



Enriching Grains with Micronutrients: Benefits for Crops and Human Health

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The talk will focus on the **potential of micronutrient fertilizers** for increasing concentration of micronutrients in cereal grains and describe the role of micronutrient-enriched grains in crop production and human nutrition.

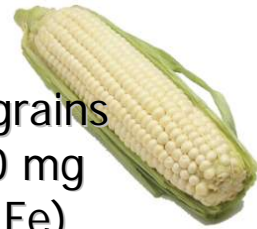
A special attention will be given on Zn and, partly Se, because it appears that the other important micronutrients in human nutrition (Fe) cannot be cost-effectively supplied to cereal grains by applying Fe fertilizers to soils or foliage.

Zinc is highly important for better health and nutrition

The recommended **daily zinc** intake: 10-15 mg/day



For improved micronutrient nutrition of humans, cereal grains should contain around 50-60 mg kg⁻¹ Zn (and similar amount Fe) as described by HarvestPlus (www.harvestplus.org)





Leaf Zn should be around 25-40 mg kg⁻¹ to ensure healthy growth and better yield



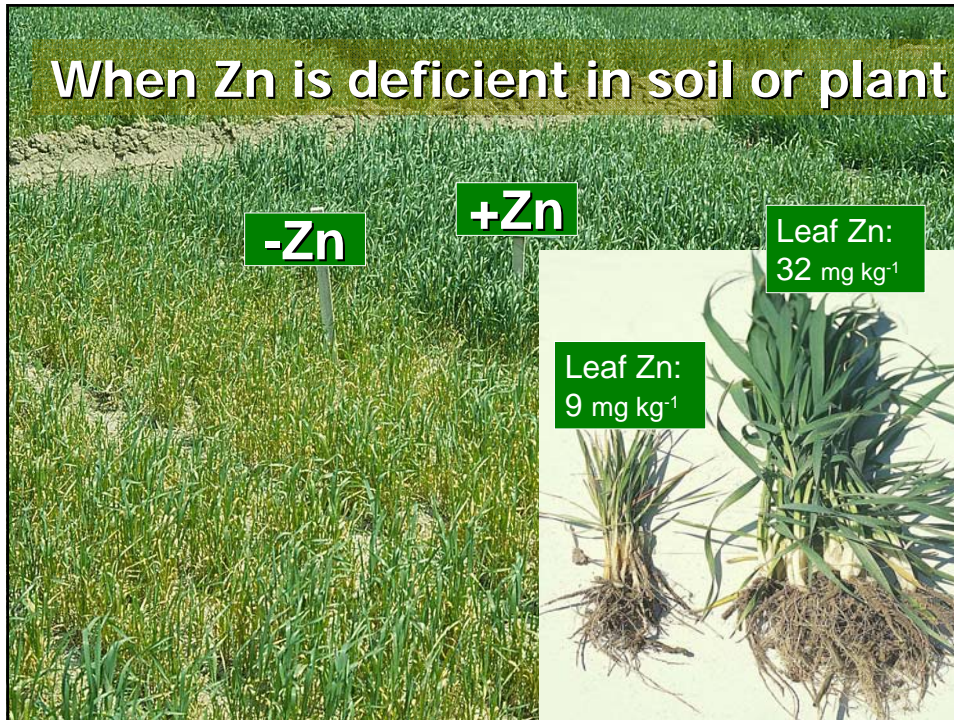
When Zn is deficient in diet



...**daily zinc** intake much lesser than 10 mg/day.....



When Zn is deficient in soil or plant



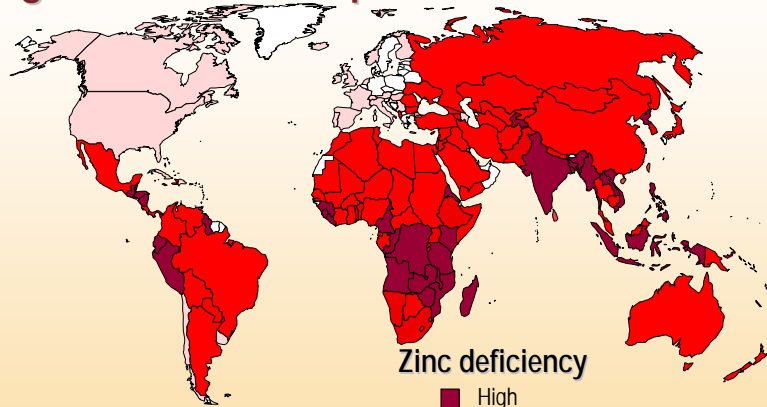
Zinc in Human Health

Zinc affects a range of functions:



- Immunity
- Growth
- Brain development
- Reproduction
- Sexual Formation

Zinc deficiency: global nutritional problem in human beings

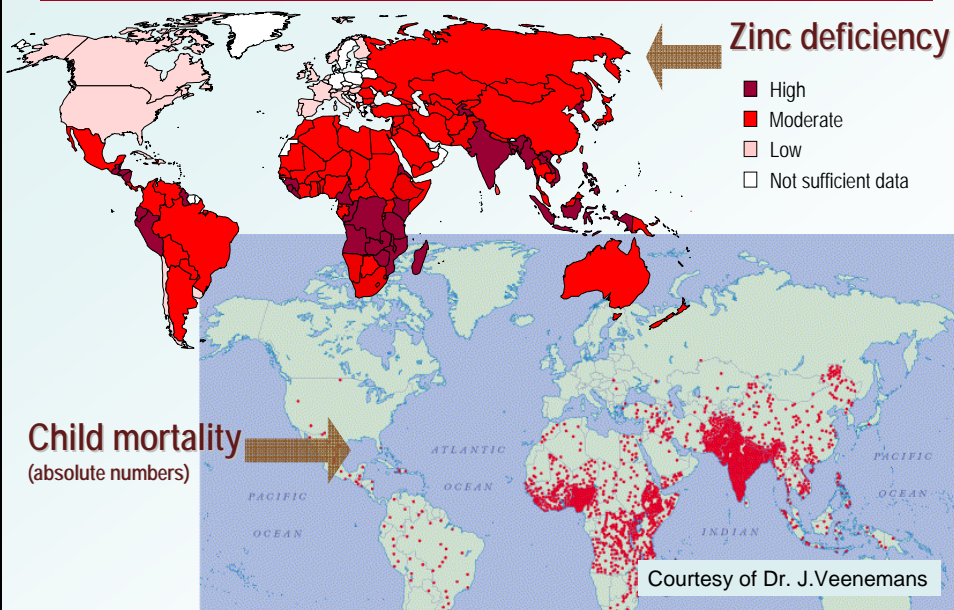


Zinc deficiency

- High
- Moderate
- Low
- Not sufficient data available

Courtesy of Dr. J.Veenemans
Wageningen University

Zinc deficiency and child mortality: geographical overlap



Courtesy of Dr. J.Veenemans

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

Courtesy of Dr. J.Veenemans

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

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%

WHO, 2002

Target Populations

- **Women**

- Pregnant
- Lactating
- Adolescent girls
- Reproductive age (15-44 yrs)

- **Children**

- Infants (0-1 yr)
- Preschool age 1 to 3 yrs and 3 to 5-6 yrs

Children are especially sensitive to Zinc deficiency

Zinc deficiency

Zinc deficiency in infant



One week after initiation of Zn therapy




ROWETT
research institute

Courtesy of Dr. Arthur

Micronutrient deficiencies: also an increasing concern in industrialized countries

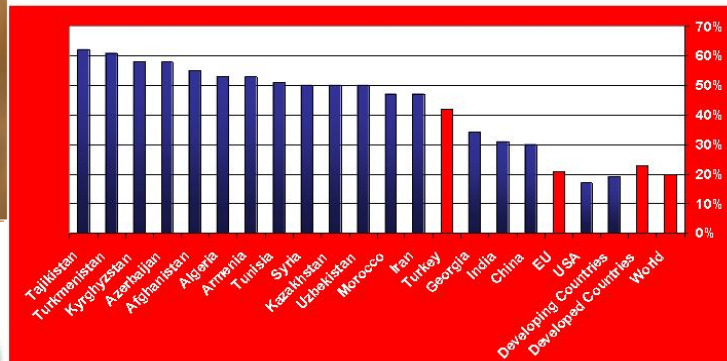
- According to UNICEF around 25 % of 1.5-2.5 year old children in UK have evidence of Fe deficiency.
- On average, 10 % of the population in USA and Europe are at risk of Zn deficiency

UNICEF; Hotz and Brown, 2004, Food Nutr. Bull.

Reason: High consumption of cereal based foods
with low zinc content is one major reason for widespread occurrence of Zn deficiency in humans in developing world

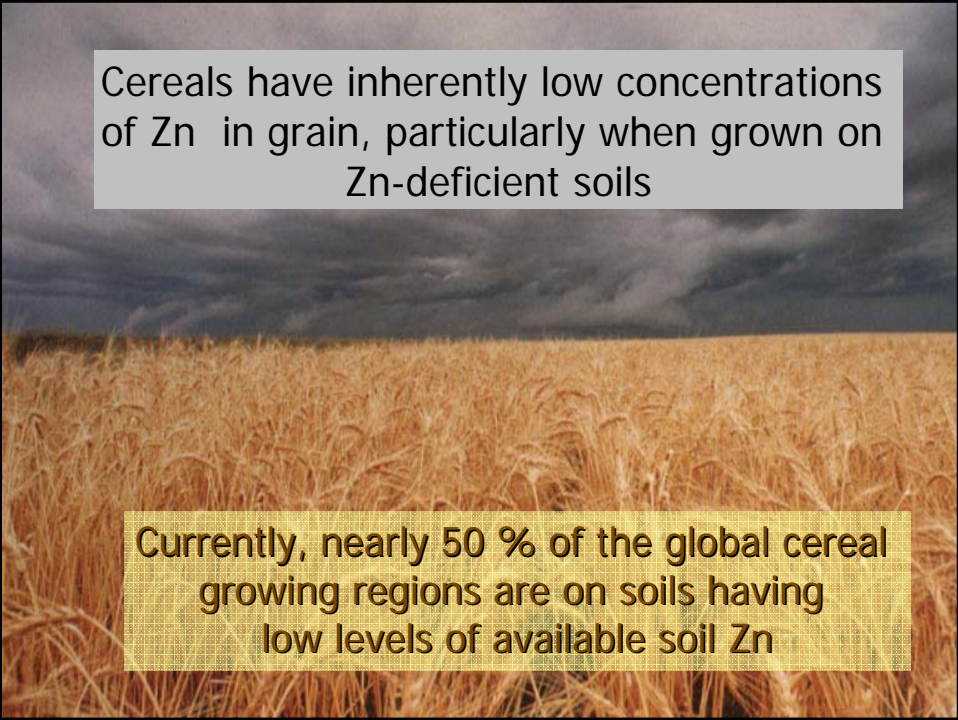


% daily Calories from Wheat



Source: FAO Database, 2003;

compiled by H.-J. Braun, CIMMYT-Turkey

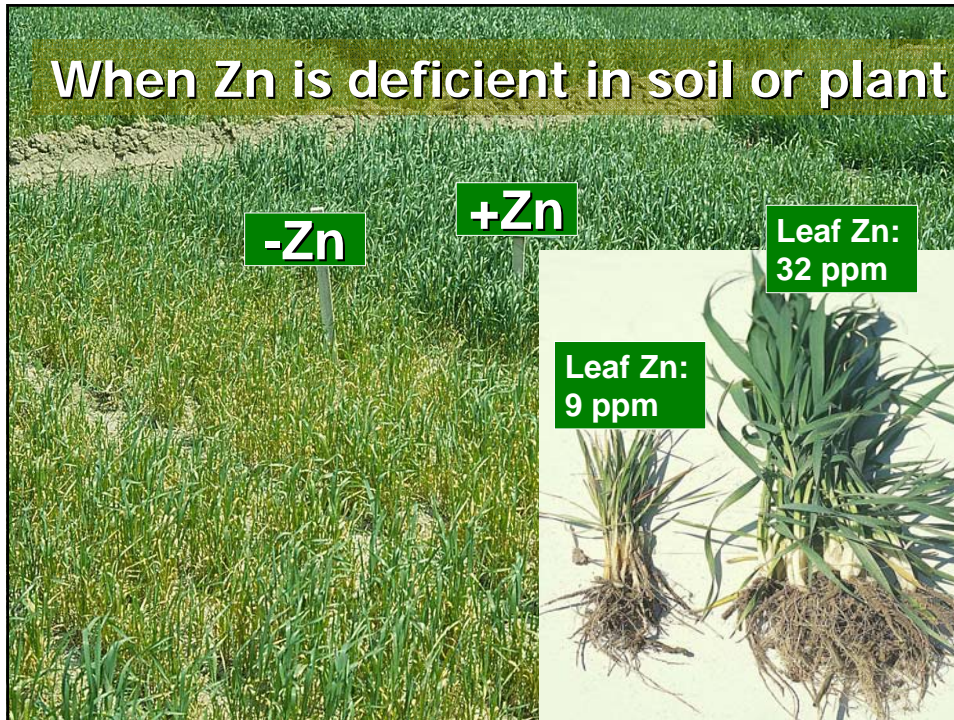


Cereals have inherently low concentrations of Zn in grain, particularly when grown on Zn-deficient soils

Currently, nearly 50 % of the global cereal growing regions are on soils having low levels of available soil Zn

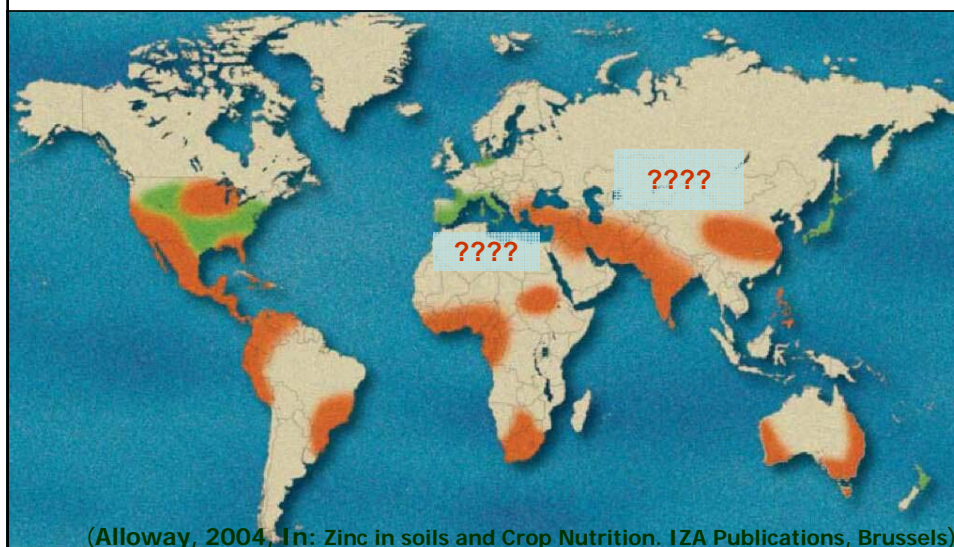
In most cases, **the regions with Zn-deficient soils are also the regions where Zn deficiency in humans are widespread** as reported in India, Pakistan, China, Iran and Turkey....

When Zn is deficient in soil or plant



Geographic distribution of severe (red) and moderate (green) **zinc deficient soils in the world**

Zn Deficiency: Global Nutritional Problem in Soils



Solutions to Zinc Deficiency



- **Supplementation**
(human health)

- **Food Fortification**
(human health)



- **Agricultural strategies**
Breeding and Application
Zn-Containing Fertilizers
(crop nutrition and human health)

Food fortification and supplementation

are too expensive, not practical to be applied on large scales and not easily accessible by those living in the rural regions.

Supplementation:

□ \$2.65 per person per year

28 million anemic pregnant women in India in any given year

□ \$37 million to treat one-half each year

Source: IFPRI
(INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE, Washington, DC)

Agricultural strategies

Breeding



Application of
Micronutrient Fertilizers



Alternative Approach- Breeding



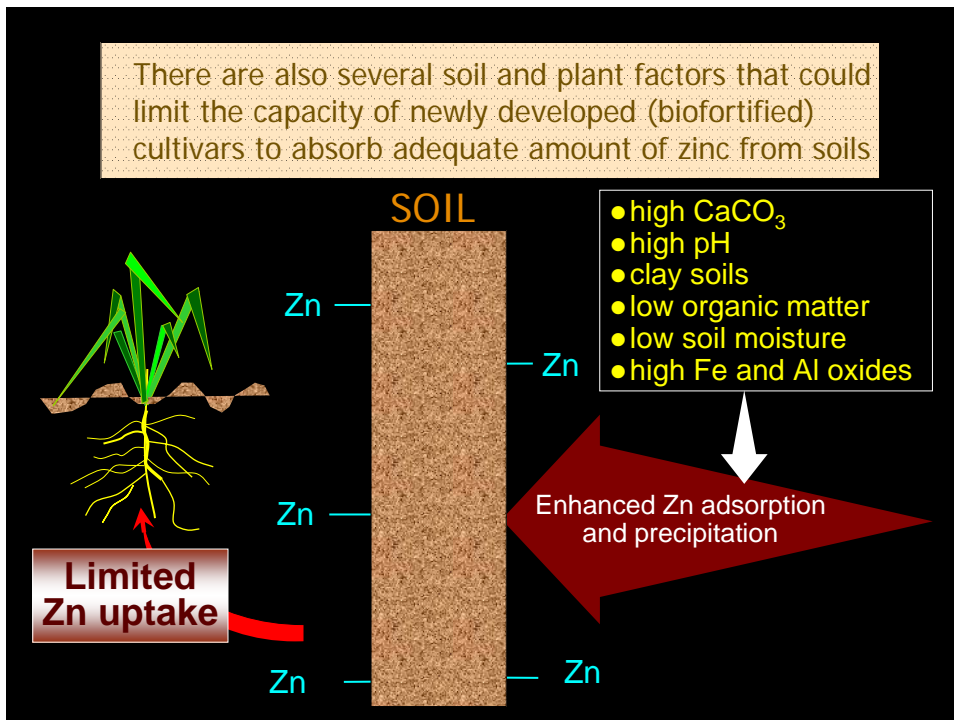
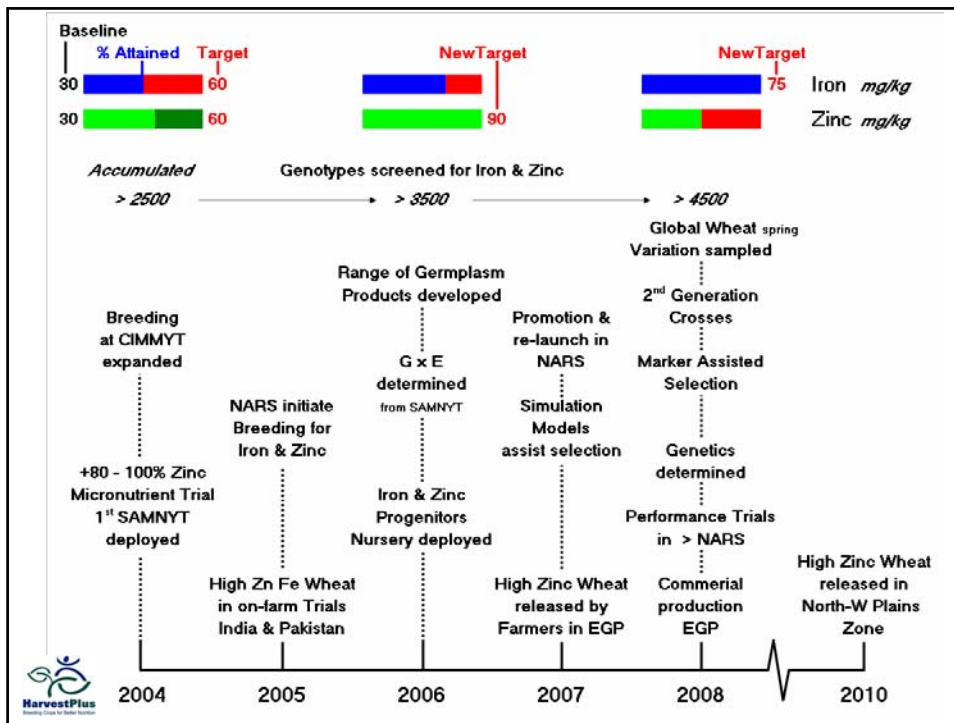
HarvestPlus- Biofortification Challenge Program

Breeding new cereal cultivars with
high micronutrient content in cereal grains

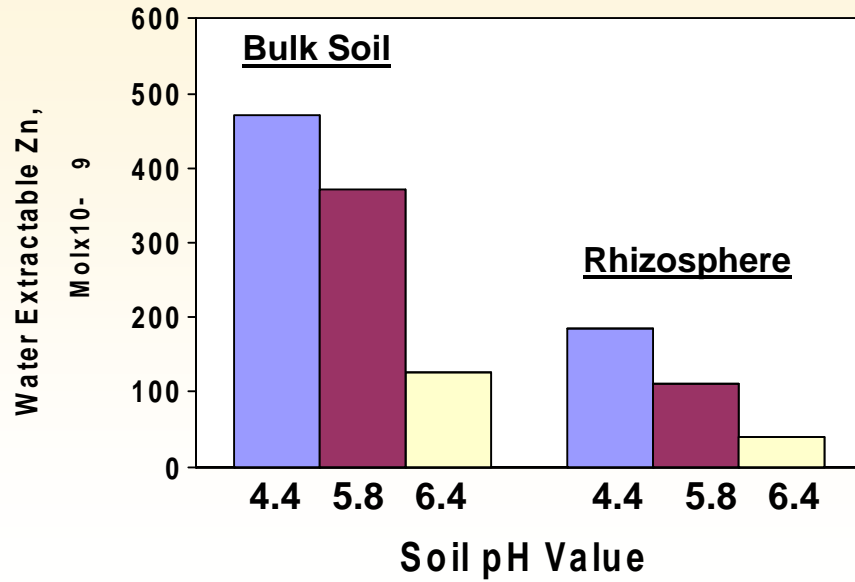
HarvestPlus
uses **agriculture (BREEDING)**
as a public health intervention
Poster No. 6

Plant Breeding.....

- Breeding strategy is, **however**, a long-term process requiring different type of efforts and significant resources,
- and it is **uncertain** whether the breeding strategy will or will not work after all these long-term efforts over many years and huge financial investments.

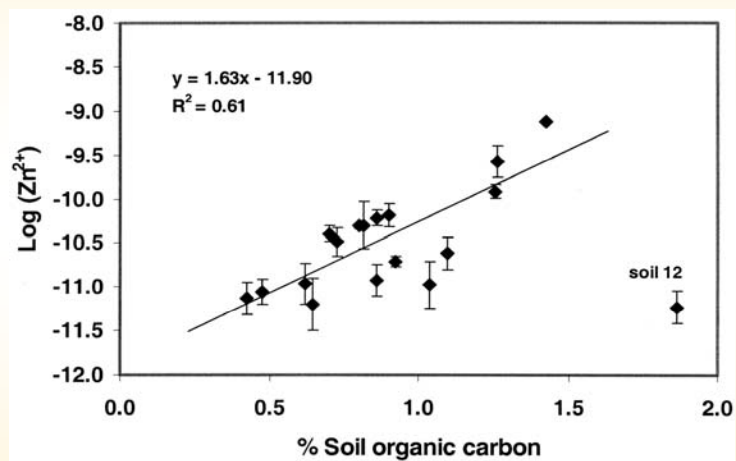


Soil pH: a critical factor reducing Zn availability

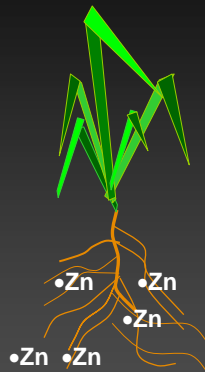


Saron et al., et al., 1989; Comm. Soil Sci. Plant Anal. 20: 271

Relationship between free Zn Activity and soil organic carbon in Soils



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



In soils with low chemical availability of Zn, the genetic capacity of the newly developed (biofortified) cultivars to

- absorb sufficient amounts of Zn from the soil and
- accumulate it in their grain

may not be expressed to the full extent without adequate available soil pools of Zn.

A successful breeding program for biofortifying cereals with Zn is very much dependent on the amount of plant-available Zn pools in the soil

Additional Problem: Zinc Depletion from Soils

Harvesting Zn-enriched grains from the fields would remove more Zn from the land.

This would cause a more rapid depletion of available soil-Zn, further aggravating Zn deficiency in soils.

Need for an alternative, rapid approach to improving micronutrient concentration of cereal grains

ZINC 



Fertilizer Strategies to Enrich Cereal Grains with Micronutrients

(Example: Zinc/Selenium Fertilization)



Zinc Fertilization to Increase Zinc Density of Cereal Grains

Application of Zn Fertilizers or
Zn-Enriched N-P-K Fertilizers

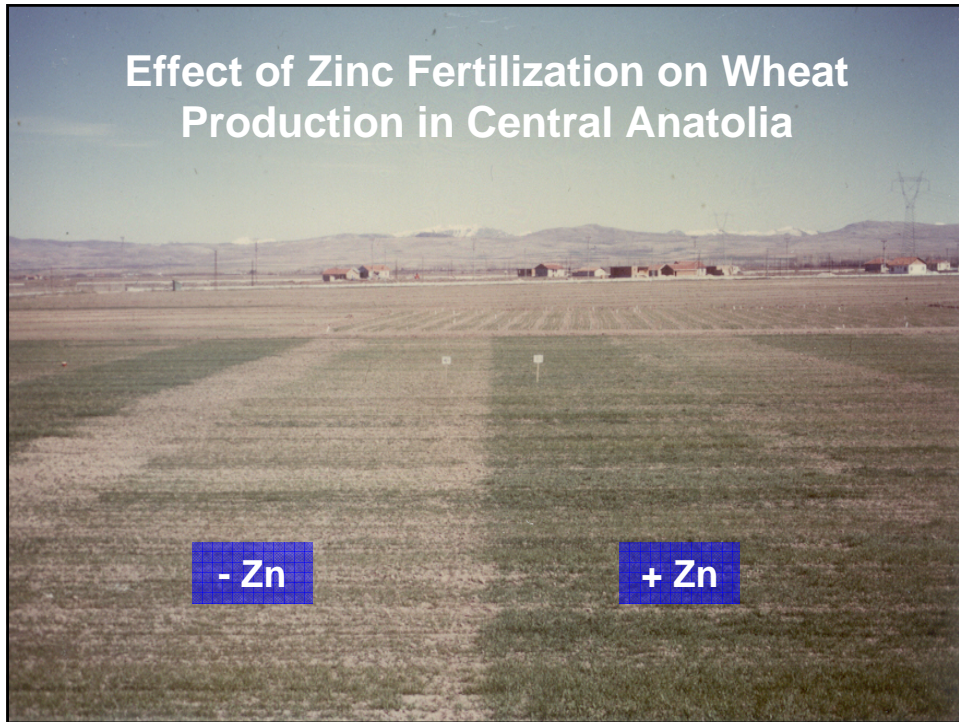
Example: NATO-Zn Project in Turkey

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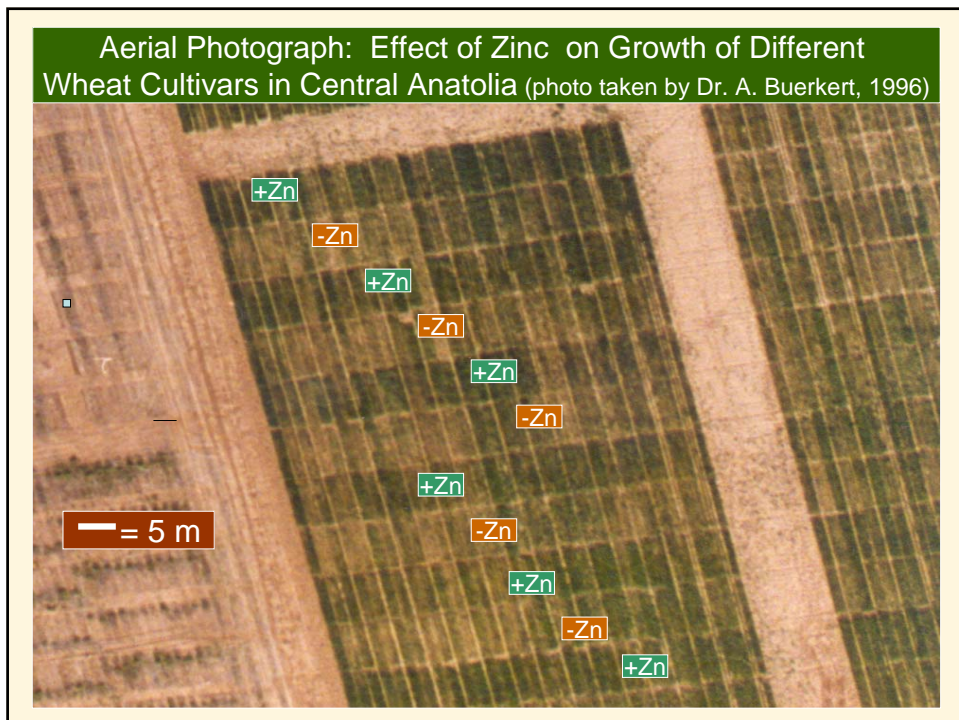
Zinc Fertilizer Applications in Anatolia (NATO-Zinc Project)



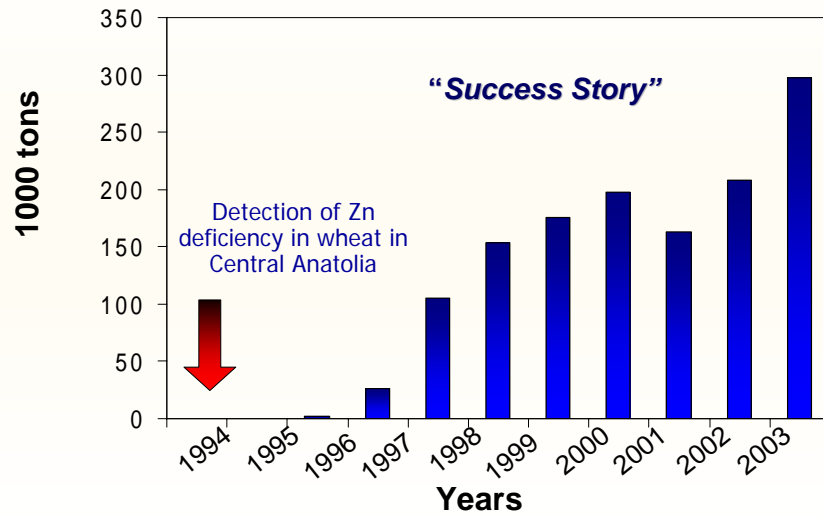
Effect of Zinc Fertilization on Wheat Production in Central Anatolia



Aerial Photograph: Effect of Zinc on Growth of Different Wheat Cultivars in Central Anatolia (photo taken by Dr. A. Buerkert, 1996)

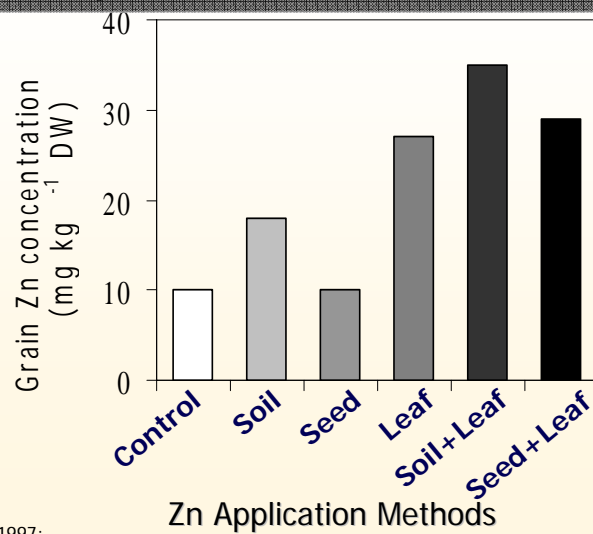


Use of Zn-enriched NP and NPK fertilizers in Turkey following “NATO-Zinc Project”



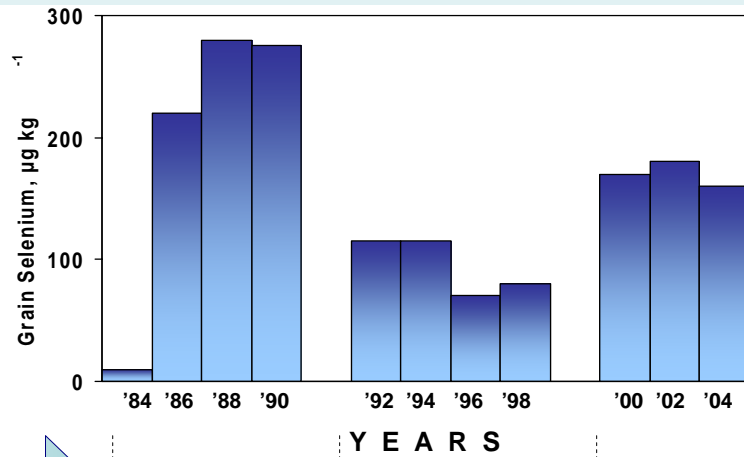
Sources: Cakmak, 2000, Plant and Soil.
Turkish Ministry of Agriculture, 2004

SHORT-TERM SOLUTION TO Zn DEFICIENCY PROBLEM:
Applying Zn to wheat in Central Anatolia increases grain Zn concentration up to 3-fold.



Yilmaz et al., 1997;
J. Plant Nutr. 21:2257-2264

Enrichment Fertilizers with Se Increased **Grain Se** in Finland



Na₂SeO₄ added to NPK fertilizers for cereals

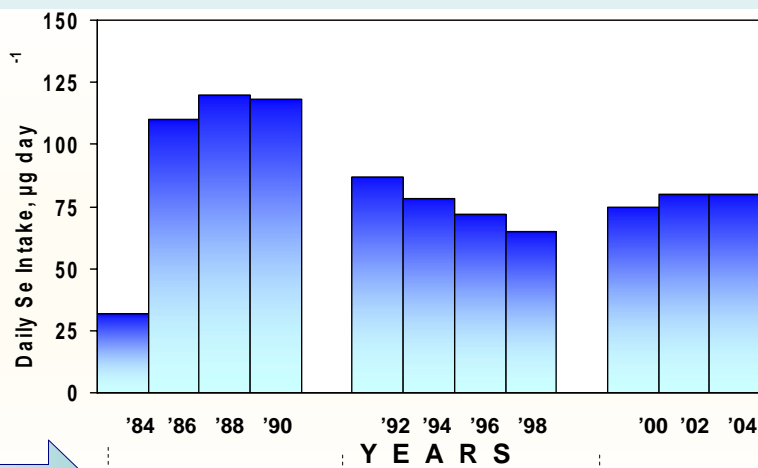
16 mg kg⁻¹

6 mg kg⁻¹

10 mg kg⁻¹

Courtesy of Jr. Combs, slide redrawn

Enrichment Fertilizers with Se Increased **Daily Se Intake** in Finland



Na₂SeO₄ added to NPK fertilizers for cereals

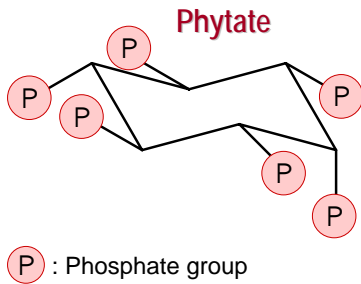
16 mg kg⁻¹

6 mg kg⁻¹

10 mg kg⁻¹

Courtesy of Jr. Combs, slide redrawn

Application of Zn Fertilizers reduces phytate concentration (and thus Phytate:Zn Molar Ratios)



- Staple cereals are rich in phytate (phytate is the primary molecule to store phosphate in plant seeds)
- Phytate forms insoluble complexes with Zn^{2+}

High **Phytate/Zn molar** ratios are indicator for poor bioavailability of Zn in diet

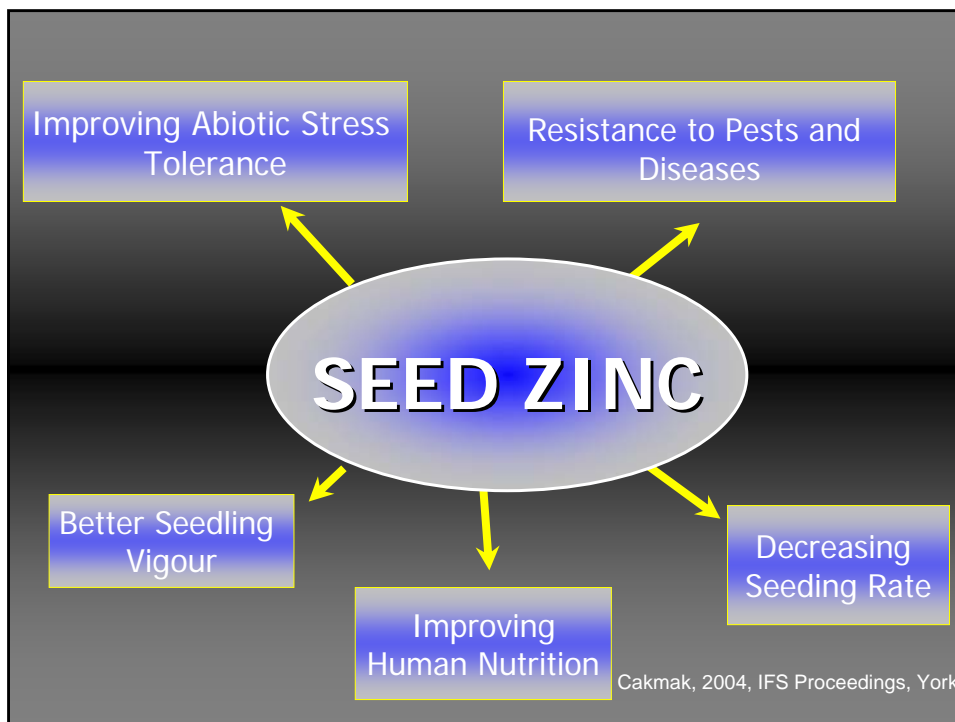
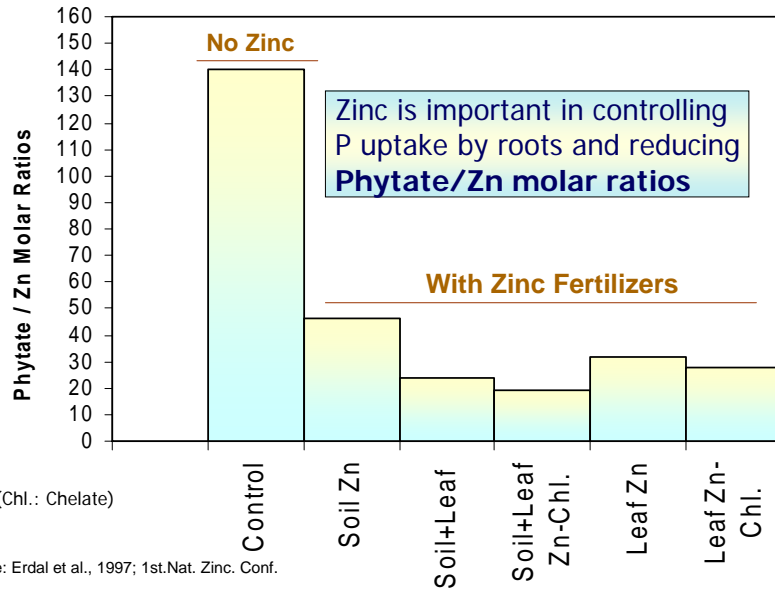
Adequate amount of Zn in soil reduces uptake of P by roots and thus accumulation of phytate in grain

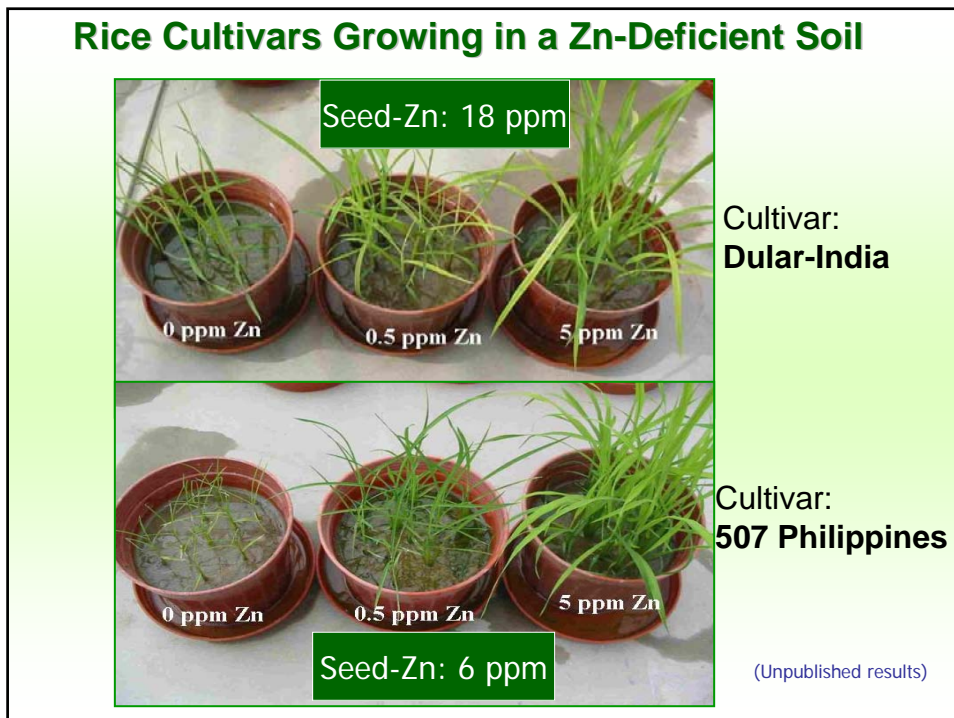
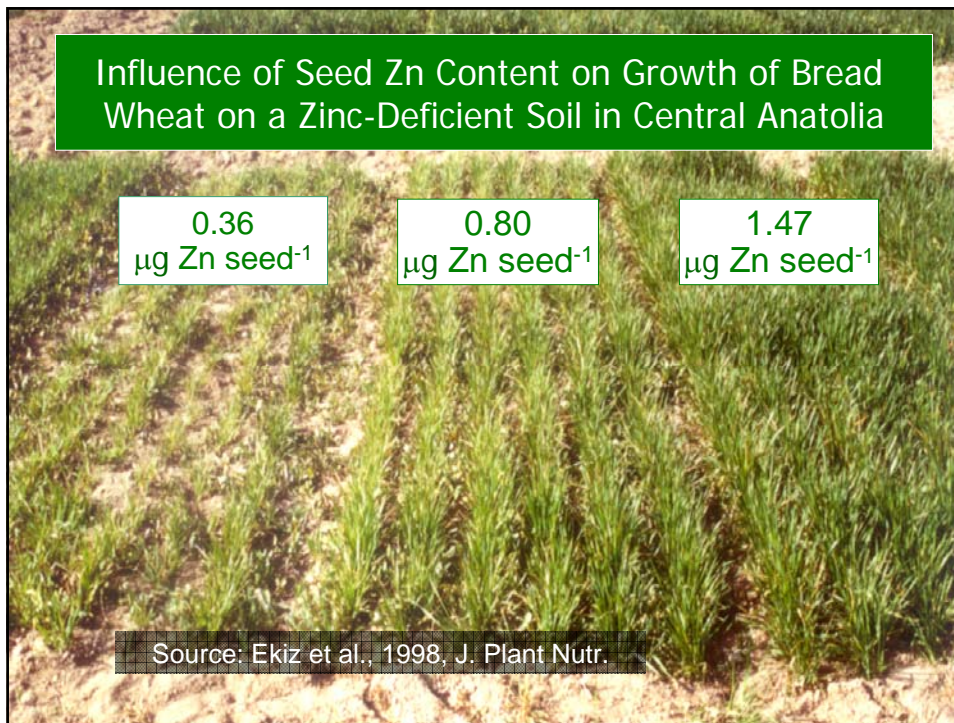
Influence of Zn fertilization on phytic acid concentrations and phytate/Zn molar ratios in 64 wheat cultivars grown in Central Anatolia

Zn Fertilization	Phytic Acid ($mg\ g^{-1}$)	Phytate : Zn Molar Ratios (range)
-	11	137 (95-216)
+	8	61 (41-85)

Source: Erdal et al., 2002; J. Plant Nutr.

Effect of Different Zn-Application Methods on Grain Phytate-Zn Molar Ratios in Central Anatolia on severely Zn-Deficient Soil





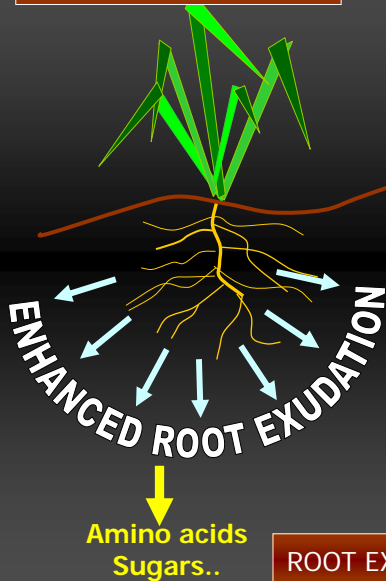
Maize, Paraguay, 1996



Plants are happy when their seeds are "galvanized"

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

Low Zn in soil induces
root exudation



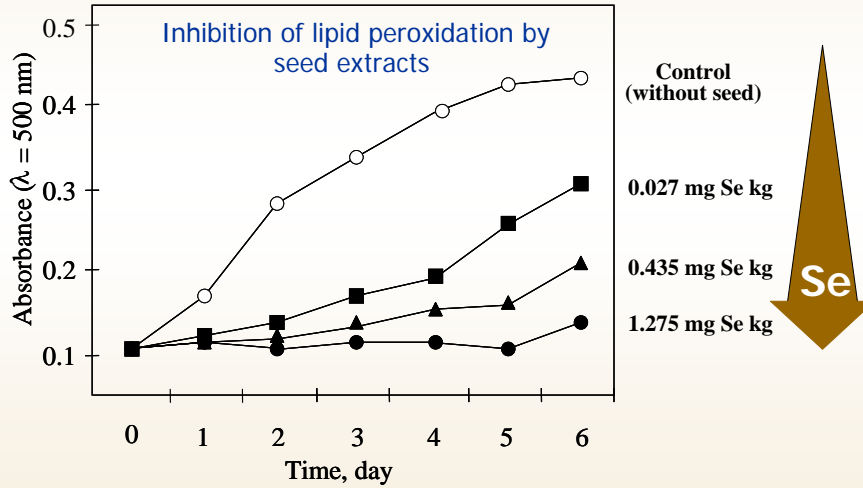
Adequate amount of Zn in
growth medium is
essential for structural and
functional integrity of cell
membranes

Any impairment in structural
integrity of cell membranes
(e.g., by Zn deficiency) induces
membrane permeability and
extensive release of exudates

ROOT EXUDATES: feeding substrates for pathogens

Increases in antioxidant activity of rice seeds with increased seed-Se concentration

(data from Xu and Hu, J. Agric. Food chem. 52: 1759-1763)



Protein (N)-Zinc Interactions

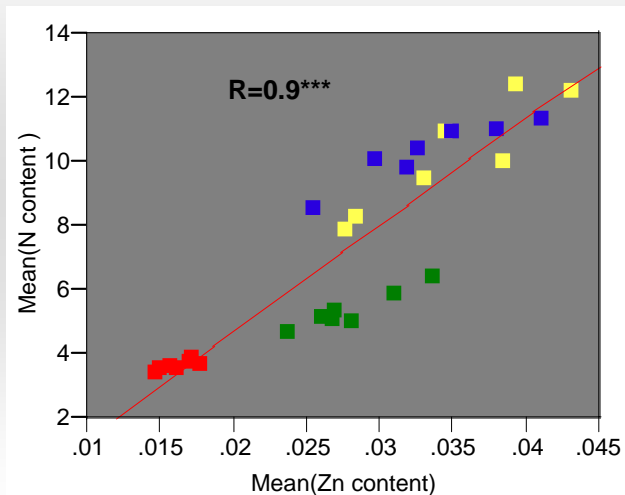
Protein in Grain:

Sink for Zinc



Foliar N Applications to Stimulate
Zn Accumulation in Grain

Zn-Nitrogen Correlation tested in 4 environments



Assaf et al., 2005

- 1) RVT – DRY
- 2) RVT – WET
- 3) HAIFA
- 4) ATLIT

CONCLUDING REMARKS



It is very **important** and **urgent** to initiate research programs directed at the development of optimal Zn application methods to maintain sufficient Zn uptake, allowing for maximum Zn accumulation in grain

Ensuring success of breeding efforts for increasing grain-Zn

CONCLUDING REMARKS

Adding Zn to Regular Fertilizers

Very Simple, Requires Little Effort and Provides Substantial Benefits

Improving

- Plant yield and health
- Grain zinc density
- Human health and nutrition

CONCLUDING REMARKS

Application of Zn-enriched fertilizers on nationwide in the target countries would be very rapid and practical approach to maximize Zn uptake and grain Zn accumulation in food crops immediately.

This approach is important in optimizing biofortification of grains with Zn and ensuring success of breeding efforts for increasing micronutrient density in grain.

Thank you

