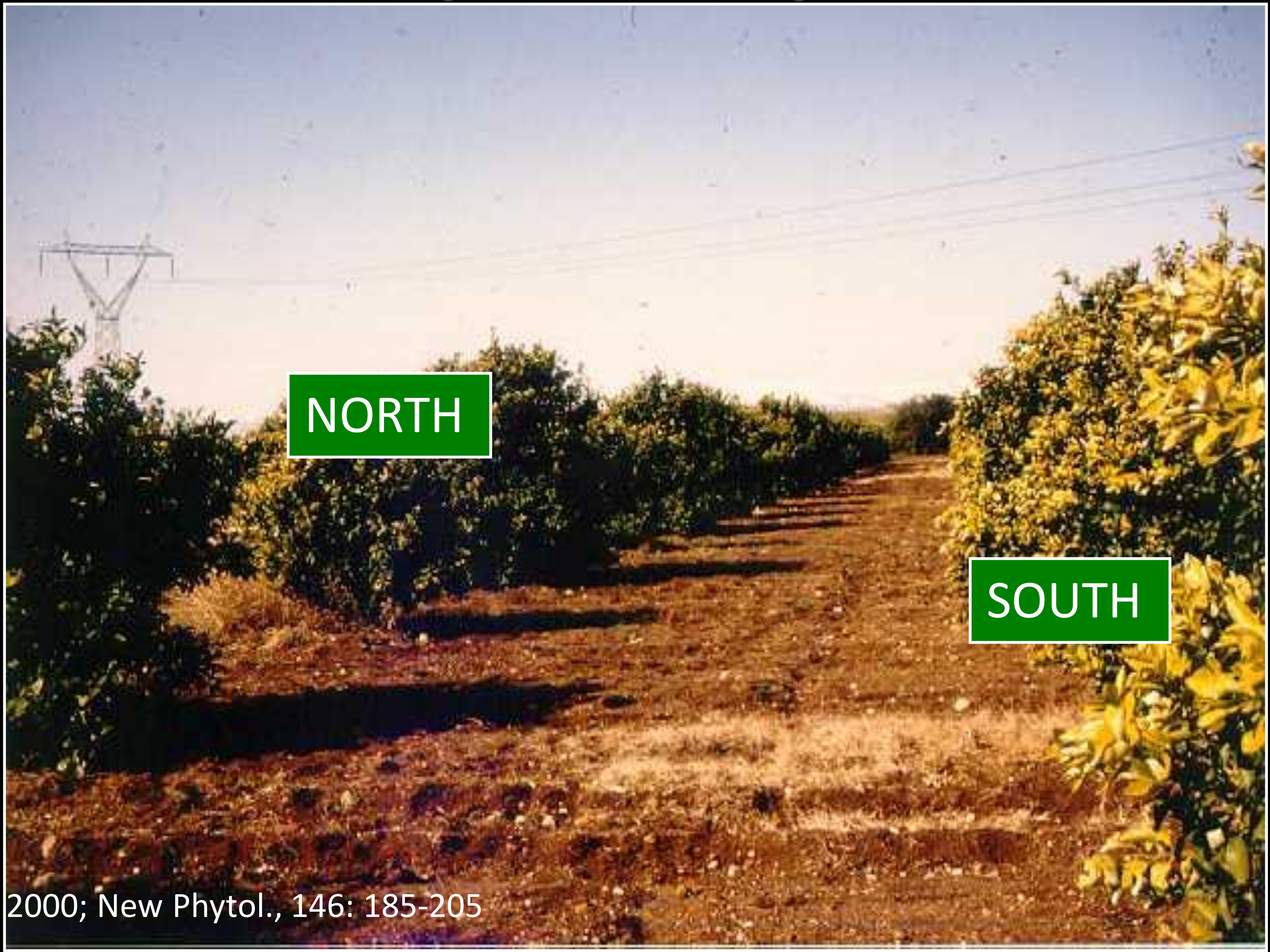
(Cakmak et al.,1996, Plant and Soil)

ZINC-DEFICIENT PLANTS ARE HIGHLY PHOTOSENSITIVE



Cakmak, 1988
PhD Thesis

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



Cakmak, 2000; New Phytol., 146: 185-205

Partial shading of primary leaves of Zn-deficient bean plants

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

Partial shading of primary leaves of Zn-deficient bean plants

High Light-Induced Zn deficiency

Marschner and Cakmak, 1989; J. Plant Physiology

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 plays a critical role in protein synthesis
- zinc is required for protection of IAA from oxidation

Cakmak, 2000, New Phytol.

Superoxide Dismutase

$$\cdot O_2^- + \cdot O_2^- + 2H^+ \longrightarrow H_2O_2 + O_2$$

Mn-SOD: mitochondria

Fe-SOD: chloroplast

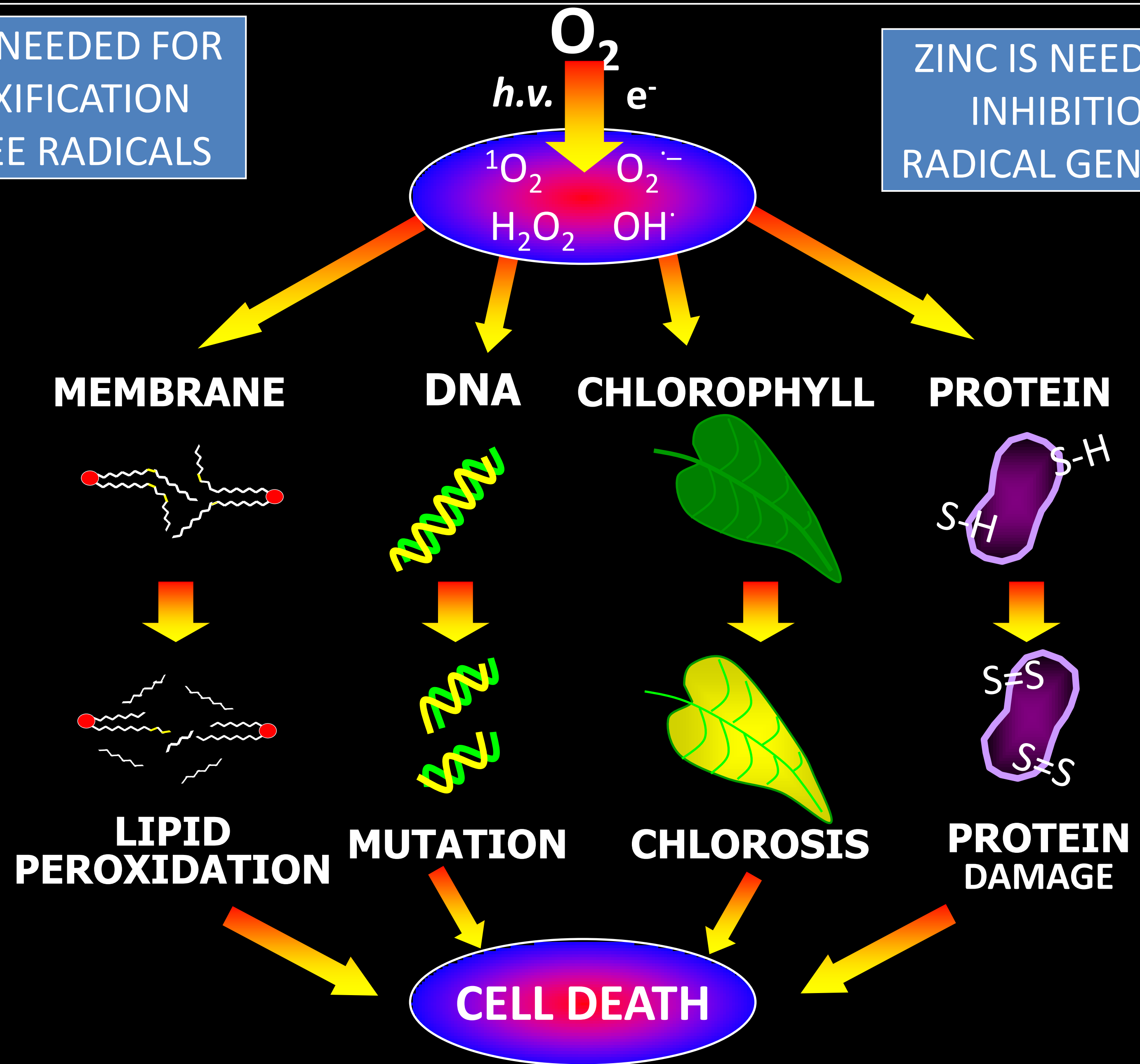
CuZn-SOD: chloroplast

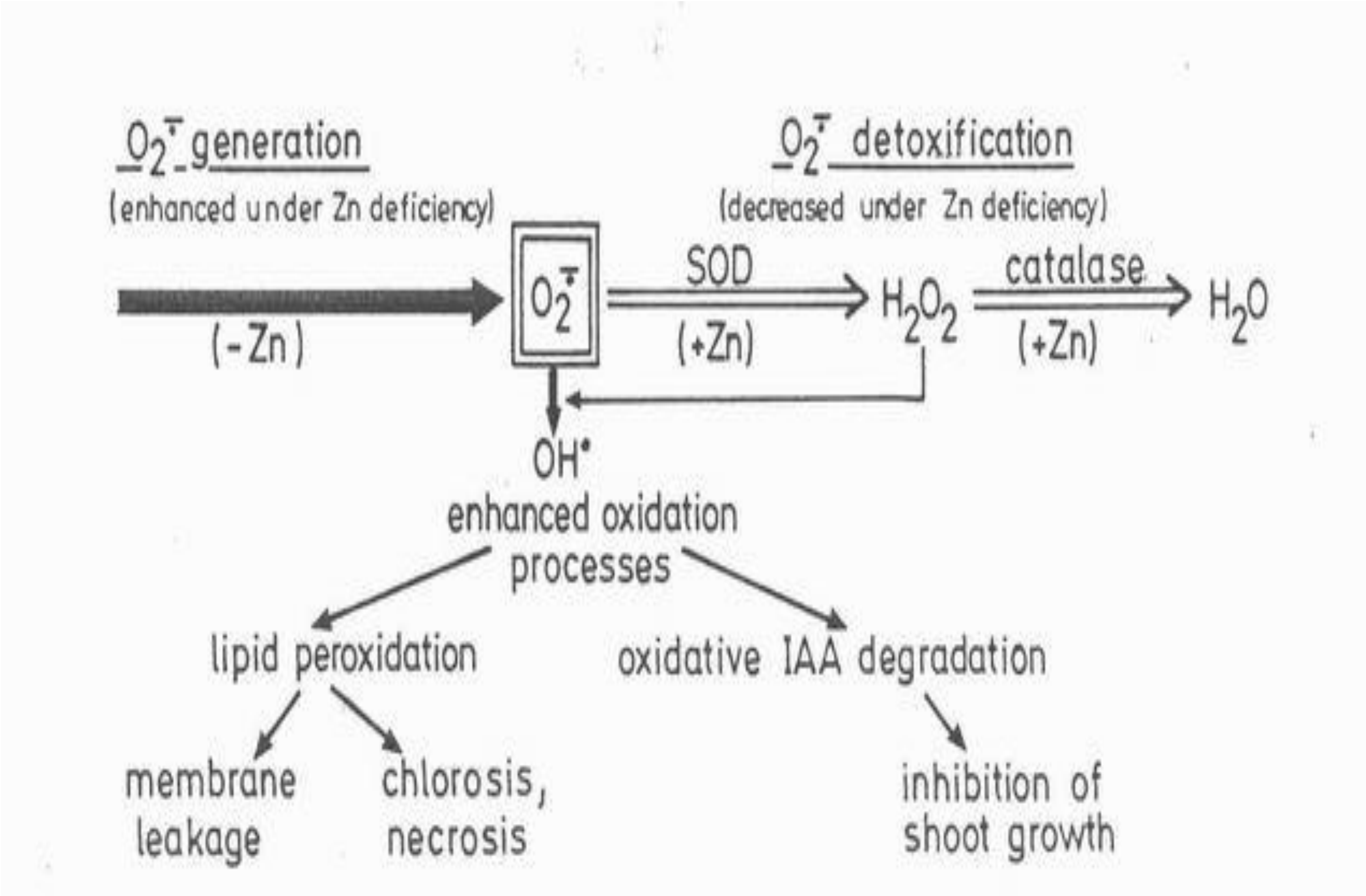
CuZn-SOD: cytosol

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





Marschner, 1995; Cakmak, 2000, New Phytol. 146:185

Root exudation of organic compounds in cotton, wheat and apple at different 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

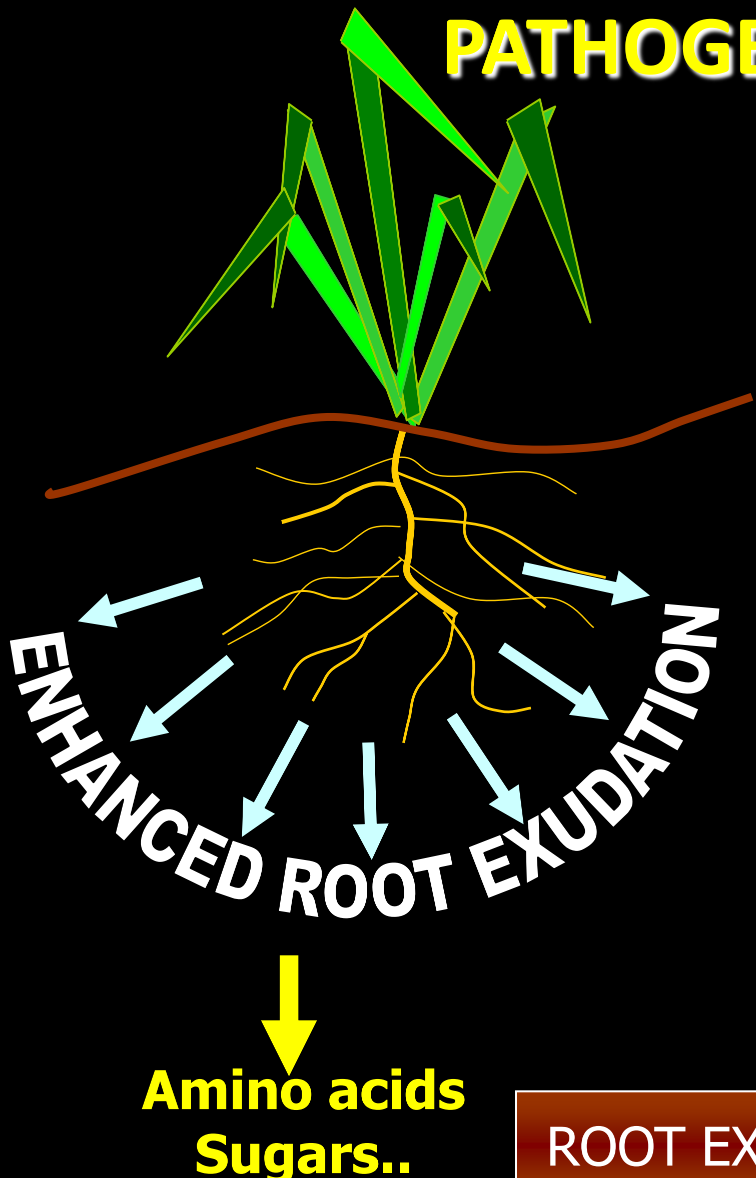
Cakmak and Marschner, 1988, J. Plant Physiol.

Due to structural impairments in cell membranes under Zn deficiency

Zinc Deficient Roots are Leaky:

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

ZINC PROVIDES RESISTANCE AGAINST PATHOGENIC INFECTION



Zinc 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

ZINC PROVIDES RESISTANCE AGAINST PATHOGENIC INFECTION

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

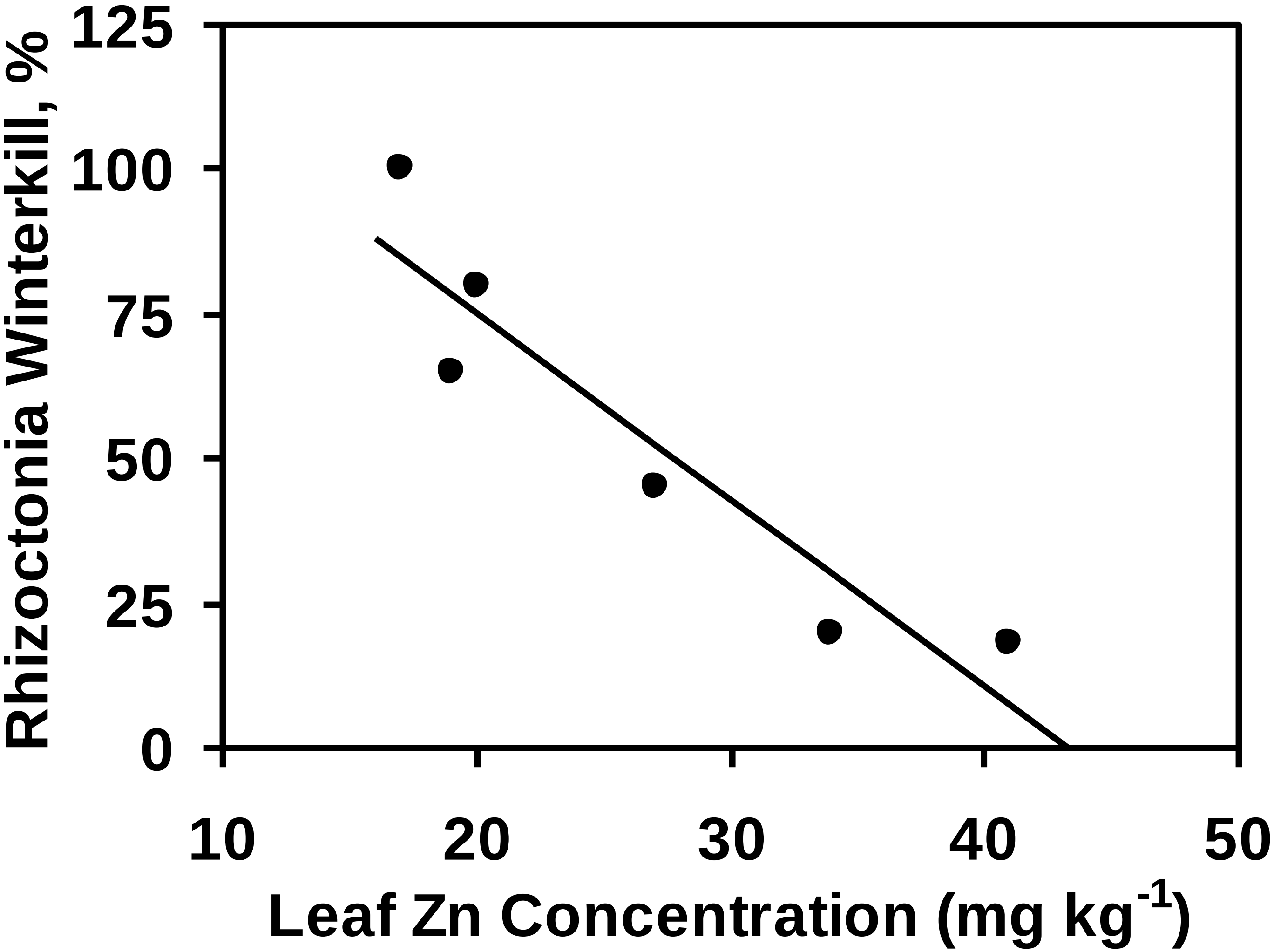
Graham and Webb, 1991

Effect of increasing Zn supply on root infection/penetration of *M. phaseolina*, *F. solani* and *R. Solani* with and without *Ps. aeruginosa* IE-6S+ biological control agent

Zn concentration (mg/kg soil)	Infection (%)		
	M. phaseolina	*F. solani*	*R. solani*
Without IE-6S+			
0	55	88	42
0.2	55	92	33
0.4	42	75	55
0.8	33	66	22
1.6	33	66	17
With IE-6S+			
0	42	77	33
0.2	33	66	17
0.4	44	58	22
0.8	33	44	8
1.6	18	50	8

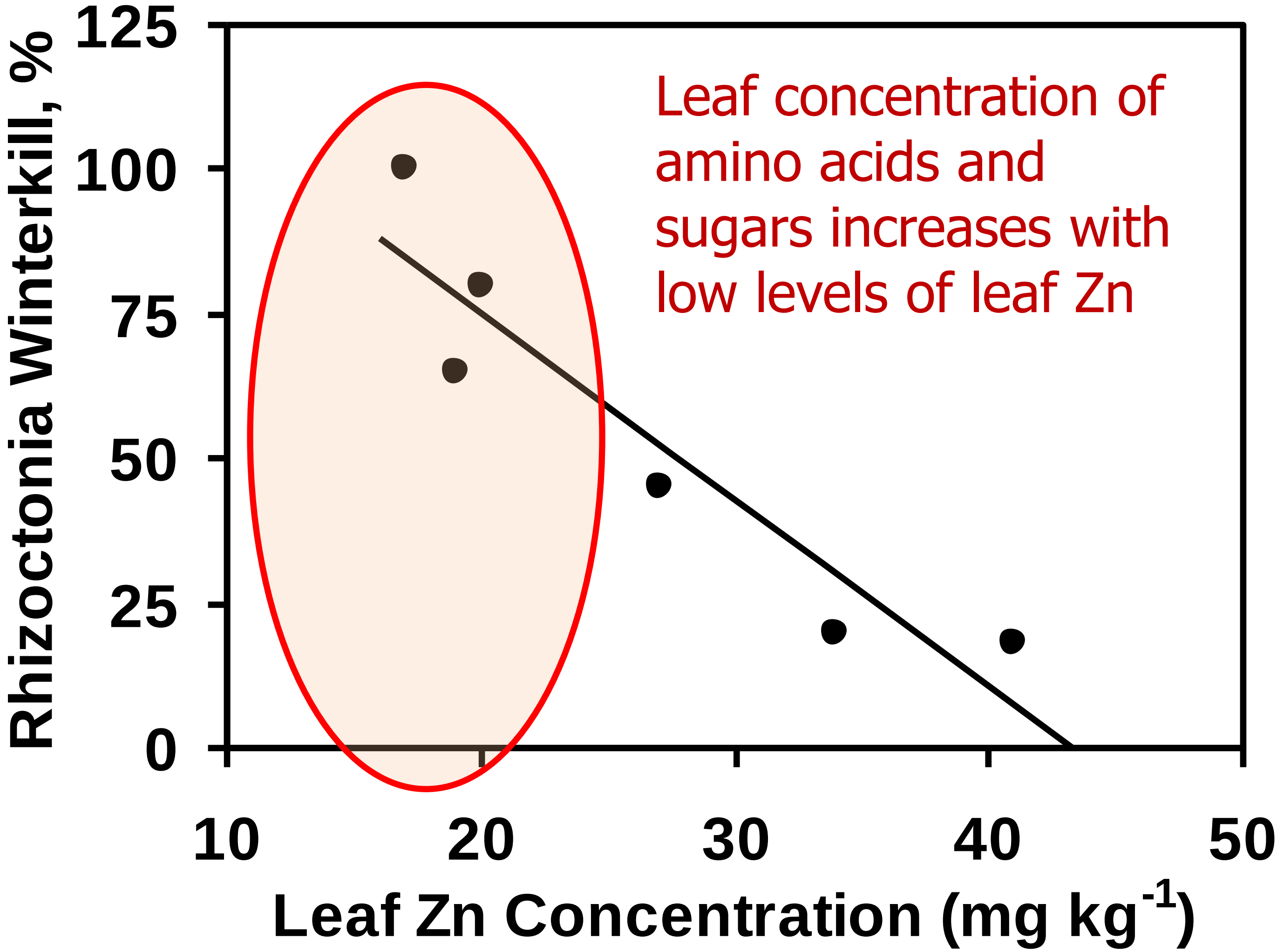
Siddique et al., 2002, J. Phytopathol.

Relationship between leaf Zn concentration and Winterkill caused by Rhizoctonia



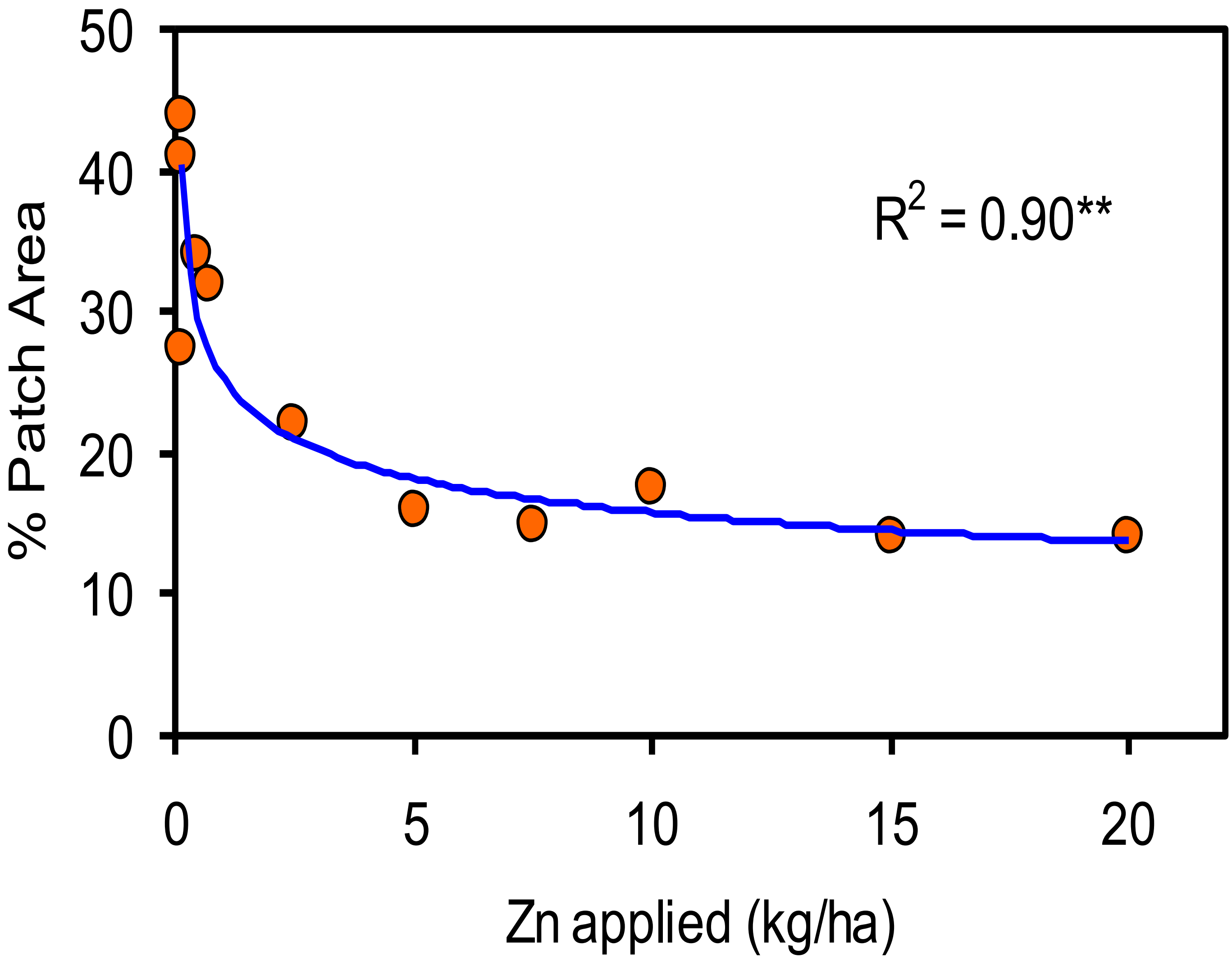
adapted from Huber and Graham, 1999

Relationship between leaf Zn concentration and Winterkill caused by Rhizoctonia



adapted from Huber and Graham, 1999

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



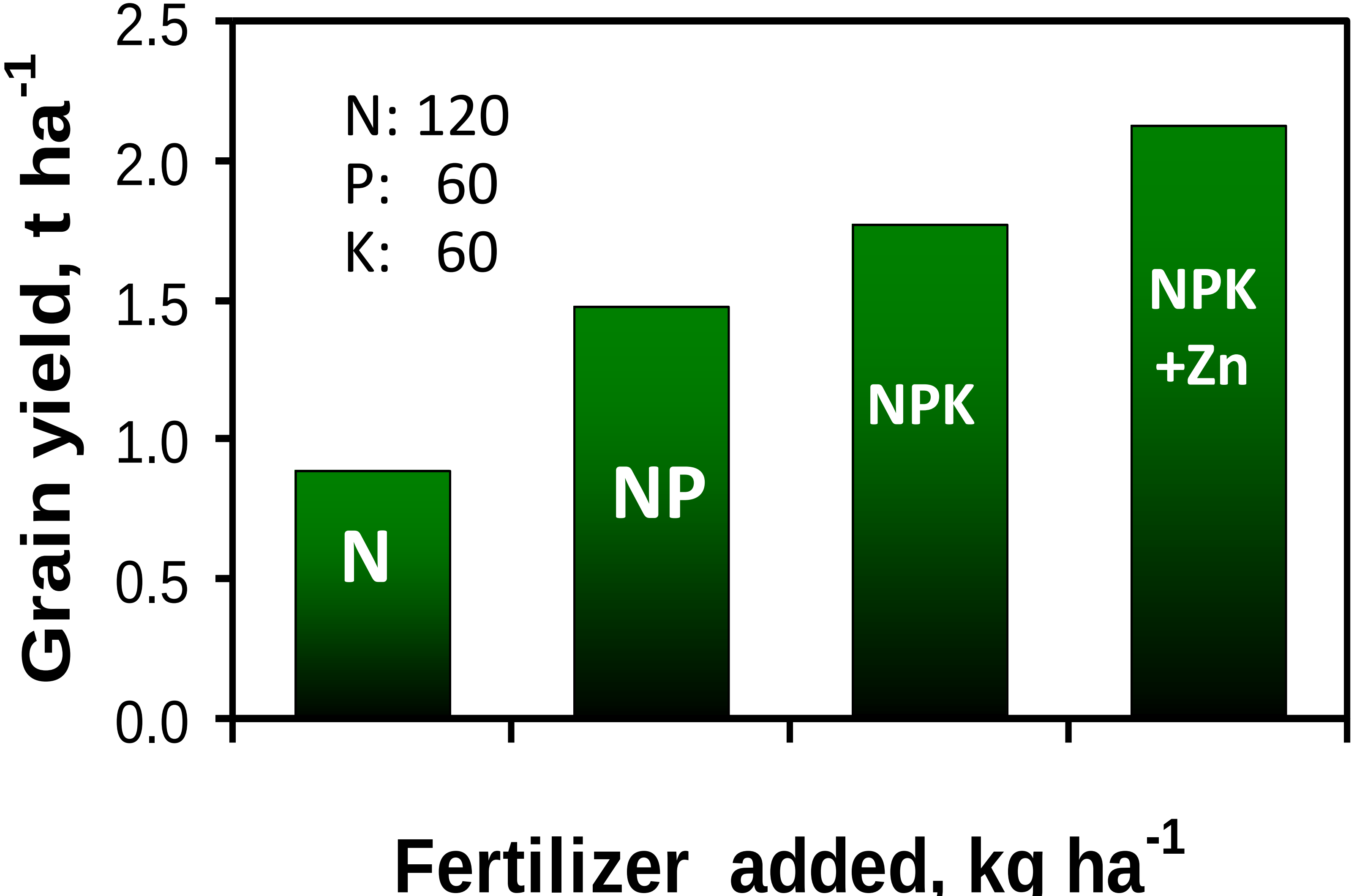
Thongbai et al., 1993, Plant and Soil

Zinc Fertilization

Zinc sulphate is most commonly used zinc fertilizer. Zinc is also increasingly applied together with compound fertilizers

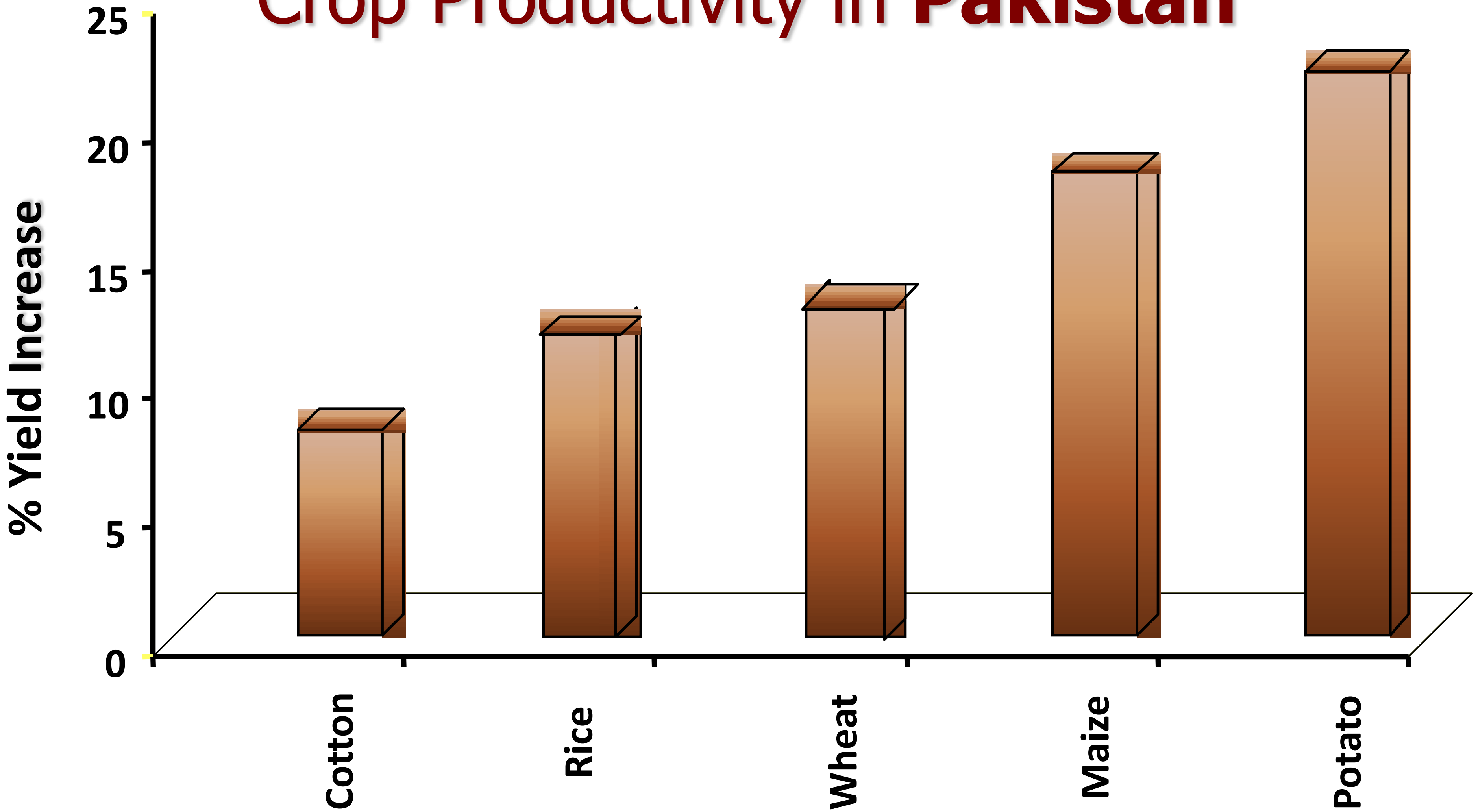
Several reports show that yield of crop plants can be increased up to 50 % by applying 2 to 5 kg Zn per ha.

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



Source: Tandon, 1995. In: Proc. Int. Potash Inst. on Potassium in Asia

Zinc Use Enhances Crop Productivity in **Pakistan**



Source: Rashid and Rafique (2000)


NATO-SFS PROJESİ
+Zn
-Zn
+Zn
-Zn
DTPA-Zn: < 0.10 mg/kg soil

Use of Zn-containing NP and NPK fertilizers in Turkey after NATO-Zinc Project

Source: Ministry of Agriculture, 2006; TOROS Fertilizer, 2008

NATO-Scientific Affairs Division

Science for Stability Programme

NATO-SFS Press Release

Project with 1 Million USD Provided a Benefit of 100 Million USD

SCIENCE FOR STABILITY PROGRAMME

Press Review

SfS Project : TU-GENOTYPES

6 Çarşamba 28 Mayıs 1997 **Milliyet**

ekonomi kulisi

Meral TAMER

1 milyon dolarlık araştırma, 100 milyon dolar kazandırdı

Newspaper MİLLİYET
Wednesday, May 28, 1997

Project of 1 million USD Provided a Benefit of 100 million USD

At the Technology Management Seminar, we learned from Tosun Terzioğlu, president of TÜBITAK, that small sized research projects can provide considerable amounts of profit.

Terzioğlu told of how the quality and yield of wheat grown in Central Anatolia is not as good as it should be. As a result of a project carried out by scientists from Çukurova University with the funds of NATO, it has been found that soils of wheat growing areas are deficient in zinc.

Zinc deficiency in wheat may be solved totally by adding zinc every 2-3 years to the soils in the Central Anatolia region.

The money spent for this project was even less than 1 million dollars. However, solving the zinc deficiency problem in wheat is providing an additional benefit of about 100 million dollars to the farmers every year.

Terzioğlu, showing this project as a major example, has made some statements for the success of scientific projects:

- First of all, there was a fund. There was a source. NATO provided funds.
- Secondly, a very good scientific research team was selected to carry out the project.
- Thirdly, there was project continuity. During this time many Ministers of Agriculture have come and gone, but none of them interferred with our work.

The total amount of project expenditures was below 1 million dollars, but it has provided a net income of about 100 million dollars for farmers every year.

1299-96

NATO SCIENTIFIC AFFAIRS DIVISION

ZnO or $ZnSO_4$??

Effects of $ZnSO_4$ and ZnO (applied at 10-11 kg Zn ha^{-1}) on Grain Yields (t ha^{-1}) of Crops on Zn Deficient Soils in India.

Zn Carrier	Wheat	Soybean	Maize	Wheat	Rice	Barley
Control	3.4	1.1	2.3	4.0	6.4	4.2
$ZnSO_4$	3.9	1.4	3.2	5.6	7.6	4.8
ZnO	4.0	1.3	3.3	4.8	6.8	4.8

From Marschner, 1993. In: Zinc in Soils and Plant, Kluwer Publisher

Effect of **Zn-enriched urea** on Grain yield and grain Zn concentrations of rice and wheat at IARI

Treatments	Rice		Wheat	
	Grain Yield	Grain Zn Concentration	Grain Yield	Grain Zn Concentration
	(ton ha^{-1})	(mg kg^{-1} DW)	(ton ha^{-1})	(mg kg^{-1} DW)
Prilled Urea	3.99	30	3.72	40
Zn-Enriched Ureas				
1% Zn as ZnO	4.46	36	4.14	46
1% Zn az $ZnSO_4$	4.67	39	4.25	49
2% Zn as ZnO	4.95	43	4.39	49
2% Zn as $ZnSO_4$	5.15	48	4.53	51

Shivay et al. (2008b) Nutr Cycl Agroecosyst

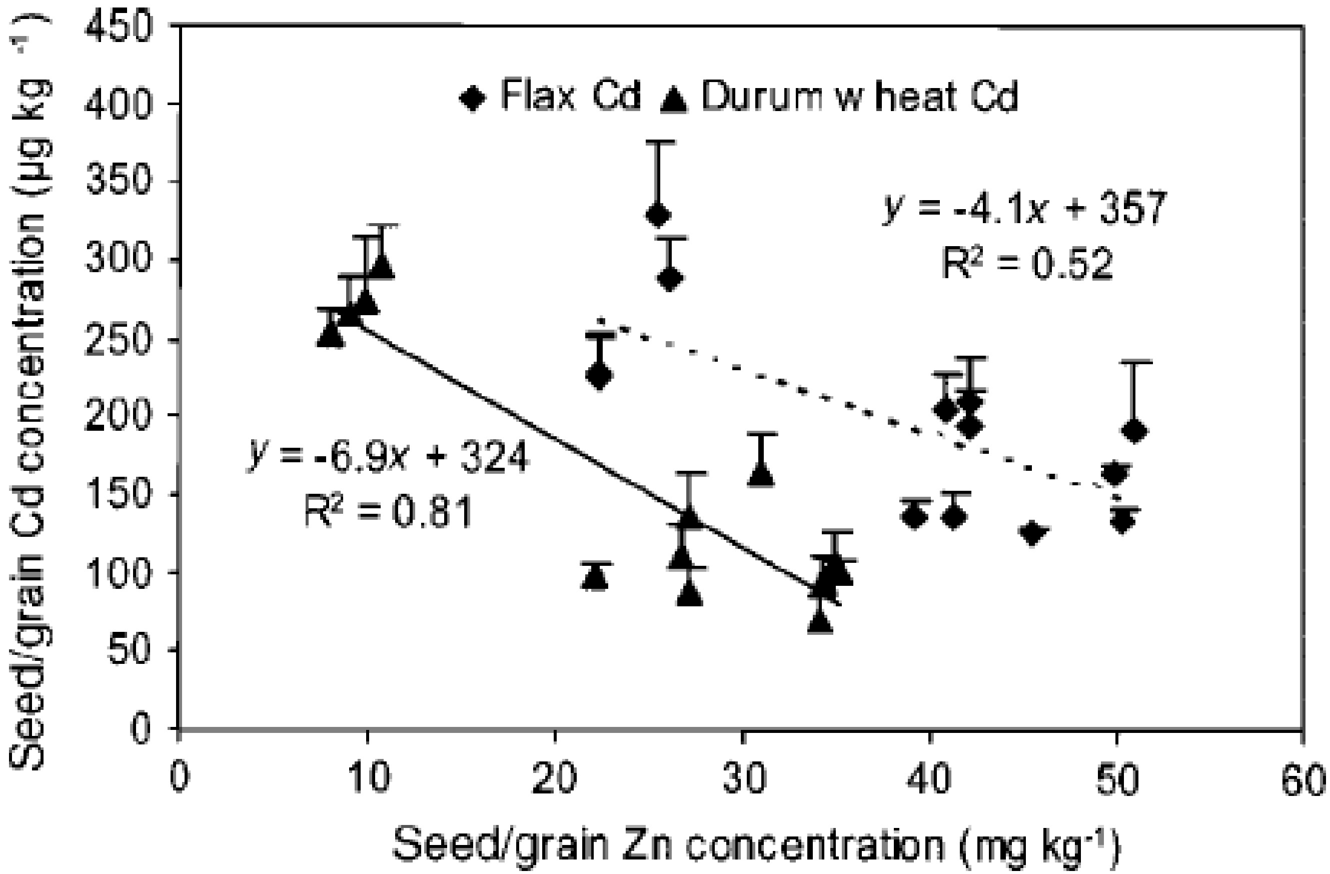
Cadmium Contamination of Food Crops: A Growing Concern

Accumulation of Cd in food crops:

- Cd potentially toxic to human-beings
- Plant-based foods predominant source of Cd in human diet
- Risk associated with long-term consumption of crops contaminated with Cd
- Sewage sludge, P-containing fertilizers and industrial pollution are major sources of Cd pollution

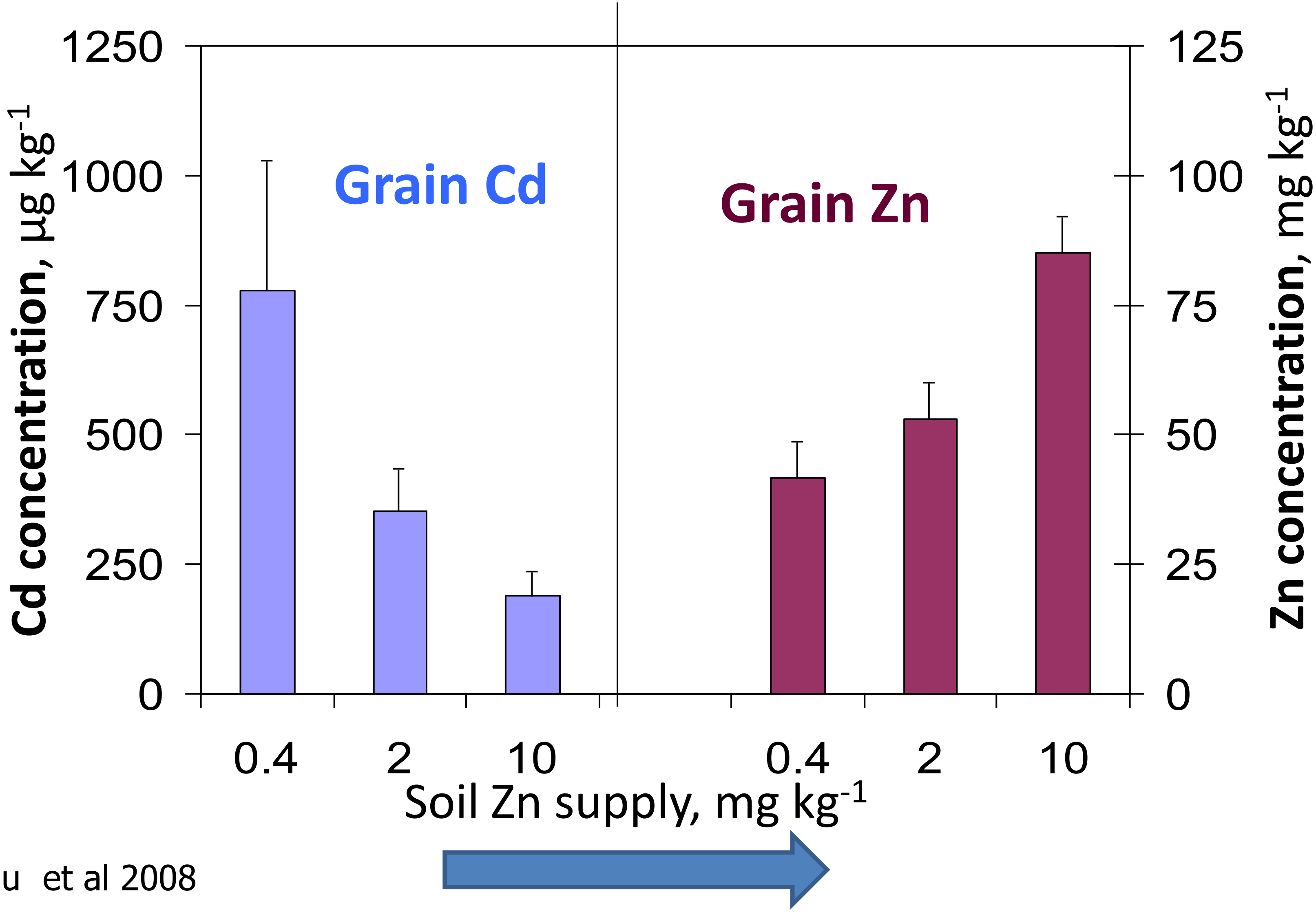
Relationship between Zn and Cd concentrations in the flaxseed and durum wheat grain across fertilizer treatments

Antagonistic effect of Zn on Cd for root uptake and distribution in the plant.



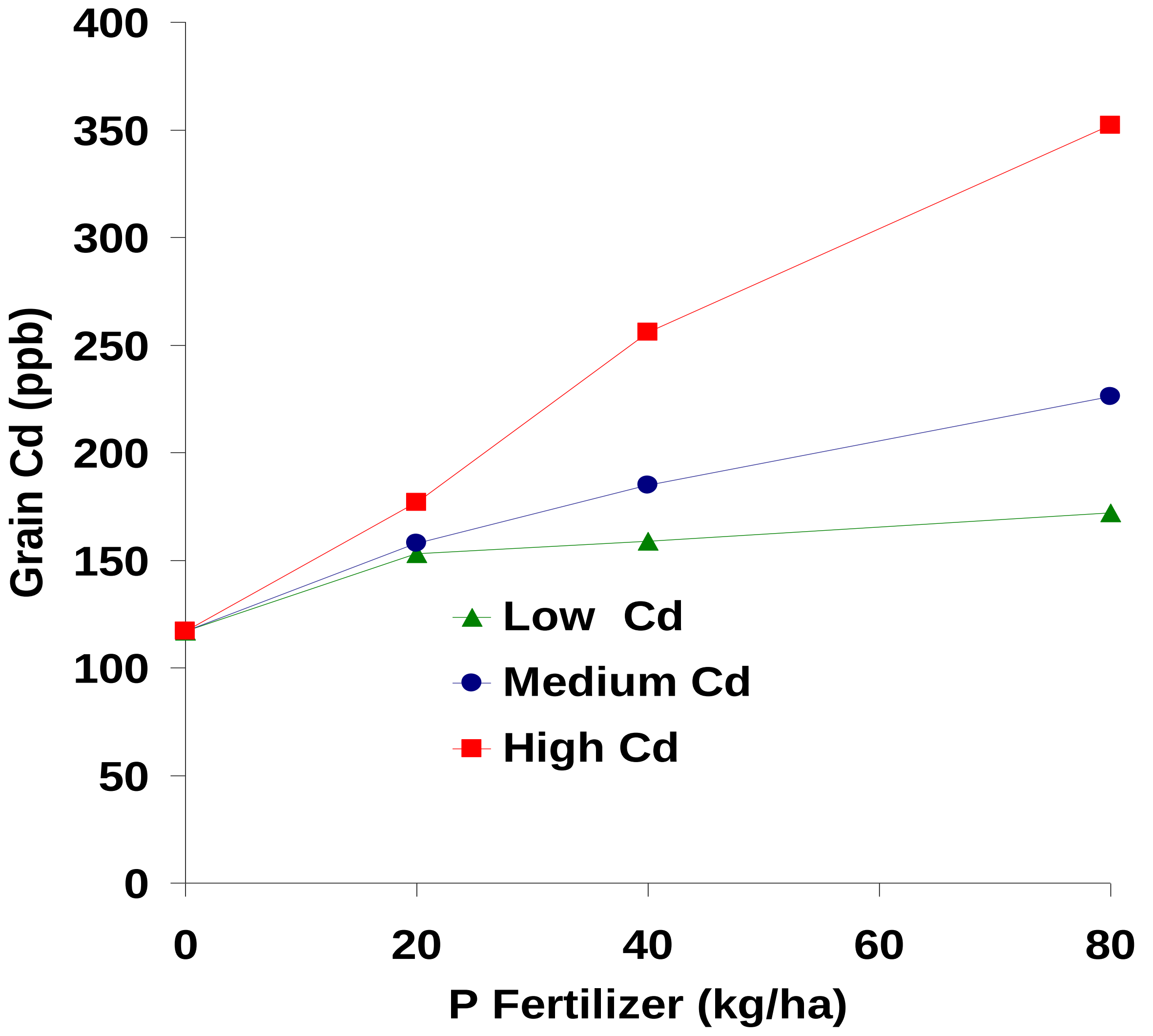
Jiao et al., 2004: J Sci Food Agric 84:777–785

Effect of Increasing Zn Supply on Grain Concentration of Cd in Plants Treated with Cd



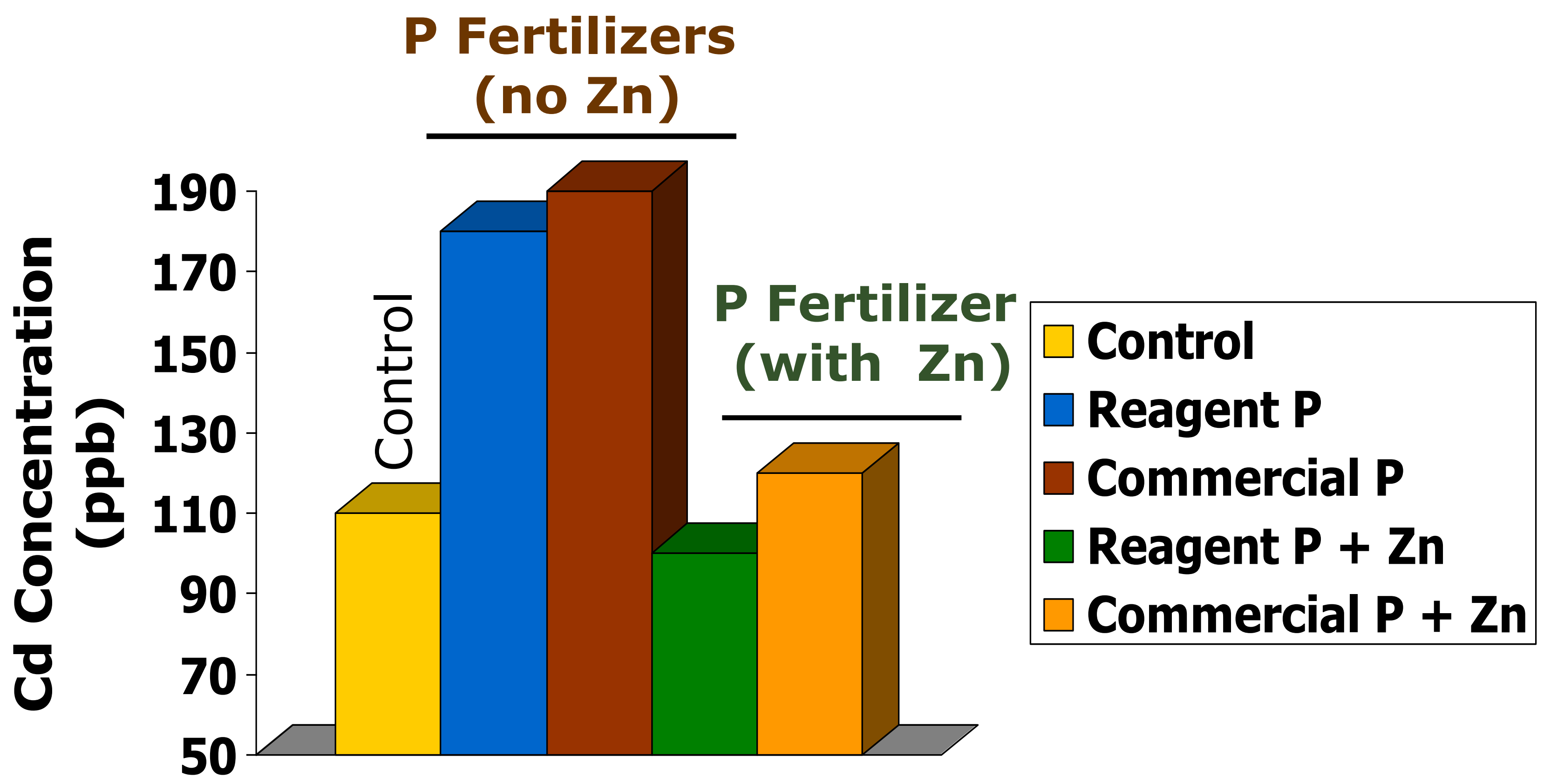
Ozkutlu et al 2008

P-Induced Cd Accumulation



Courtesy from C. Grant, 2008

Effect of Zn-containing P-Fertilizers on Cd concentration in durum wheat grain



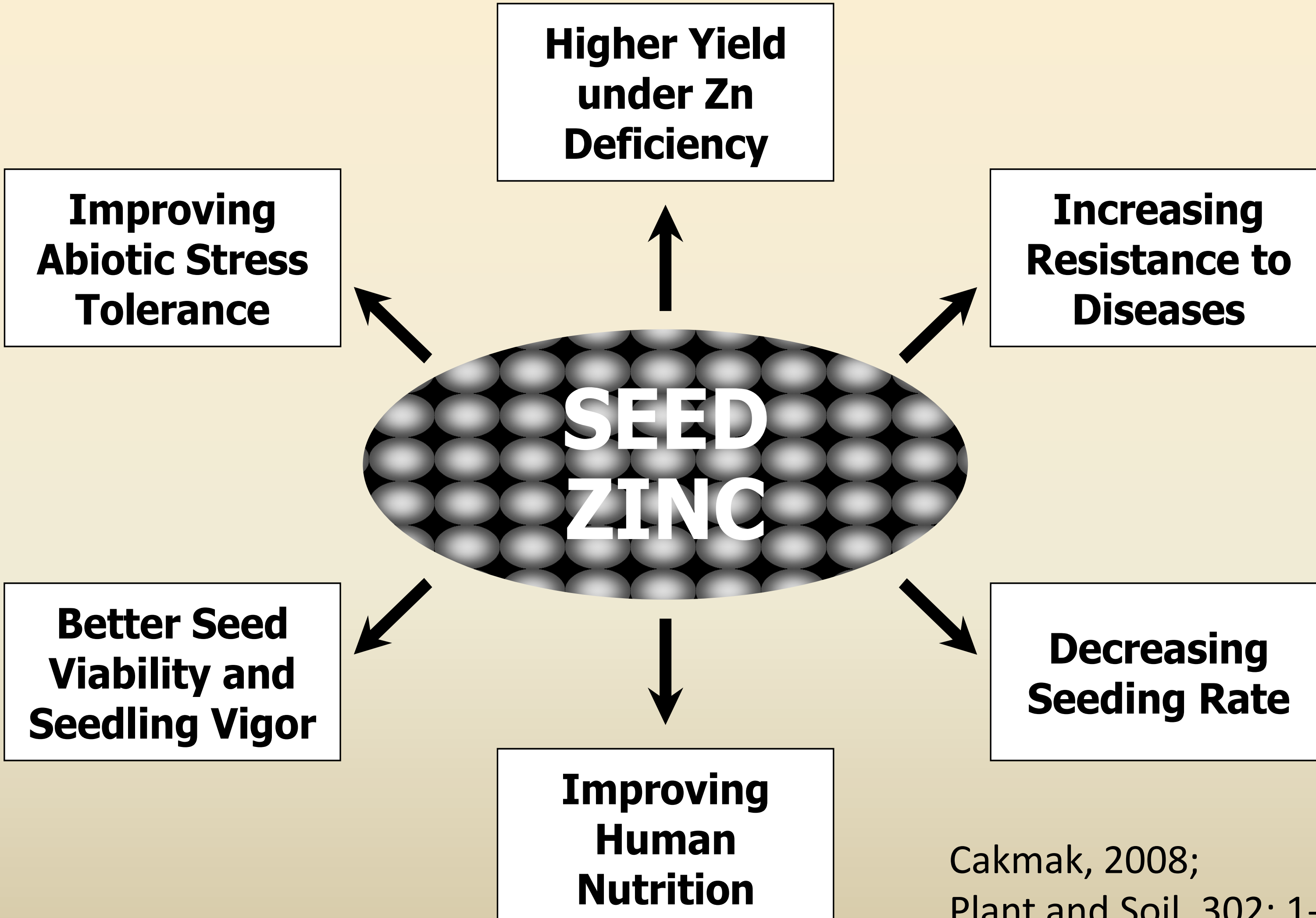
Courtesy from C. Grant, 2008

Seedlings are happy when the seeds are **“galvanized”**

Seed Zinc

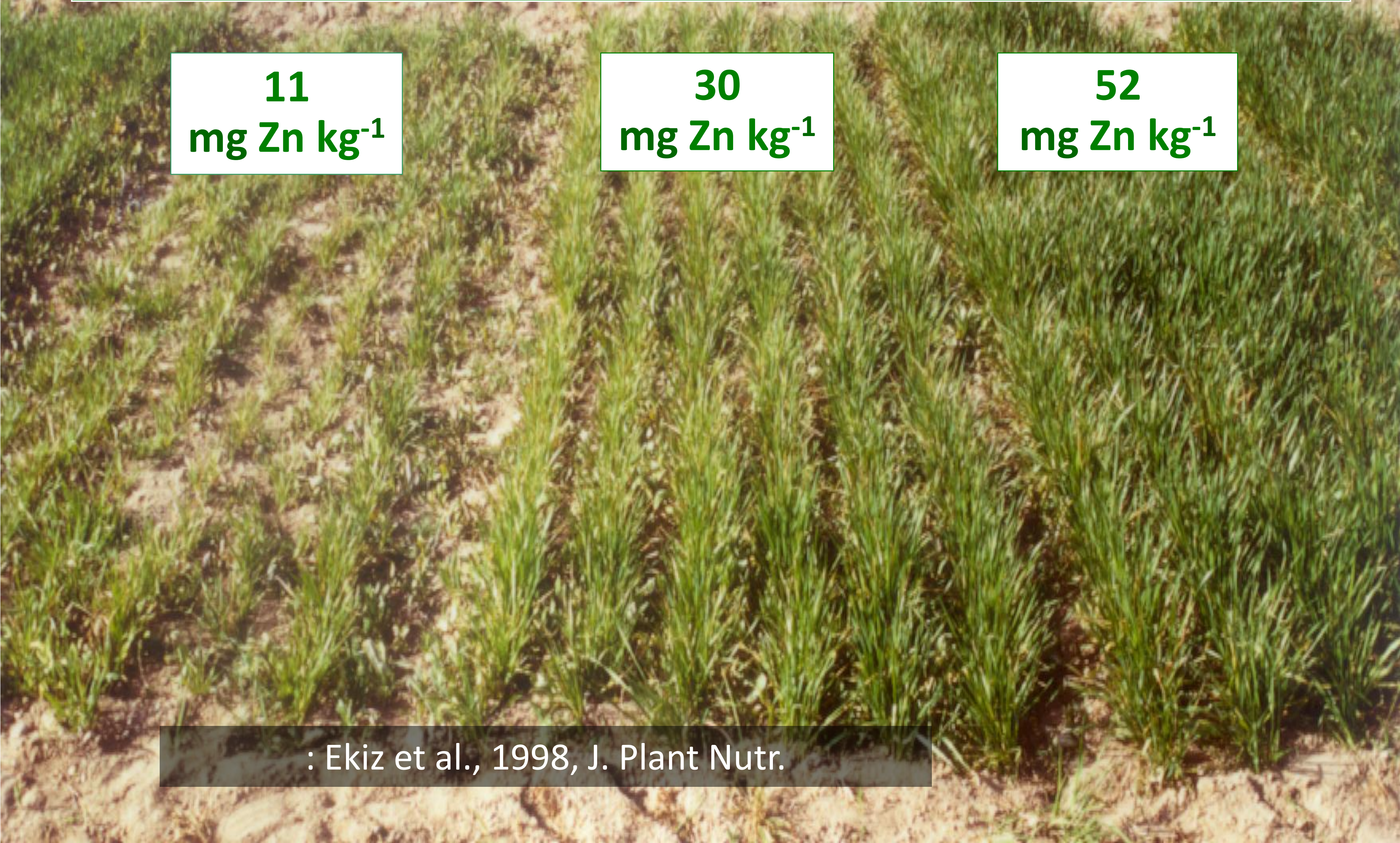
Dress seeds with zinc before sowing

Agronomic and human nutritional benefits resulting from use of Zn-enriched seeds



Cakmak, 2008;
Plant and Soil, 302: 1-17

Effect od Seed Zn on Growth of Wheat in Central Anatolia



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

Maize, Paraguay, 1996

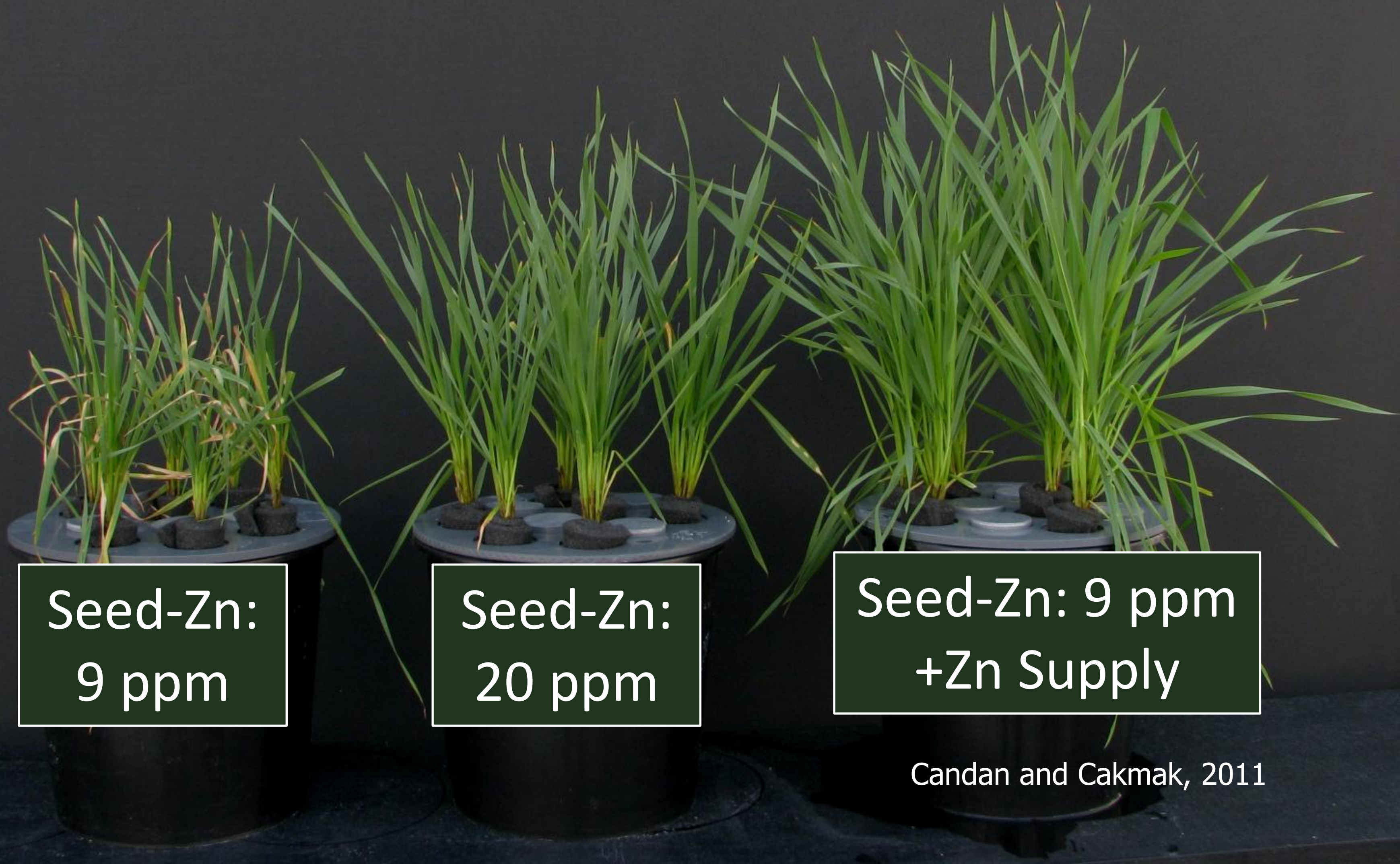
Modified slide from Dr. Kevin Moran:
“*Farming for Health*”, Oslo, Oct.-2005

Impact of Micronutrient Dense Rice Seed in Bangladesh (data from J. Duxbury, 2002, Cornell Univ.)

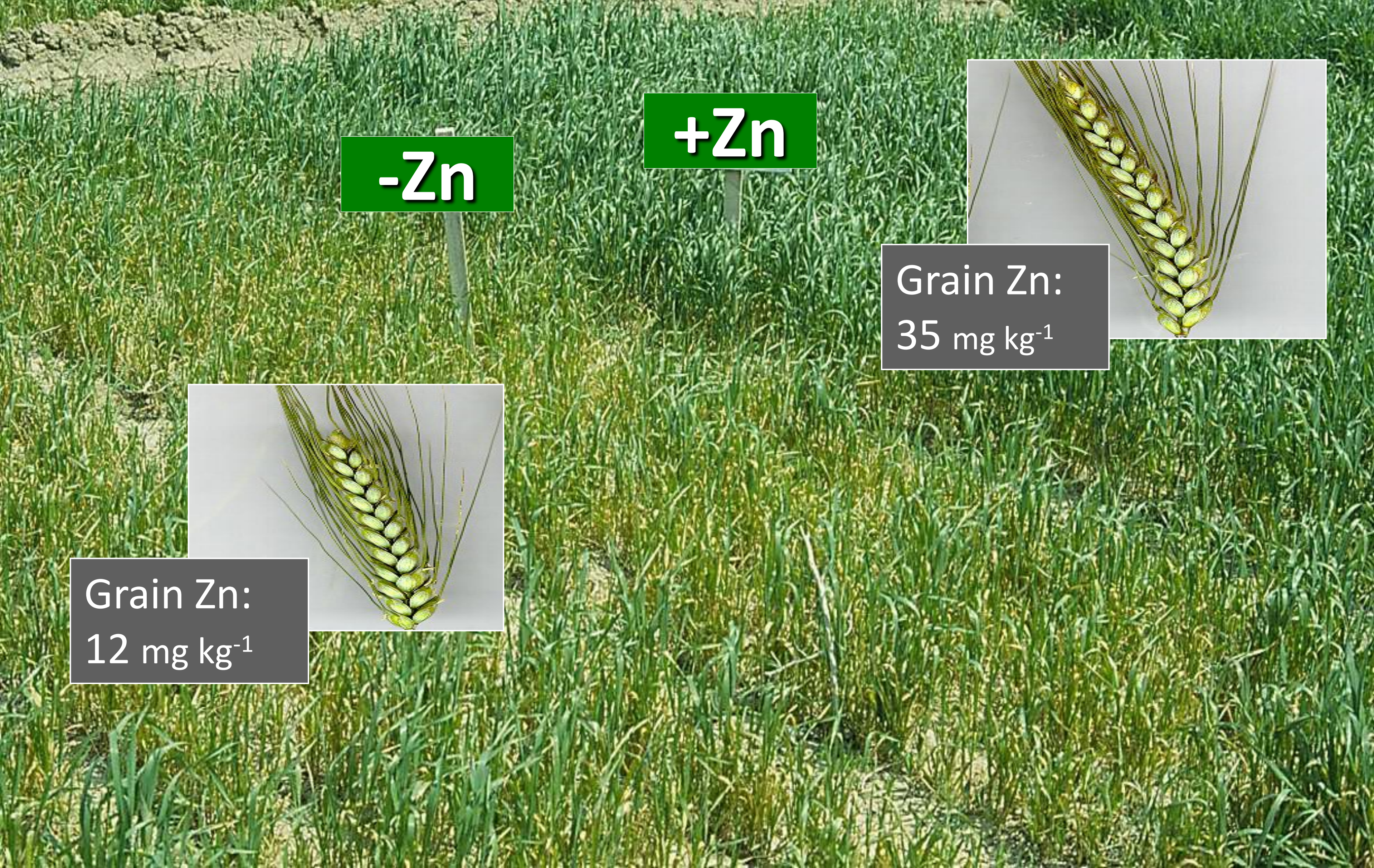
Seed Treatment	Yield (t/ha)
Complete (Zn, Mn, Cu, Mo,	4.6 a
Zn only	4.0 b
Complete - Mo	4.1 b
Control	3.6 c

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

Role of Seed Zn on Growth of Plants in a Growth Medium with low Zn supply



When Zn is deficient in soil or plant



Role of High Seed Zn in Human Nutrition

Micronutrient Deficiencies: Global Malnutrition Problem

Iron Estimated 2 billion

Zinc Estimated 2 billion

www.harvestplus.org

Zinc affects a range of functions:

- Immunity
- Growth
- Brain development
- Reproduction
- ….

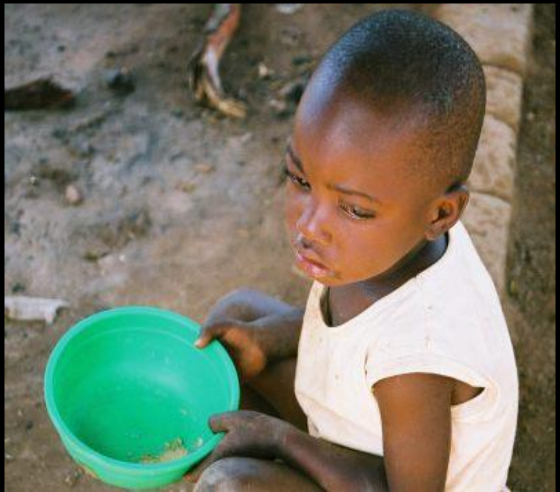
www.harvestplus.org

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%



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

"ZINC SAVES KIDS" Campaign

unicef

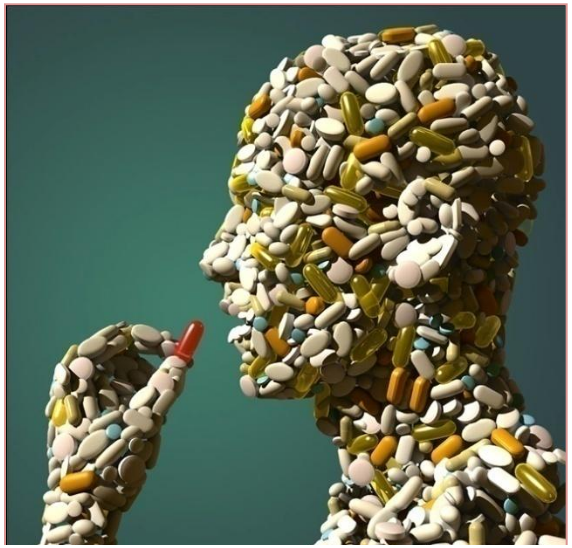
International Zinc Association

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.

Solutions to Micronutrient Deficiencies



- Supplementation
- Food Fortification

(not affordable in rural regions)

Golden Wheat Fortfied with Zn

Copenhagen Consensus-2008

Eight leading economists (including five Nobel Prize Winners) have been asked to decide:

How Would You Best Spend

$75 billion?

Copenhagen Consensus-2008

Top Global 5 Challenges

	Solution	Challenge
1	**Micronutrient supplements for children (vitamin A and zinc)**	**Malnutrition**
2	The Doha development agenda	Trade
3	**Micronutrient fortification (iron and salt iodization)**	**Malnutrition**
4	Expanded immunization coverage for children	Diseases
5	**Biofortification**	**Malnutrition**

Copenhagen Consensus 2008

	Solution	Challenge
1	**Micronutrient supplements for children (vitamin A and zinc)**	**Malnutrition**
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3	**Micronutrient fortification (iron and salt iodization)**	**Malnutrition**
4	Expanded immunization coverage for children	Diseases
5	**Biofortification**	**Malnutrition**
6	Deworming and other nutrition programs at school	Malnutrition & Education
7	Lowering the price of schooling	Education
8	Increase andimprove girls' schooling	Women
9	**Community-based nutrition promotion**	**Malnutrition**
10	Provide support for women's reproductive role	Women
11	Heart attack acute management	Diseases
12	Malaria prevention and treatment	Diseases
13	Tuberculosis case finding and treatment	Diseases
14	R&D in low-carbon energy technologies	Global Warming
15	Bio-sand filters for household water treatment	Water

From The Times

May 31, 2008

'Forget climate change, we should spend on nutrition'

(Edgard Garrido/Reuters)

Malnutrition in mothers and their young children will claim 3.5 million lives this year

TIMES RECOMMENDS

- Prince Philip attacks big families
- Take a dip in Dubai-on-Thames
- Eco Worrier: How can I persuade my husband to use a push mower?

BLOG: GREEN CENTRAL

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

Studying grain, Karsana, Nigeria

www.gatesfoundation.org

"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."

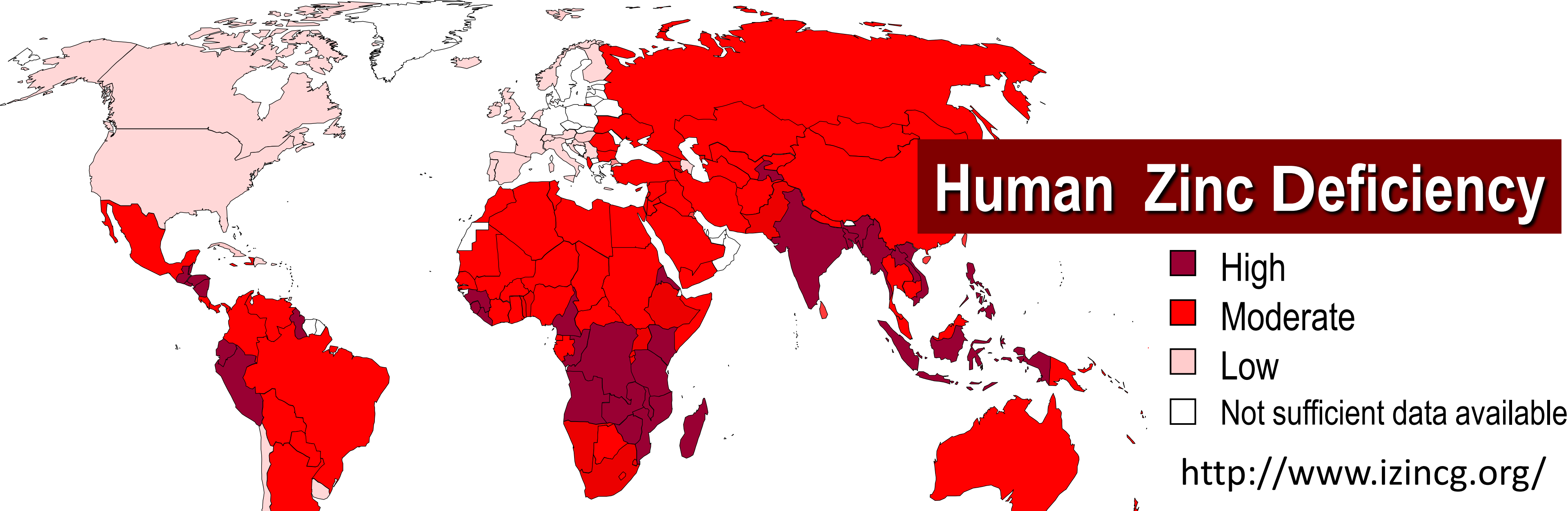
Rapid and Sustainable Solution

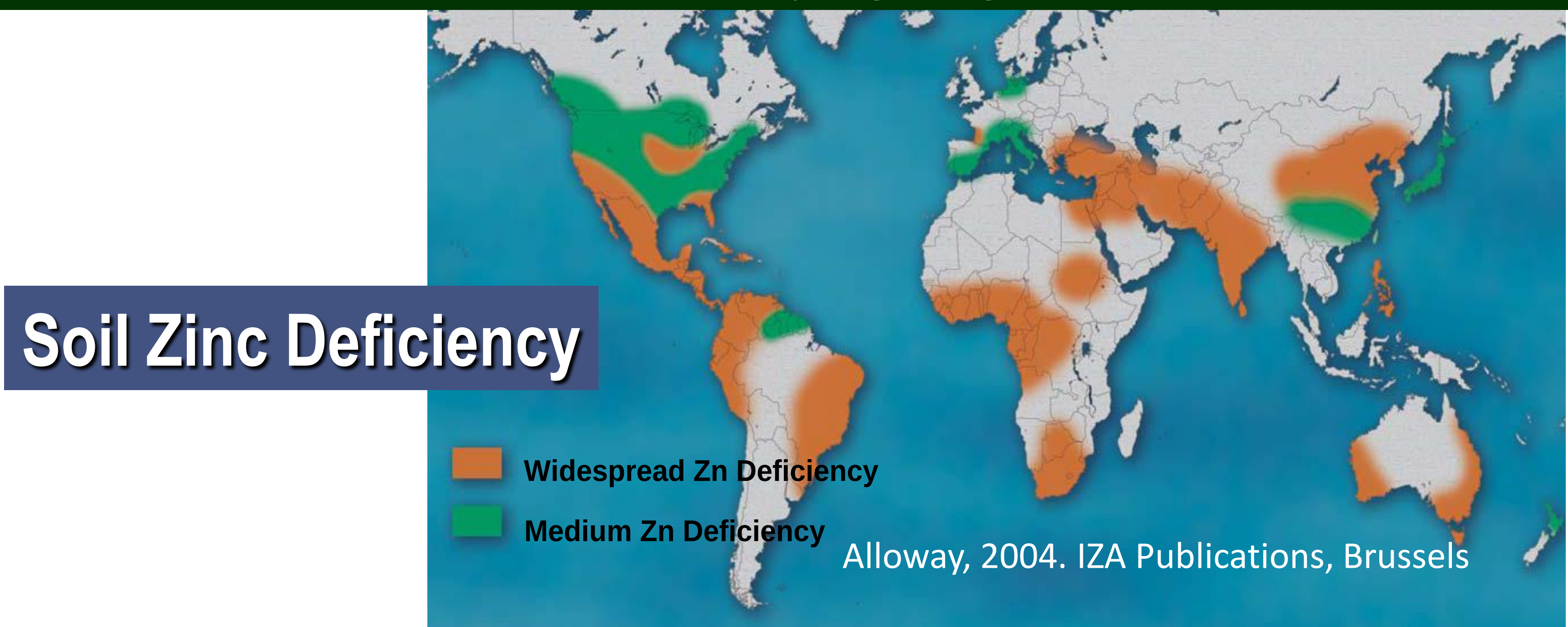
Application of Zinc Fertilizers:
(Agronomic Biofortification)

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}

Soil and Human Zn Deficiency: geographical overlap





Application of Micronutrient Fertilizers

Application of Zn- or Fe-containing fertilizers offers a rapid solution to the problem, and represents an important complementary approach to on-going breeding programs for developing new genotypes with high Zn or Fe density in grain.

CLINTON GLOBAL INITIATIVE

***Clinton Global Initiative* highlighted the importance of Zn-containing fertilizers to alleviate Zn deficiency problem in human populations at 5th Annual Event in September 24, 2009**

HarvestPlus
Breeding Crops for Better Nutrition

Global Zinc Fertilizer Project

2008 April-2011 March

Harvest Zinc
Exploring Fertilizer Use to Increase Zinc in Cereals

Mosaic

KALI

OMEX

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IPNI

Sabancı Üniversitesi

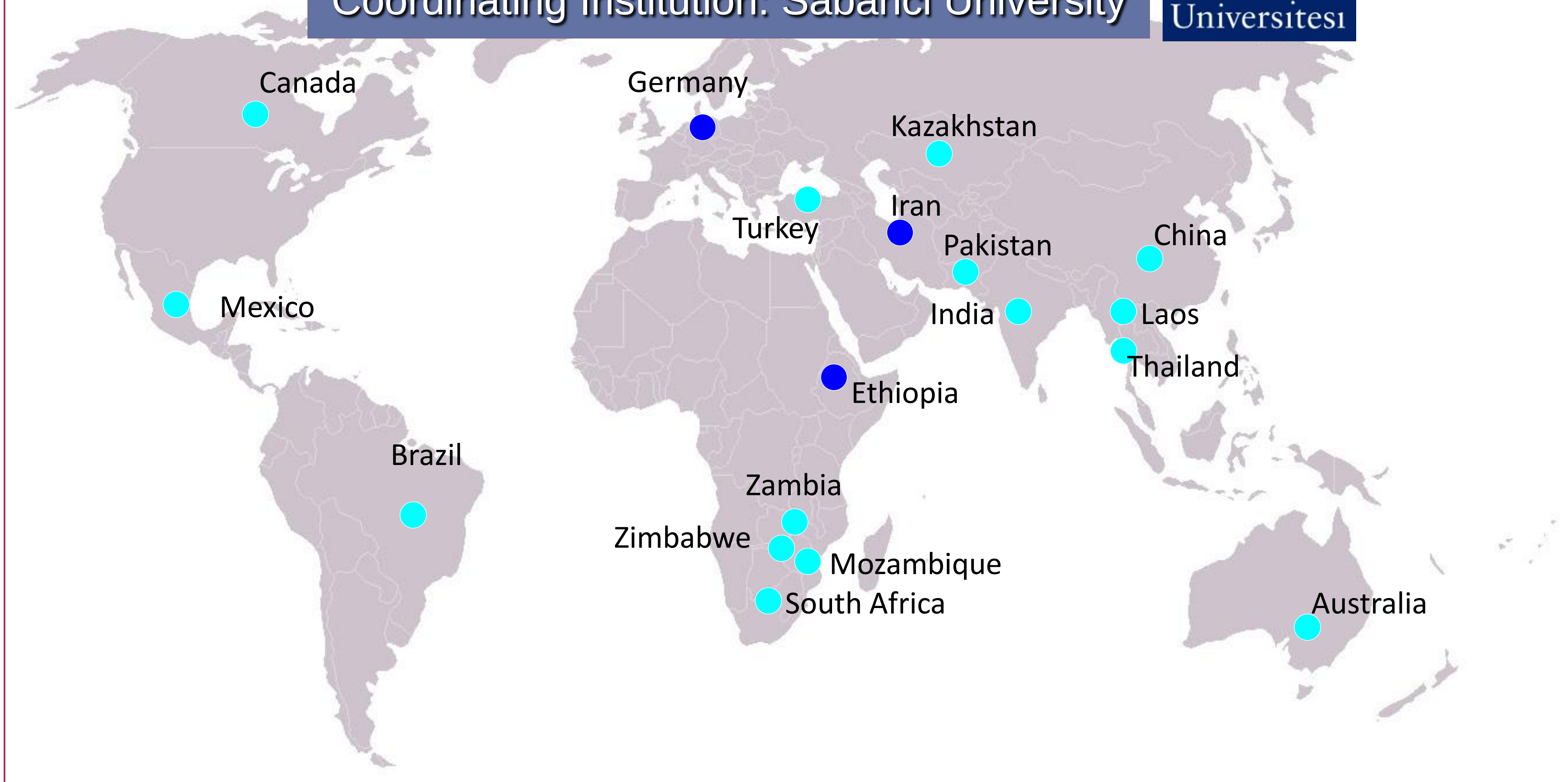
Global Zinc Fertilizer Project

HarvestPlus
Breeding Crops for Better Nutrition

International Zinc Assoc.

Coordinating Institution: Sabanci University

Sabancı Üniversitesi



HarvestPlus
Breeding Crops for Better Nutrition

Global Zinc Fertilizer Project

Harvest Zinc
Exploring Fertilizer Use to Increase Zinc in Cereals

2011 April - 2014 March

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ATP NUTRITION
Powering Growth with Science ™

BAYER
Bayer CropScience

ADOB

Valagro

2011-2014 ?

Sabancı
Universitesi

Effect of Soil and/or Foliar Applied $ZnSO_4$ on Grain yield and Grain Zn Concentrations in Wheat

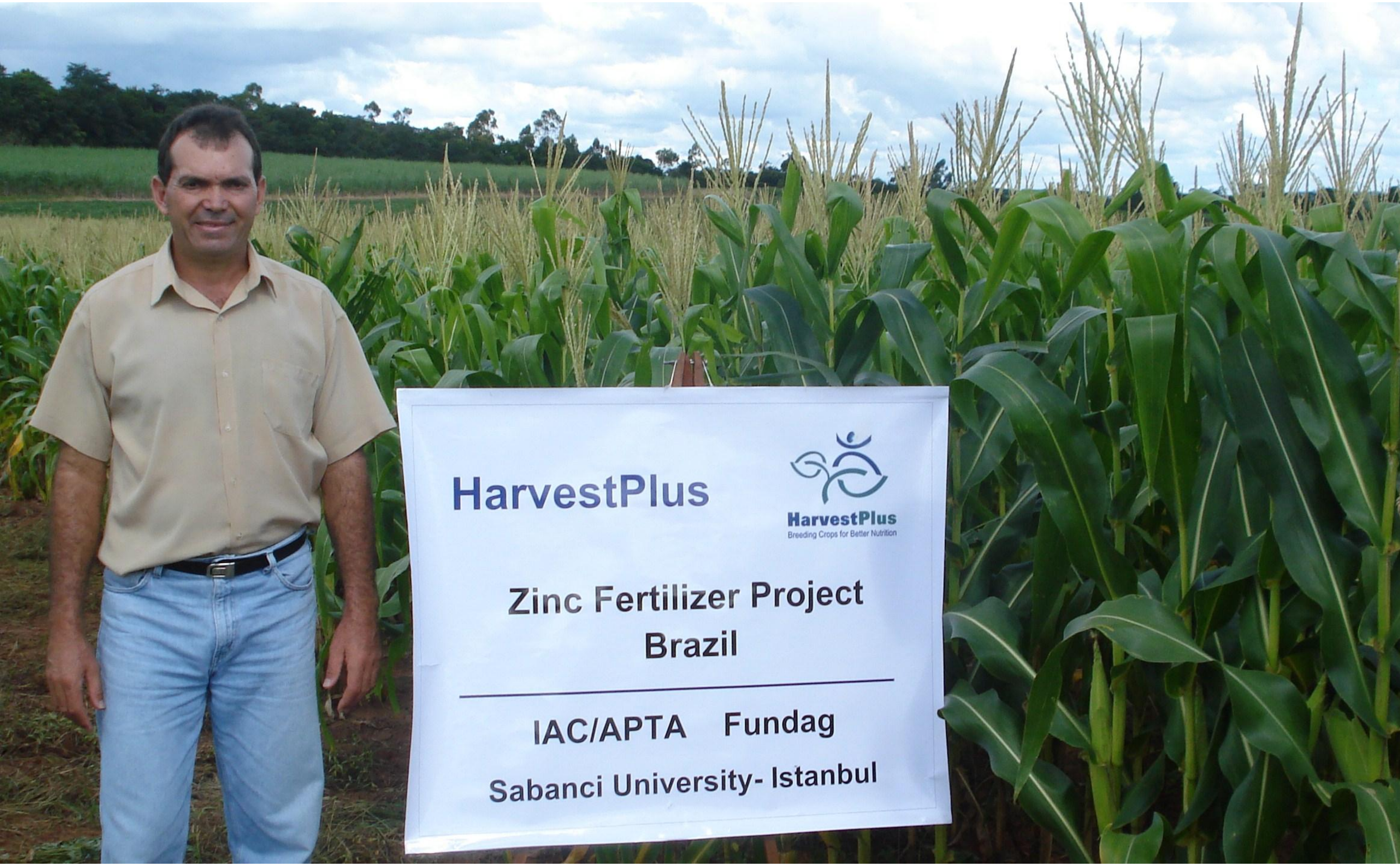
Soil Zn Application : 25 to 50 kg $ZnSO_4.7H_2O$ ha^{-1}

Foliar Zn Application: Generally 2 times: before and after flowering (1 to 4 kg $ZnSO_4$ ha^{-1})

Rice Trials in Thailand

Maize Trials in Zambia

Wheat Trials in India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Zinc Fertilizer Project
Brazil
IAC/APTA Fundag
Sabanci University- Istanbul


HarvestPlus
Sabancı Üniversitesi
Zinc Fertilizer Project
Ludhiana (INDIA)

Maize Trials in Zimbabwe

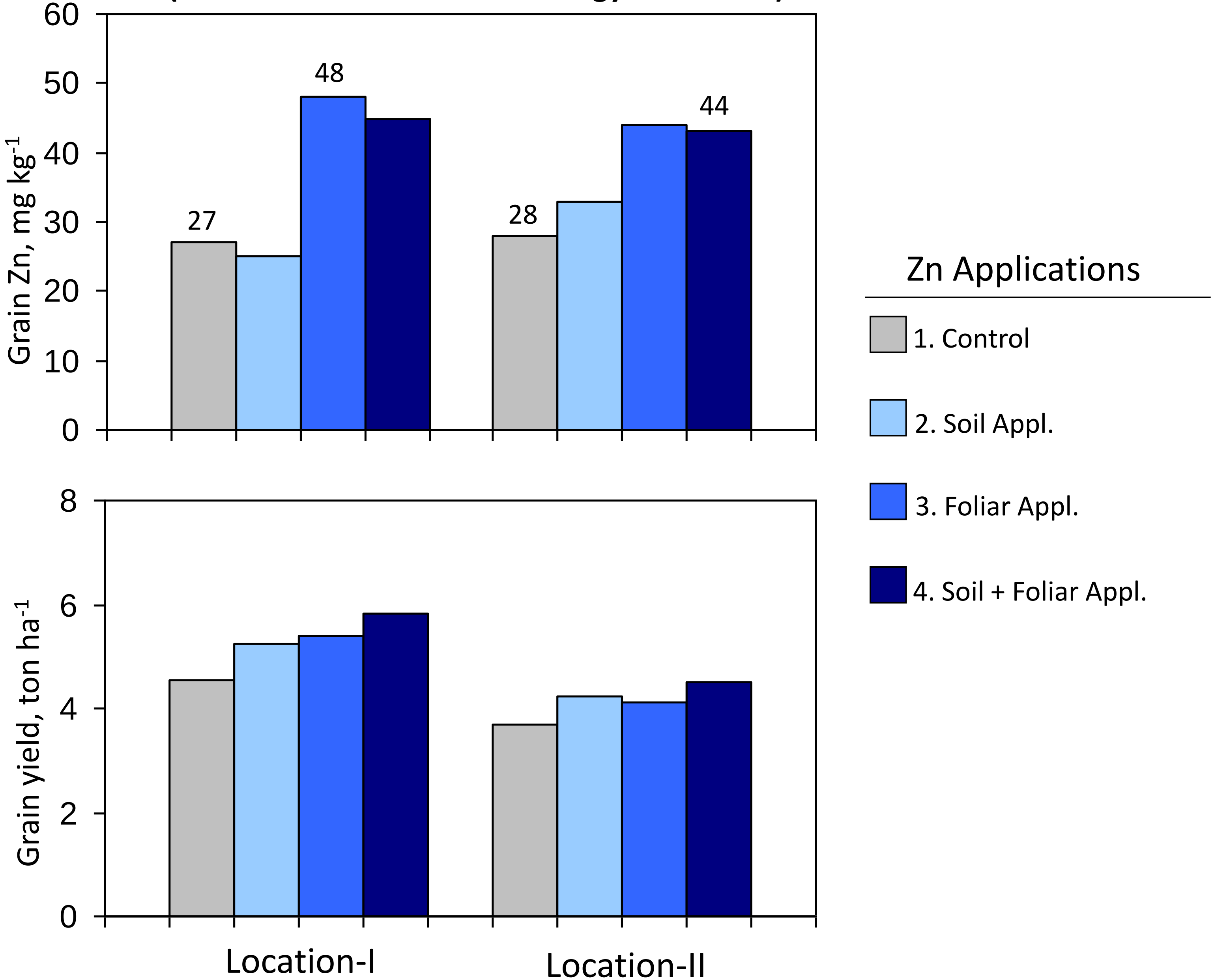
Trials in Pakistan

Maize Trials in Mozambique

Wheat trials in China, Yanglin-Xian

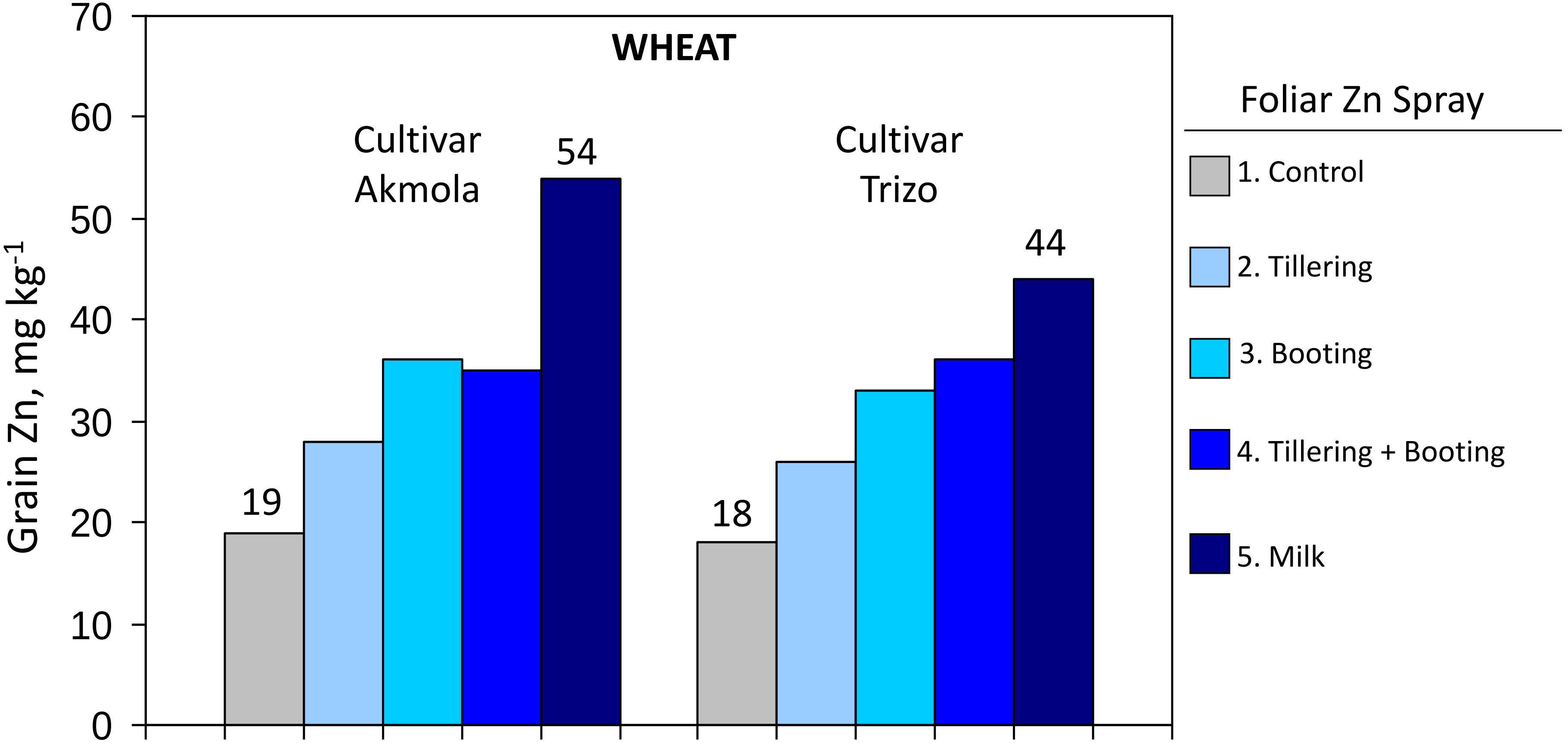
PAKISTAN

(Partner: Pakistan Atomic Energy Comission)



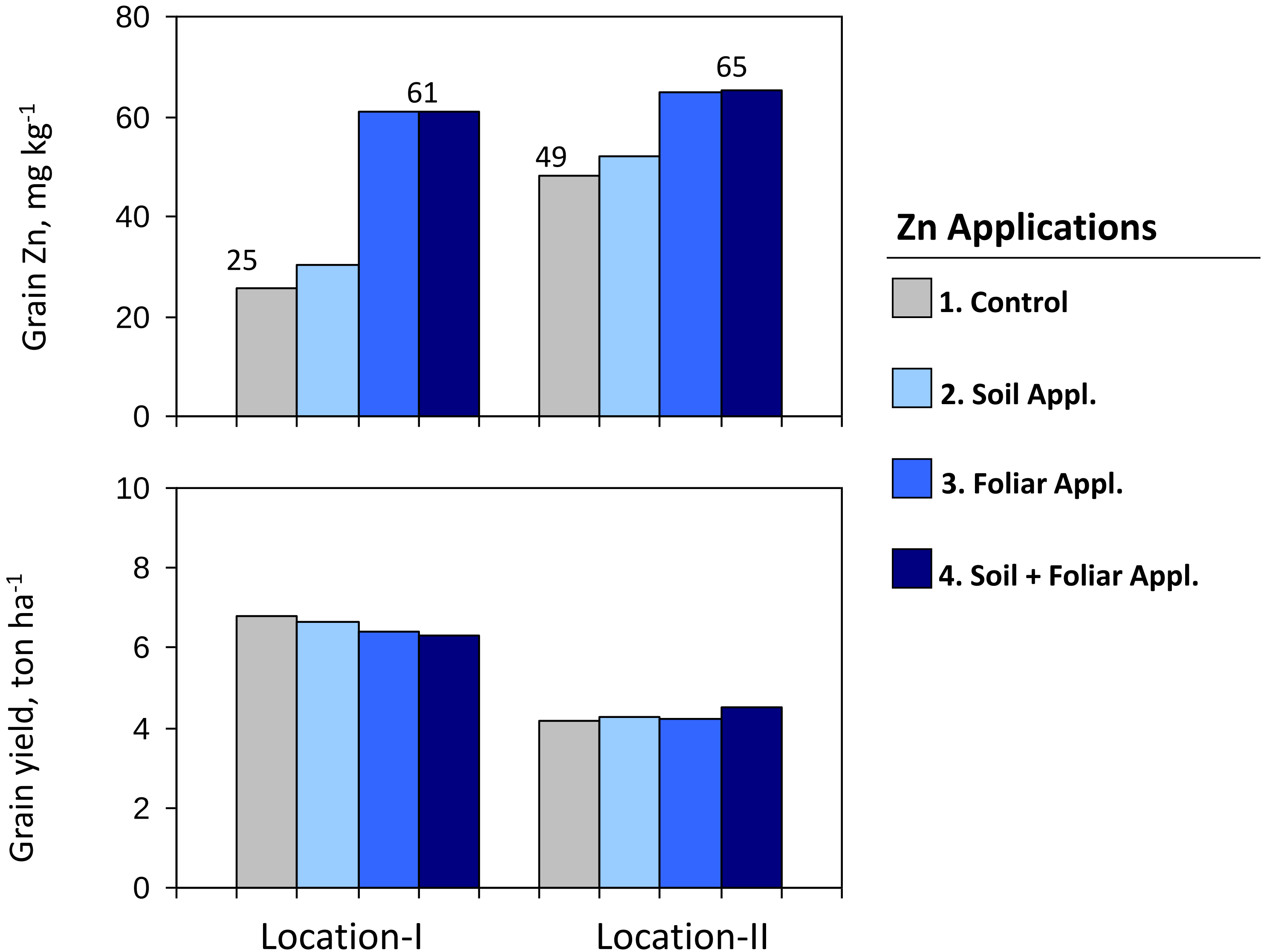
KAZAKHSTAN

(Partner: CIMMYT Kazakhstan)



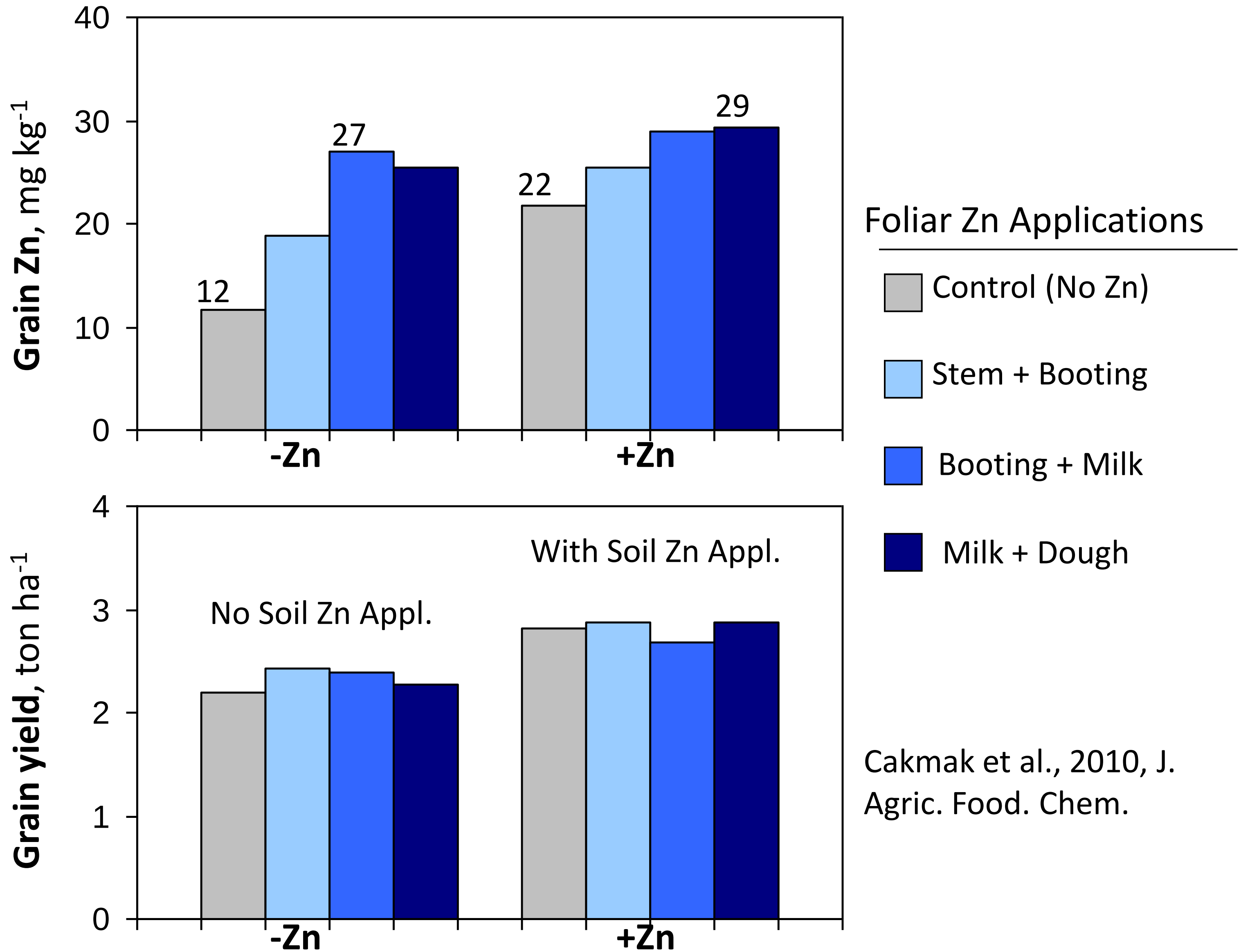
INDIA - Punjab State

(Partner: Punjab Agricultural University)



TURKEY

(Partner: Ministry of Agriculture)



Cakmak et al., 2010, J. Agric. Food. Chem.

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[illegible]		
•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
[illegible]	36	60
[illegible]	12	29
[illegible]	32	57
[illegible]	23	49
[illegible]	22	43
[illegible]	28	54
[illegible]	19	26
[illegible]	18	39
[illegible]	20	32
Iran		
•Average	17	28
Brazil		
•Average	30	52

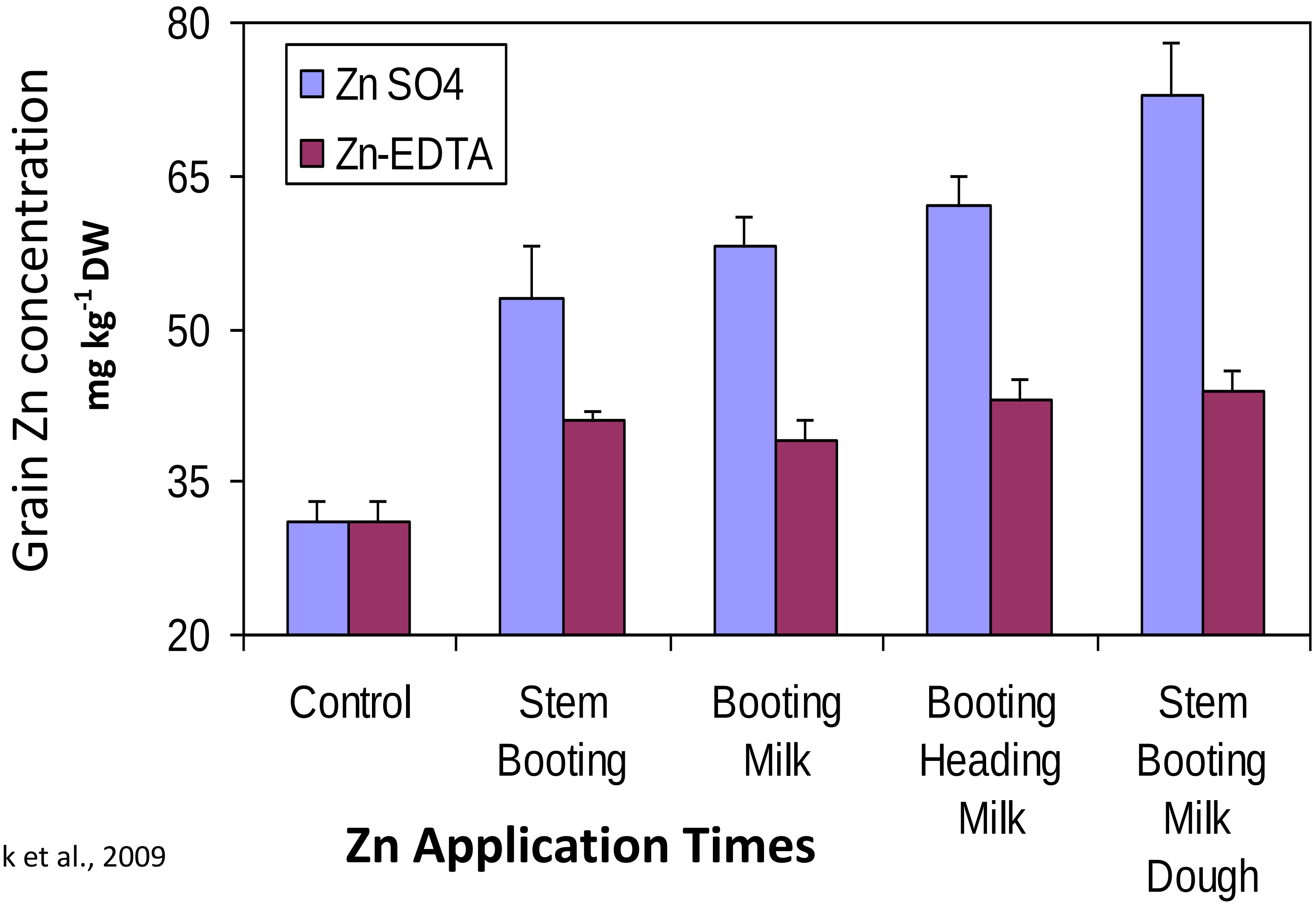
Average Concentrations of Grain Zn

(10 Countries with 32 locations)

-Zn: 26 ppm

+Zn: 50 ppm

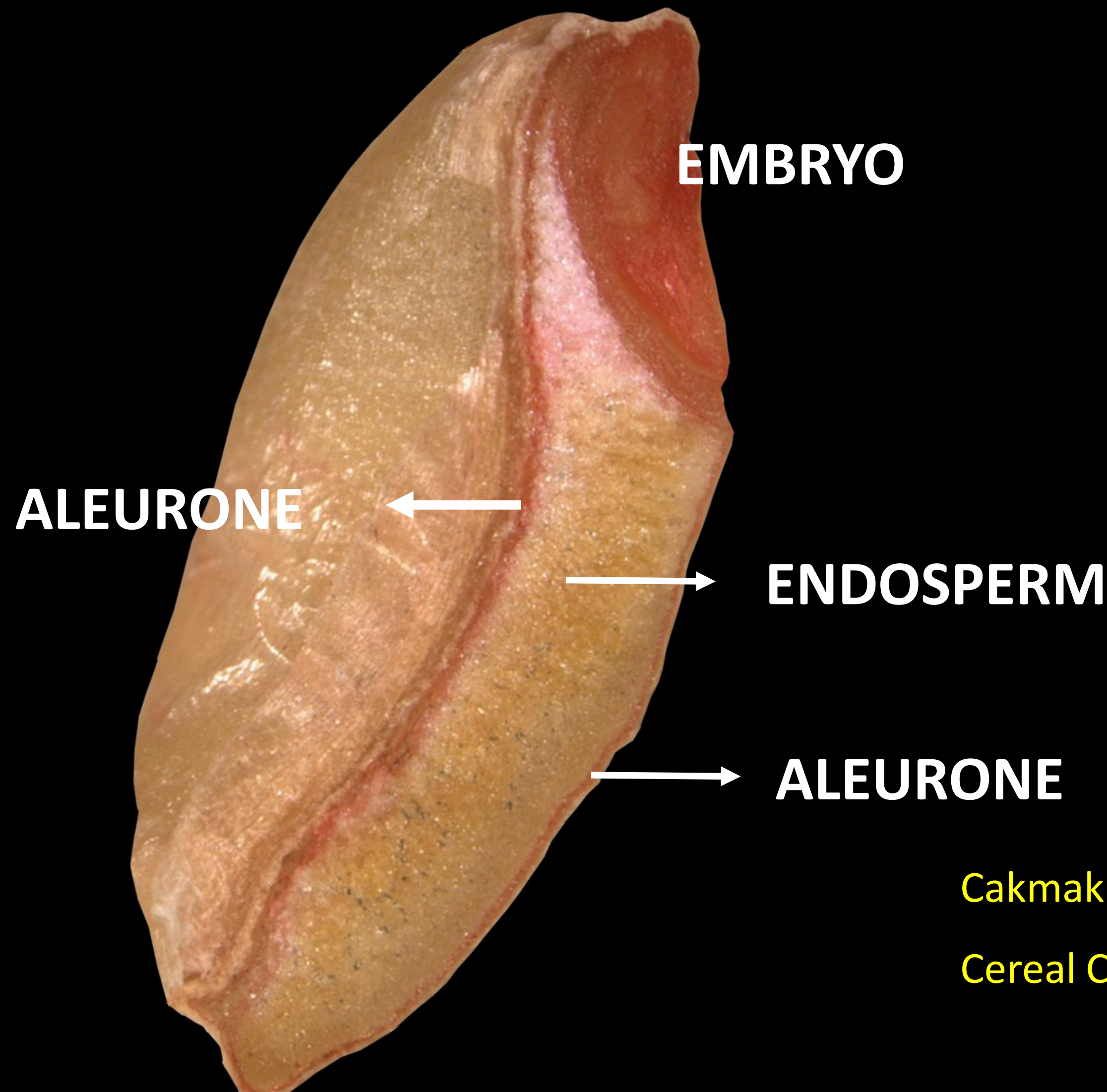
Foliar spray of ZnSO4 is more effective than ZnO and ZnEDTA in increasing grain Zn concentration



Cakmak et al., 2009

Localization of Zn in grain after foliar application?

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



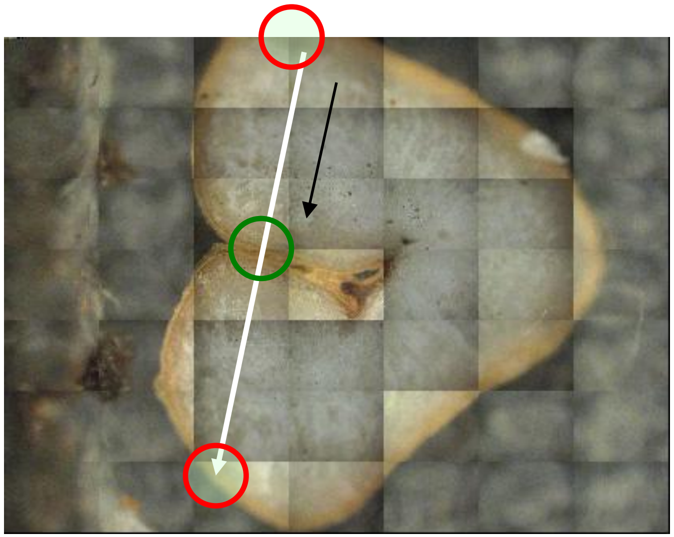
Cakmak et al., 2010

Cereal Chemistry, 77: 10-20

LA-ICP-MS Tests on Seeds

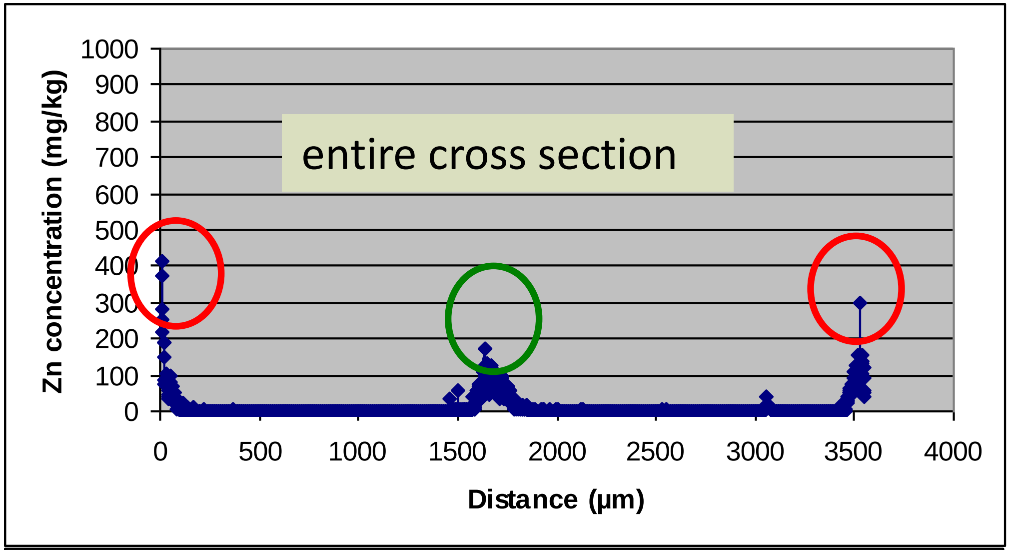
White arrow: Zn in entire cross section

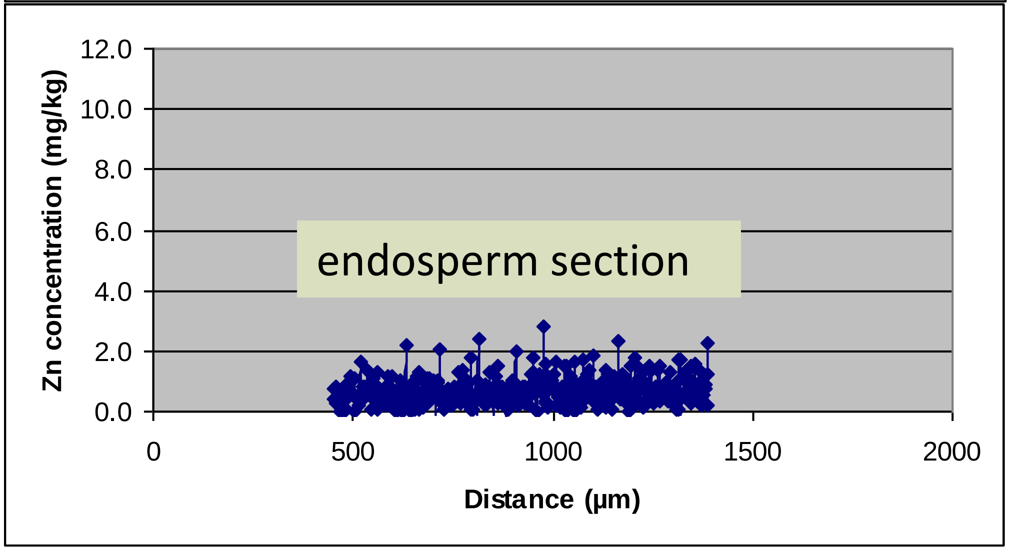
Black arrow: Zn in endosperm section



Cakmak et al., 2010,

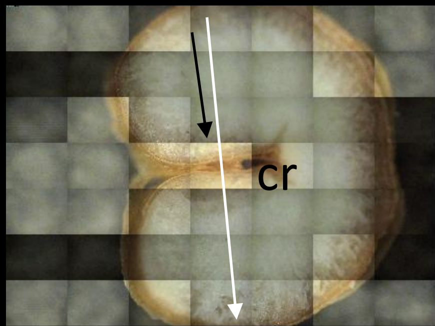
J. Agric. Food. Chem.

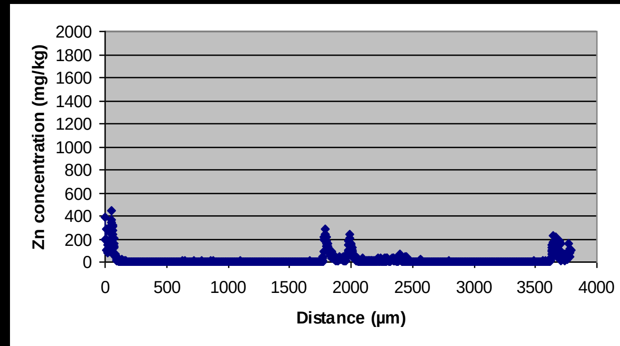


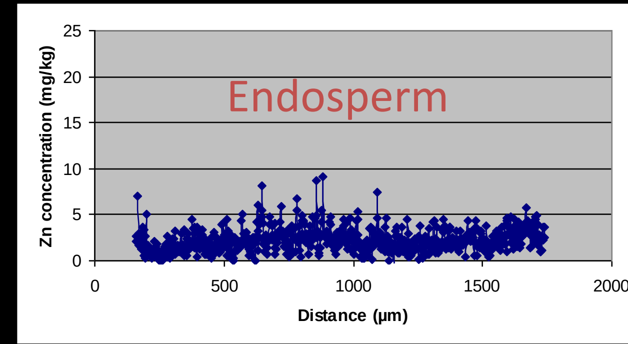


LA-ICP-MS Tests

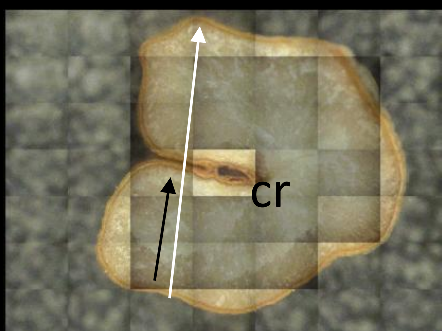
No Foliar Zn Application

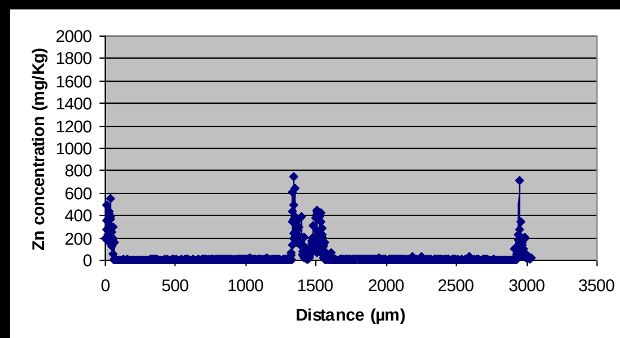


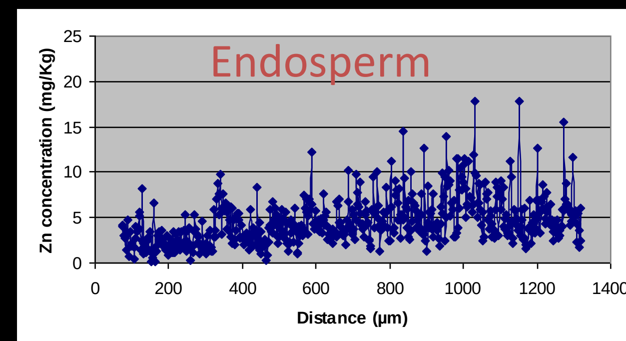




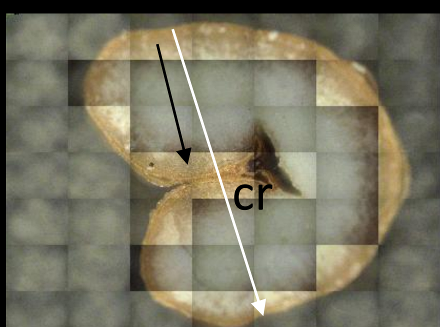
Foliar Zn Application at Stem Elongation and Booting Stages

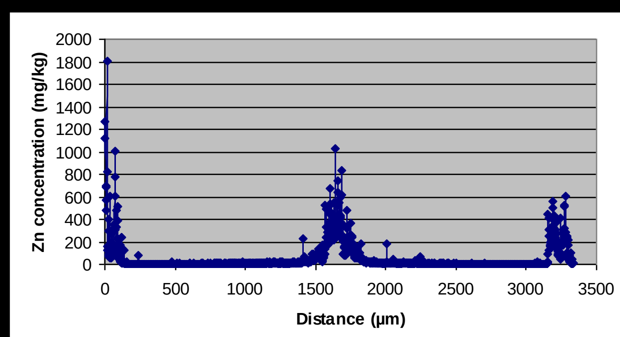


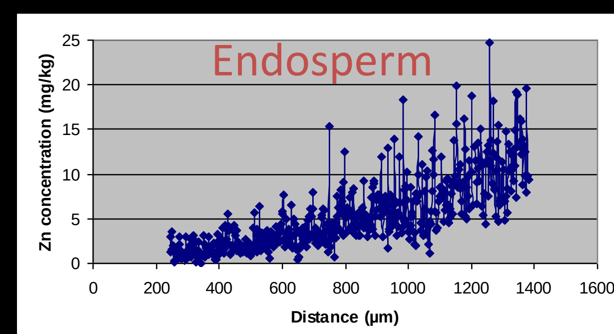




Foliar Zn Application at Milk and Dough Stages



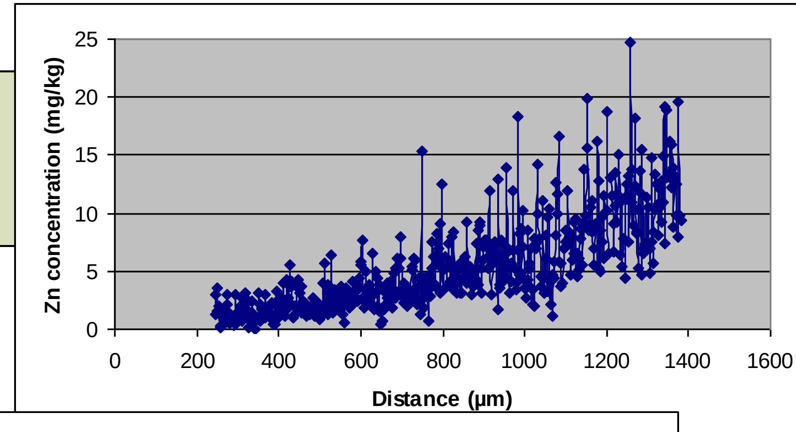




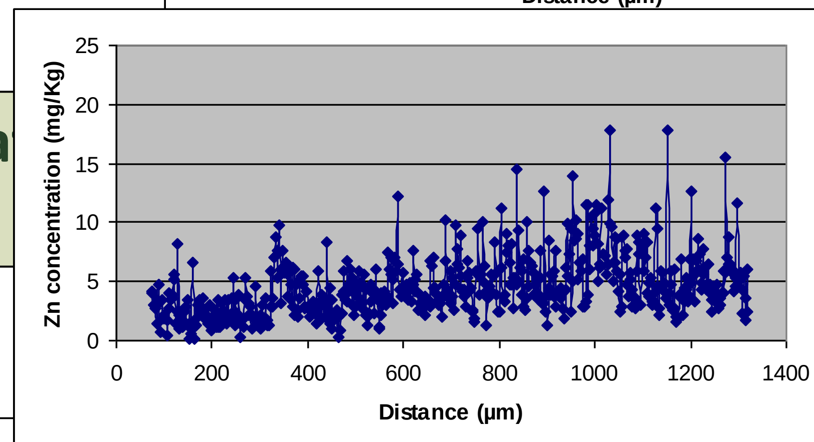
Cakmak et al., 2010, J. Agric. Food. Chem. 58:9092-9102

Changes in Endosperm Zinc Concentrations

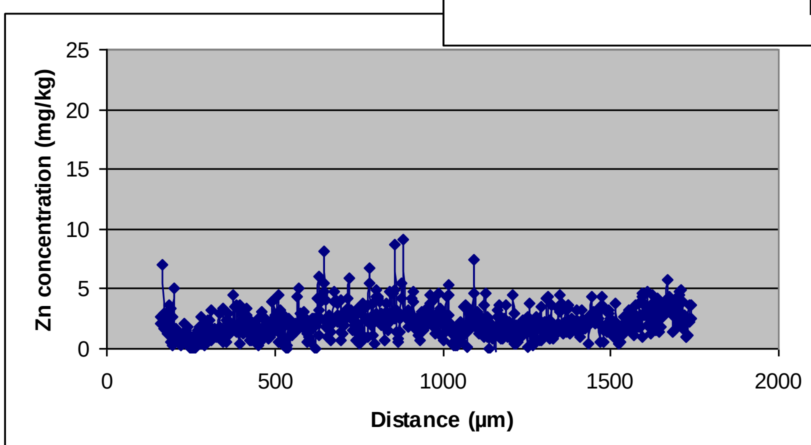
Zn applied at milk and and dough stages



Zn applied at stem elonga and boot



No Zn



Cakmak et al., 2010,

J. Agric. Food. Chem.

Thank You…

Sabanci University

3rd International

ZINC SYMPOSIUM

Improving Crop Production and Human Health

Hyderabad, India - October 10-13, 2011

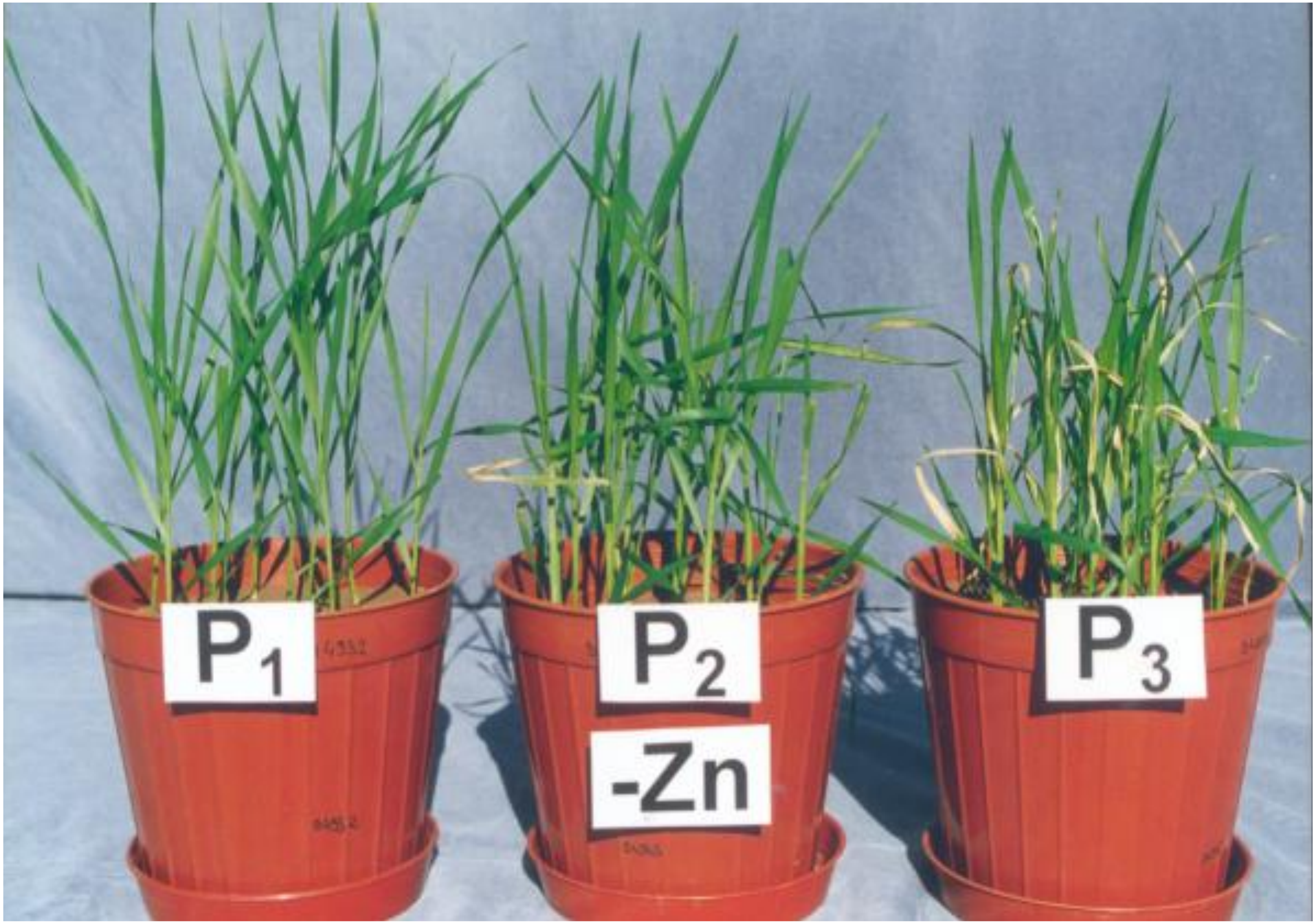
Zinc ...essential for life

FAI ENSURING FOOD SECURITY

International Fertilizer Industry Association

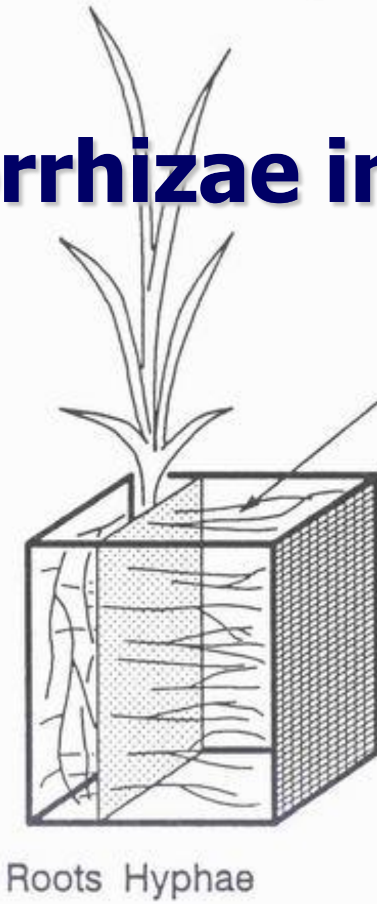
HarvestPlus
Breeding Crops for Better Nutrition

Increasing P supply induces Zn deficiency in wheat



Kalfa and Cakmak, unpublished

Role of Mycorrhizae in Zn Uptake



Contribution of extraradical hyphae (% of shoot content)

	Maize	Clover
P	20	79
Zn	25	50
Cu	25	60

Kothari et al., 1991, New Phytol. 117:649;
Li et al.,1991; Plant and Soil, 136: 49-57

Growth and shoot contents of P and Zn in non-mycorrhizal and VA mycorrhizal maize grown in an Oxisol*

Treatment P-fertilizer	VAM inoc.	Shoot dry matter (g $plant^{-1}$)	Shoot P (g kg^{-1})	Shoot Zn (mg kg^{-1})
-P	-VAM	1.75	1.0	107
+P	-VAM	5.05	2.3	69
+P	+VAM	6.02	3.2	108

From Marschner, 1993. In: Zinc in Soils and Plant, Kluwer Publisher

Table 2.4 Uptake and Translocation of Zinc by Barley Plants[a]

Zinc supplied as[b]	Rate of uptake and translocation (μg Zn g^{-1} dry wt per 24h) Roots	Shoots
$ZnSO_4$	4598	305
ZnEDTA	45	35

[a]Based on Barber and Lee (1974).
[b]Concentration of zinc in nutrient solution: 1 mg l^{-1}

Marschner, 1995; Mineral Nutrition of Higher Plants