# Agronomic biofortification of cereal grains with zinc: A vital approach to overcome the zinc malnutrition from Indian population

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'Forget climate change, we should spend on nutrition' - Times Online - Windows Internet Explorer

http://www.timesonline.co.uk/tol/news/environment/article4033272.ece?token=null&offset=0

'Forget climate change, we should spend on nutrition' ...



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

Mark Henderson, Science Editor, in Copenhagen

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



Intelligent, informed insights

# Copenhagen Consensus-2008

www.copenhagenconsensus.org

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

***"How to spend an imaginary $75 billion to achieve high returns and immediate consequences for humanity and global stability"***

# Combating Zinc Deficiency: Most profitable public investment issue

1993 Nobel Economics laureate Douglass North said:

**Eliminating Zn and vitamin A deficiencies** have immediate and important consequences for improving the well-being of poor people around the world, that's why it should be our number one priority…

# 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% |





# Annual Impact of Vitamin A and Zinc Deficiencies

**Child deaths**: Over 1 million from Zinc & Vitamin A deficiencies

**Black et al., 2008: The Lancet**
**Maternal and Child Undernutrition**

# **Global deaths in children** under 5 years of age attributed micronutrient deficiencies in 2004

| Type of deficiency | Deaths | % of deaths in children under 5 years |
|---|---|---|
| Vitamin A | 666,771 | 6.5 |
| Zinc | 453,207 | 4.4 |
| Iron | 20,854 | 0.2 |
| Iodine | 3,619 | 0.03 |

Black et al. 2008. The Lancet Maternal and Child Under nutrition Series

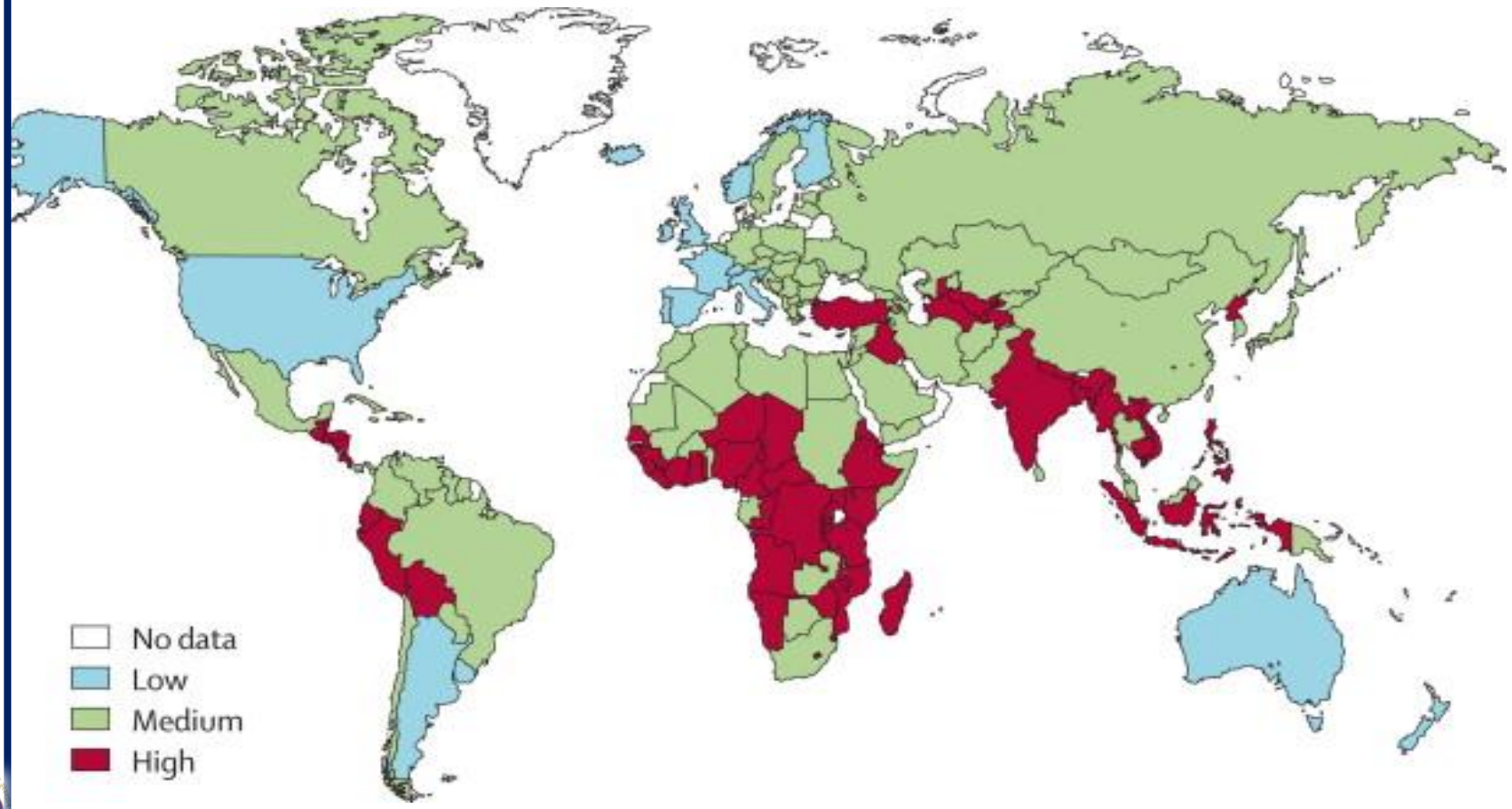




# Zinc affects a range of functions:

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

# Countries at Risk of Zinc Deficiency in Children




Black et al. 2008. The Lancet Maternal and Child Undernutrition Series

# World Bank Report: **Nearly half of the Indian children are stunted**

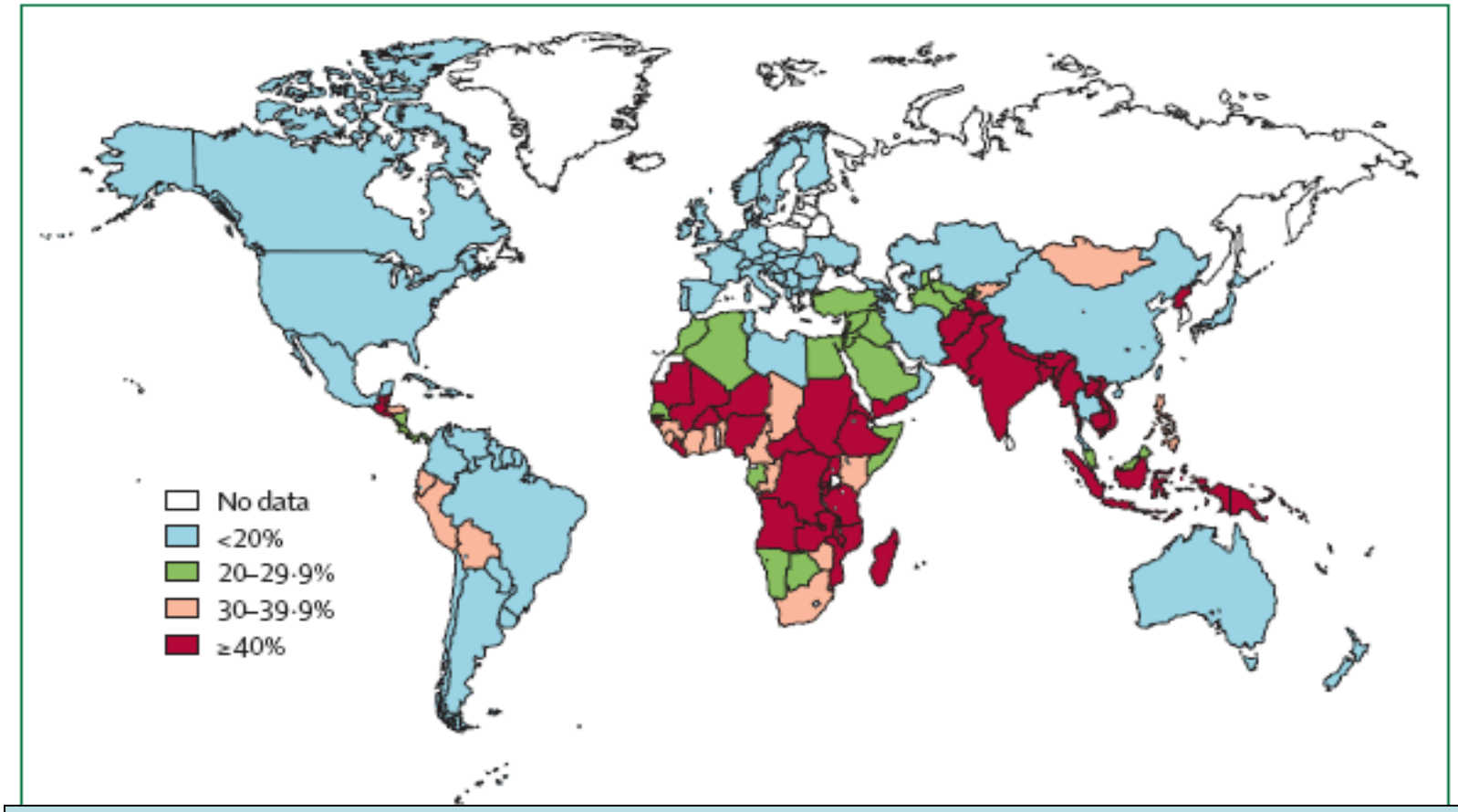
Nearly half of the Indian children (e.g., 61 million) under the age of five are stunted which is associated with under-nutrition of children.

The mentioned number of stunted children in India represents 34% of all stunted children globally



(Gragnaolati et al., 2005; Black et al., 2008)

# Most of world's malnourished children lives in India




Prevalence of Stunting in Children under 5

*Figure 2:* Prevalence of stunting in children under 5 years

# Major Reason:
## High Consumption Cereal Based Foods with Low Zn Concentrations

In the rural areas of India, rice and wheat 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 $kg^{-1}$**





# Link between Soil Zn Deficiency and Zn Deficiency in Human Beings

- Because Zn in cereal grains is inherently very low, growing cereals on potentially Zn-deficient soils further decreases grain Zn concentrations.
- It is, therefore, not surprising that high Zn deficiency incidence in humans occurs predominantly on regions where soils are deficient in plant-available Zn.
- India has some of the most Zn deficient soils in the world.

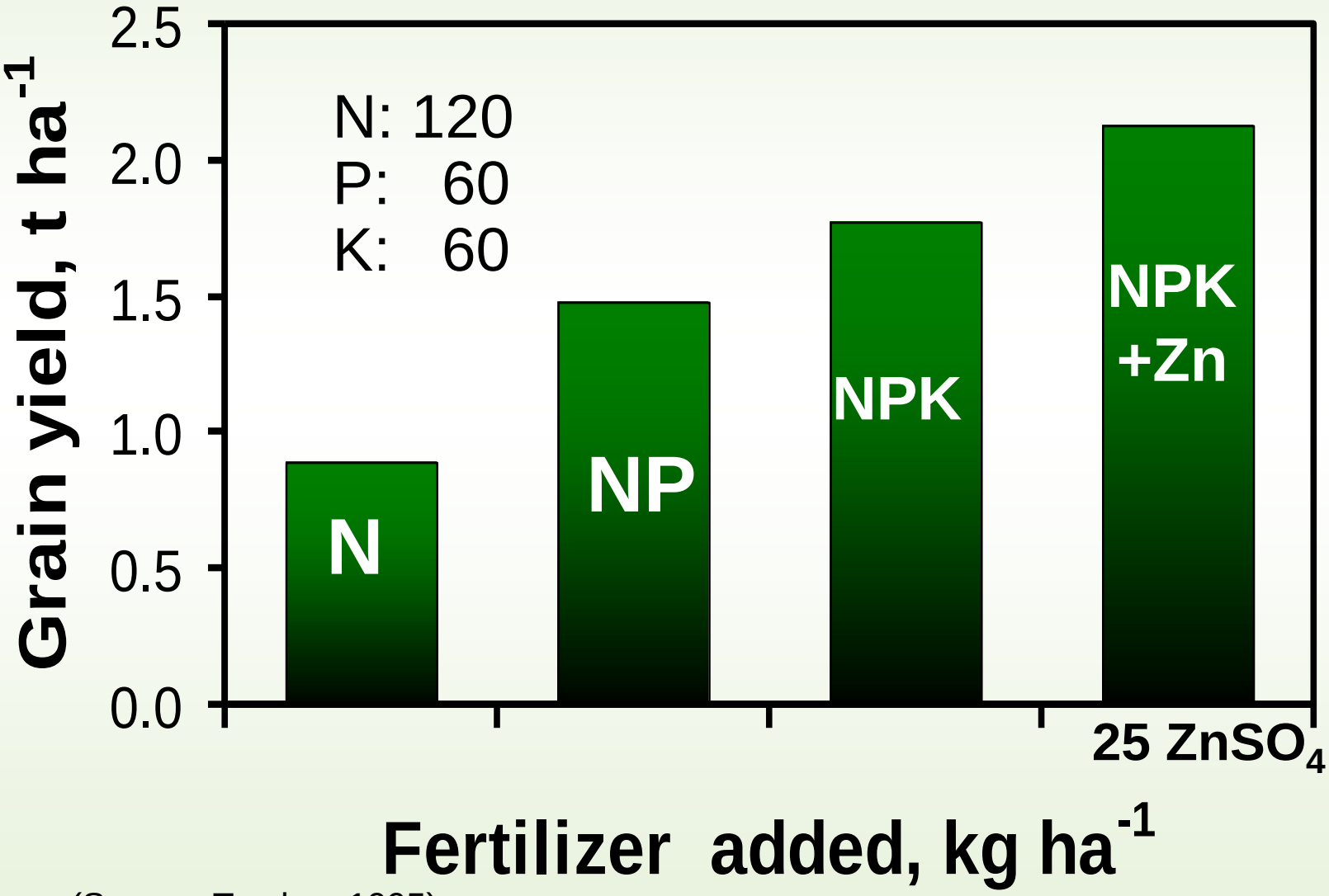
# Micronutrient Deficiencies in Indian Soils

## Nearly 50% of Indian soils are Zn-deficient

| Area | Number of samples | Percentage of soils deficient | | | |
|---|---|---|---|---|---|
| | | Zn | Cu | Fe | Mn |
| East | 54,061 | 47.3 | 1.4 | 0.4 | 4.9 |
| North | 64,906 | 51.2 | 1.3 | 12.8 | 3.1 |
| South | 68,863 | 59.9 | 5.1 | 21.6 | 9.6 |
| West | 63,717 | 34.7 | 19.4 | 7.6 | 2.4 |
| **All India** | **251,547** | **48.6** | **7.0** | **11.2** | **5.1** |

(Takkar, 1996; Singh, 2007)

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




(Source: Tandon, 1995)

# Plants are highly responsive to Zn applications in India

In Zn fertilizer trials conducted on 5,800 fields in India, it has been found that in the 63% of the trials crops responded to Zn fertilization with yield increases

Singh, 2007, In: Alloway BJ (ed.) Micronutrient Deficiencies in Global Crop Production. Springer, pp 93-125.

# Two Important Challenges:

- **Improve density of zinc in edible parts of food crops**

- **Improve Zn nutritional status of crop plants to increase yield**

# Solutions to Zinc Deficiency in Human Beings



- Supplementation
- Food Fortification

**(Expensive approaches)**







# Costs of Interventions to Reduce Micronutrient Malnutrition

- **Fortification plus Supplements (recurrent costs) more than $1 billion per year**
- **5% annual loss in GDP in South Asia…**

HarvestPlus
Breeding Crops for Better Nutrition

www.harvestplus.org

# Rapid and Sustainable Solution

## Agricultural Strategies
(Breeding and Fertilizer Approaches)

### Application of Zinc Fertilizers:
(Agronomic Biofortification)








HarvestPlus
Breeding Crops for Better Nutrition

# HarvestPlus- Biofortification Challenge Program

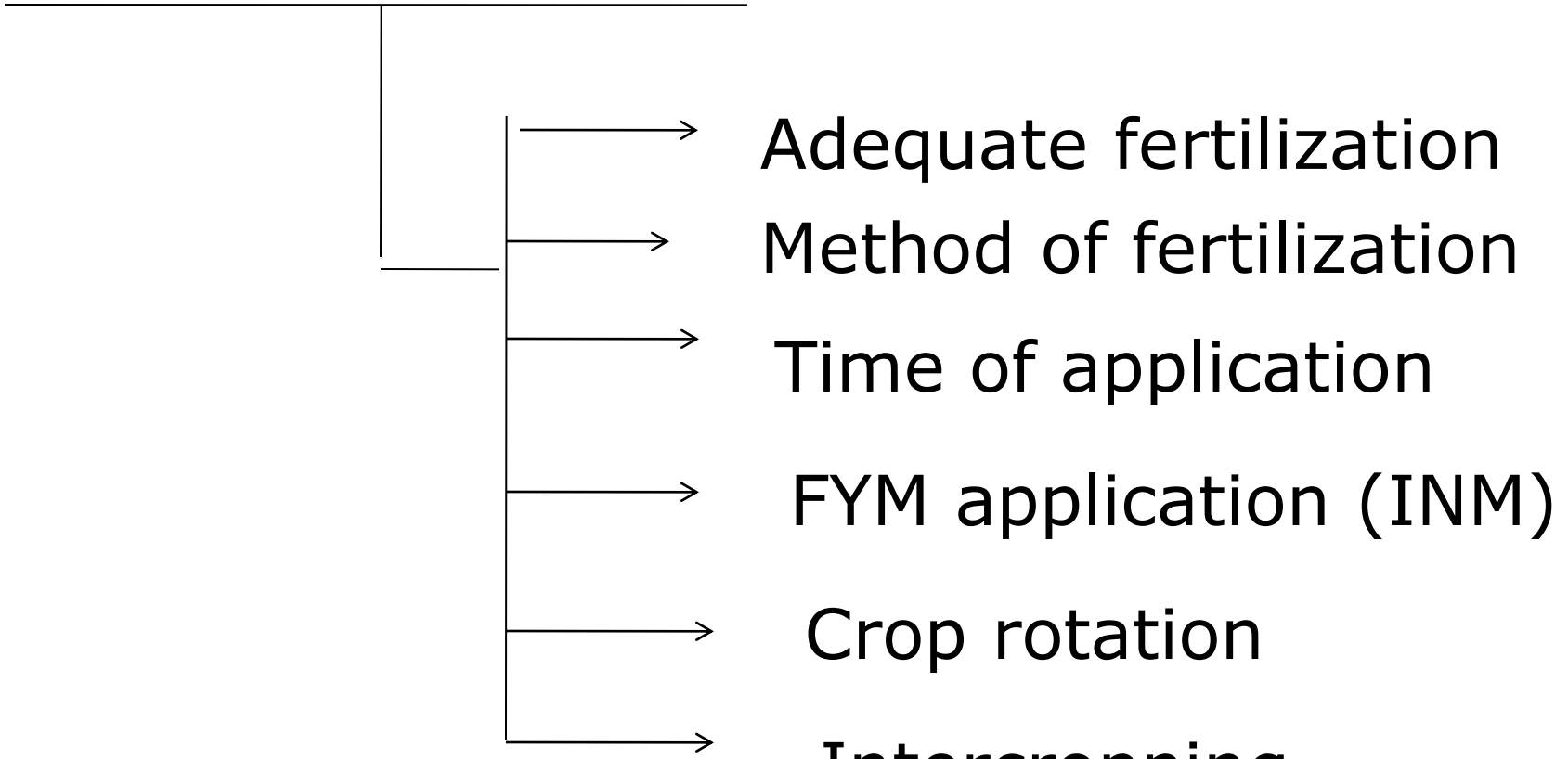
**Breeding** new cereal cultivars with high micronutrient content in cereal grains

**Coordinating Institution:**
International Food Policy Research Institute (IFPRI)
Washington DC

**Main Sponsor:** Gates Foundation

www.harvestplus.org

# Agronomic approaches to bio-fortification




(Rengel *et al*., 1999)

# Agronomic Biofortification

## (Application of Zinc-Containing Fertilizers)



# Case Study: **NATO-Zinc Project**

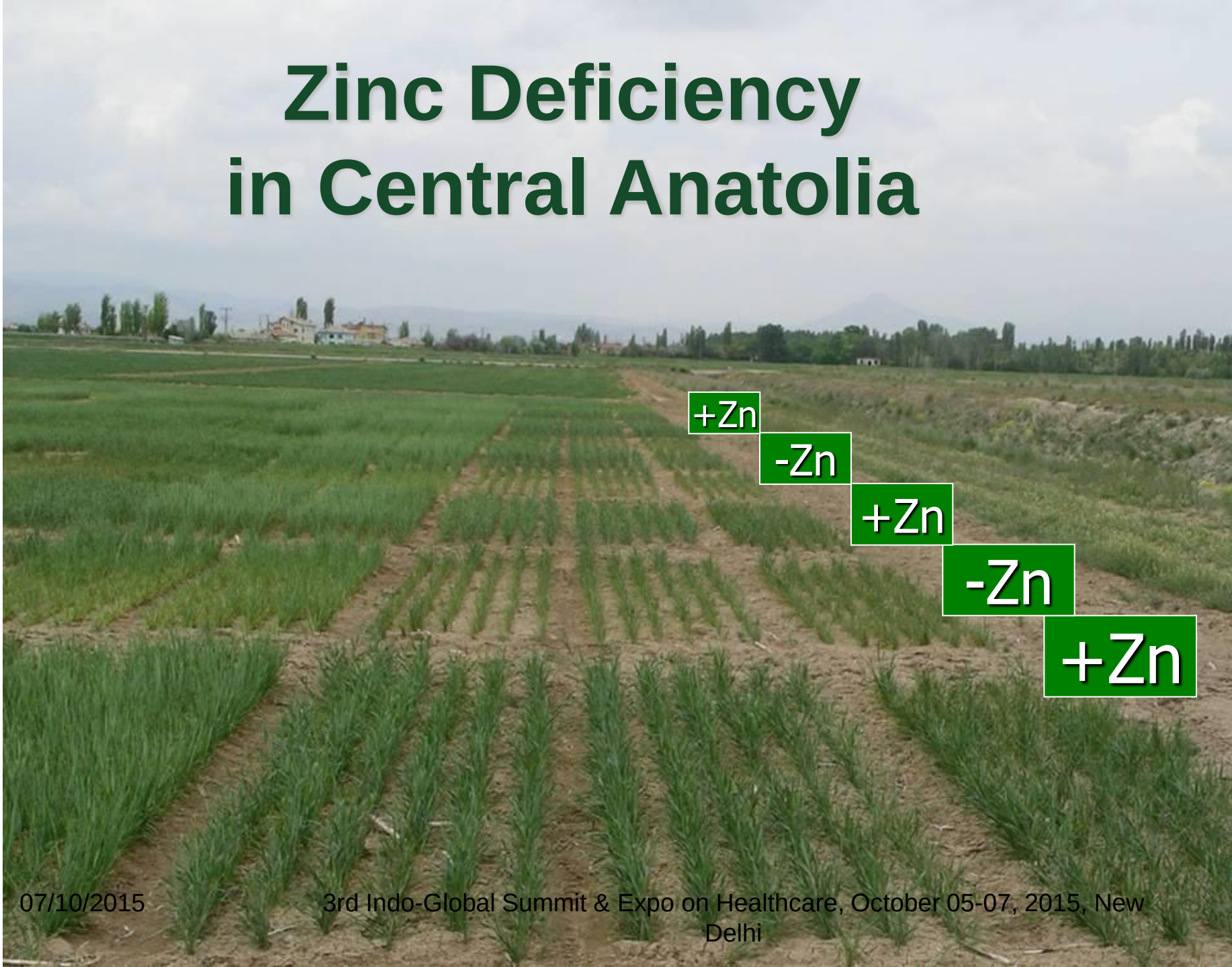



-Zn

+Zn


NATO-SFS PROJESİ
"TU-GENOTYPES"
+Zn
-Zn
+Zn
-Zn

# Zinc Deficiency in Central Anatolia




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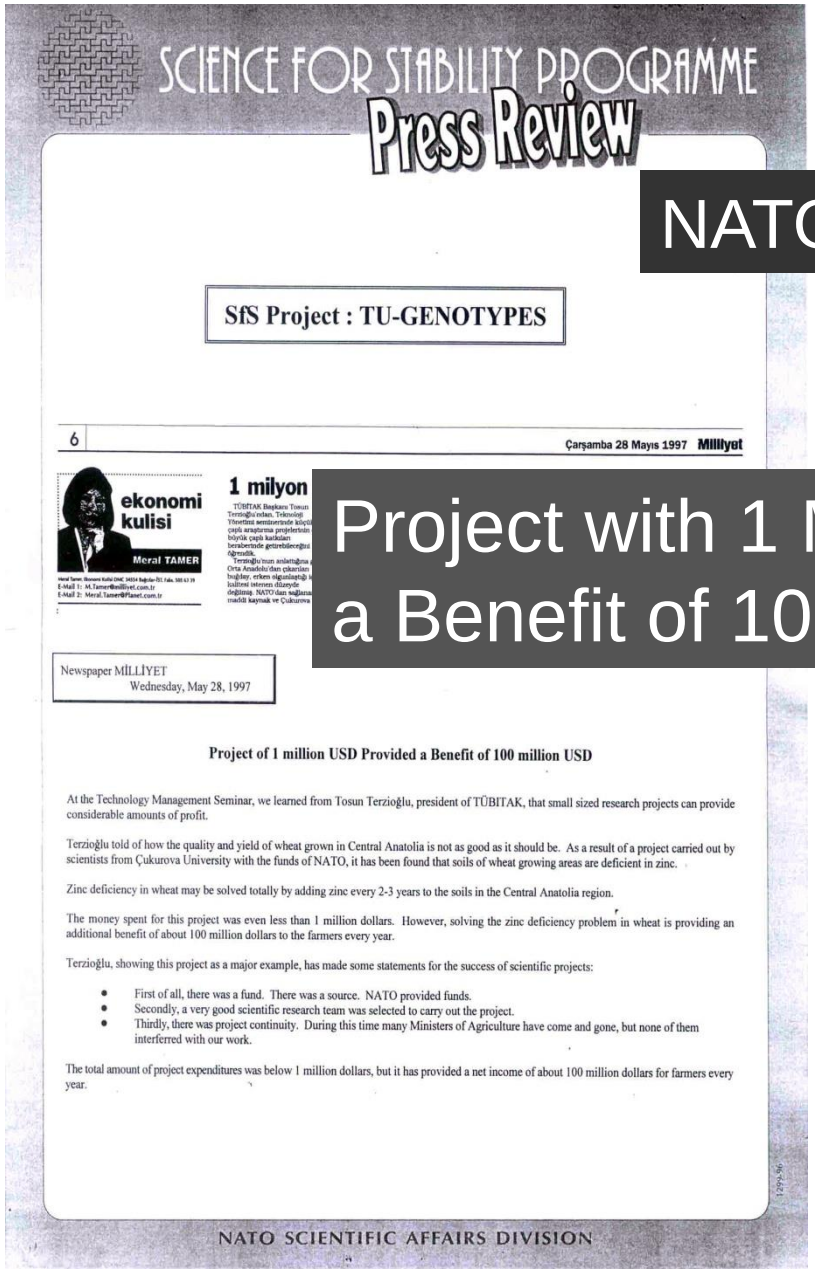
# Foliar Application of Zn on Barley Field

(Published as cover picture in "*Plant and Soil*" Journal;
Cakmak et al.,1996, Plant and Soil)

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




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



SCIENCE FOR STABILITY PROGRAMME

Press Review

SfS Project : TU-GENOTYPES

6 Çarşamba 28 Mayıs 1997 Milliyet

ekonomi kulisi

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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.

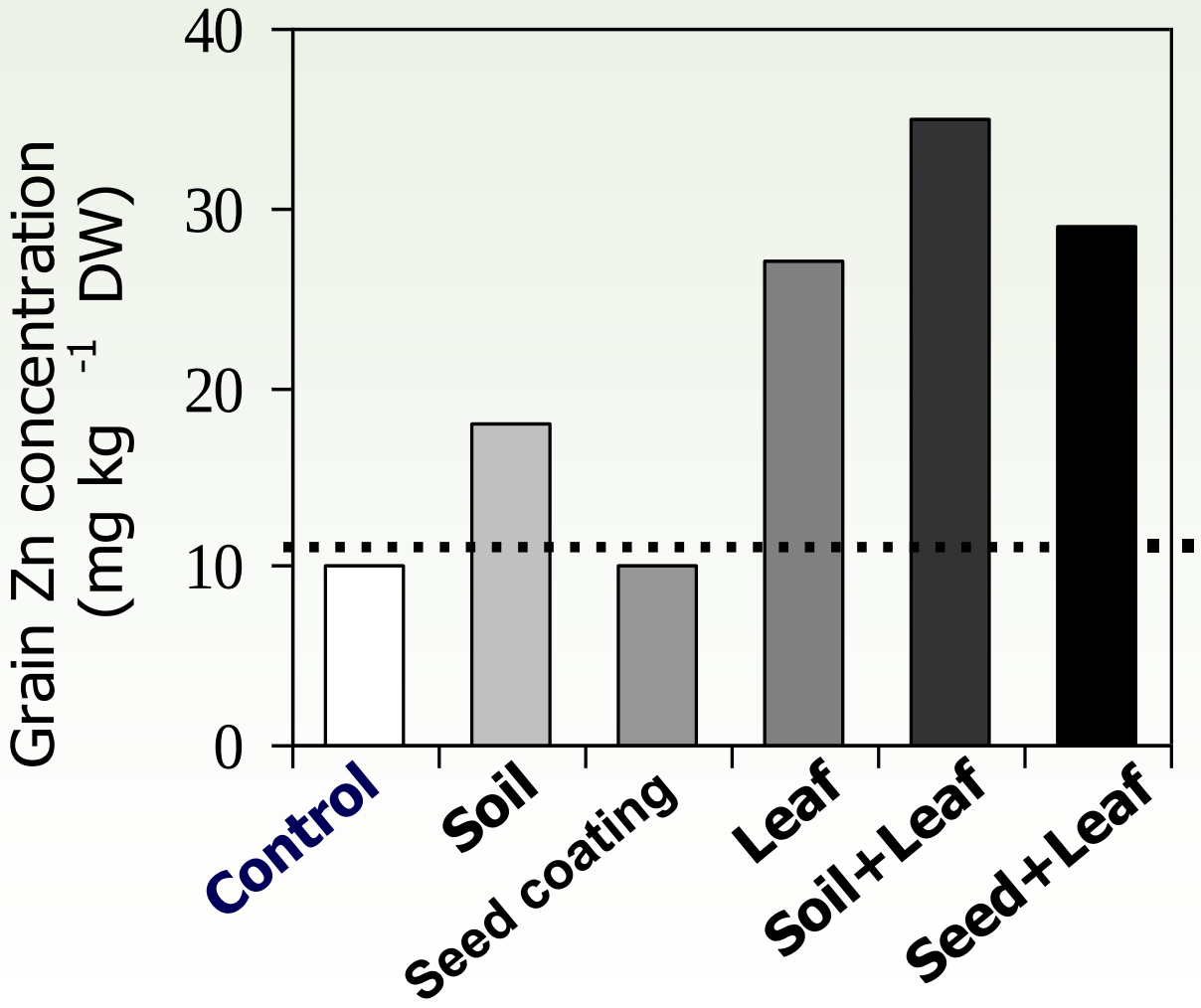
The total amount of project expenditures was below 1 million dollars, but it has provided a net income of about 100 million dollars for farmers every year.

NATO SCIENTIFIC AFFAIRS DIVISION

# NATO-SFS Press Review

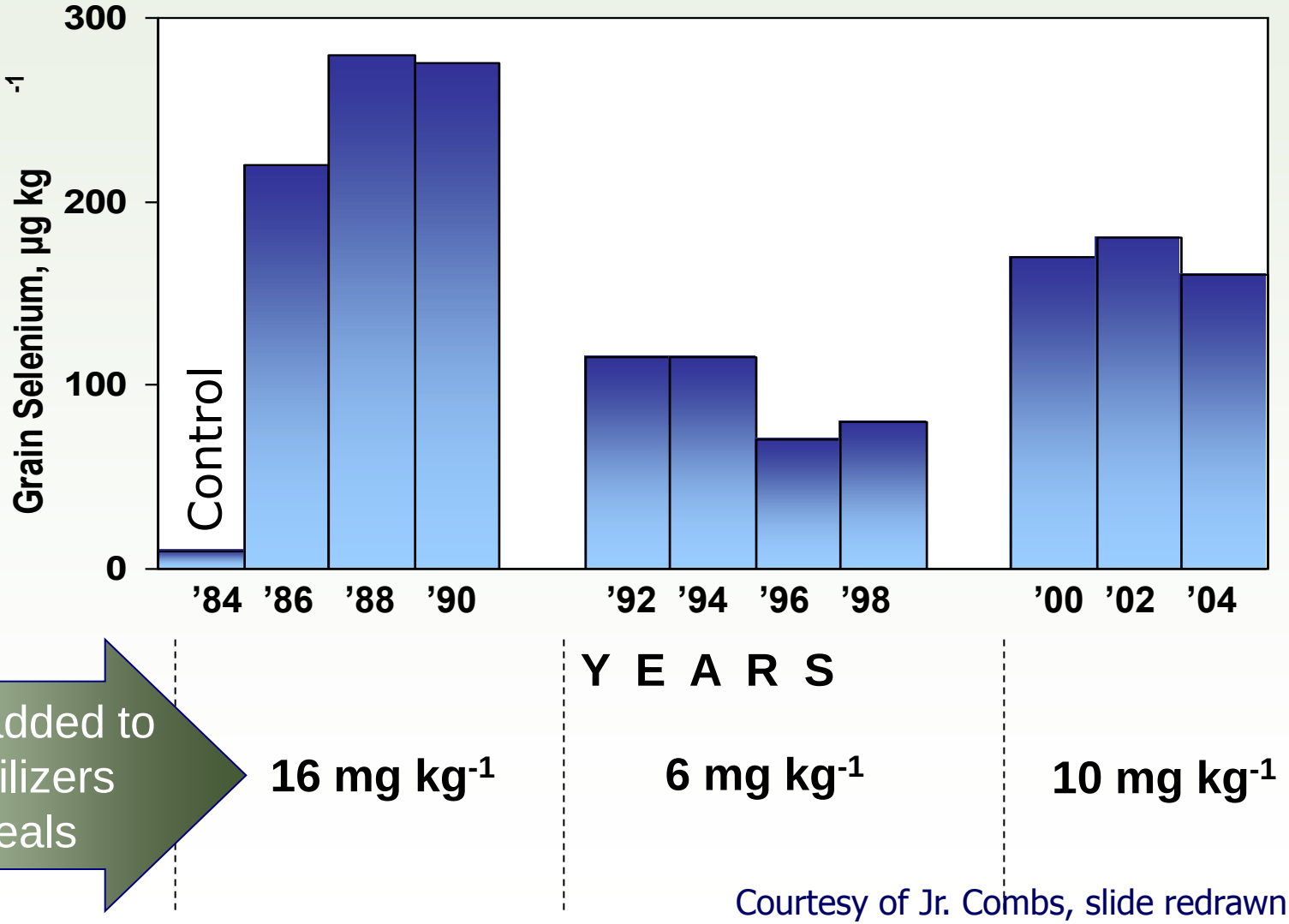
# Project with 1 Million USD Provided a Benefit of 100 Million USD

# Zinc Application in Central Anatolia increases grain Zn concentration up to 3-fold.




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

# Similar Approach in Finland:
## Enrichment Fertilizers with Se Increased **Grain Se** and Contributed to Human Health




Courtesy of Jr. Combs, slide redrawn

# Less Attention Given to Human Nutritional Aspects

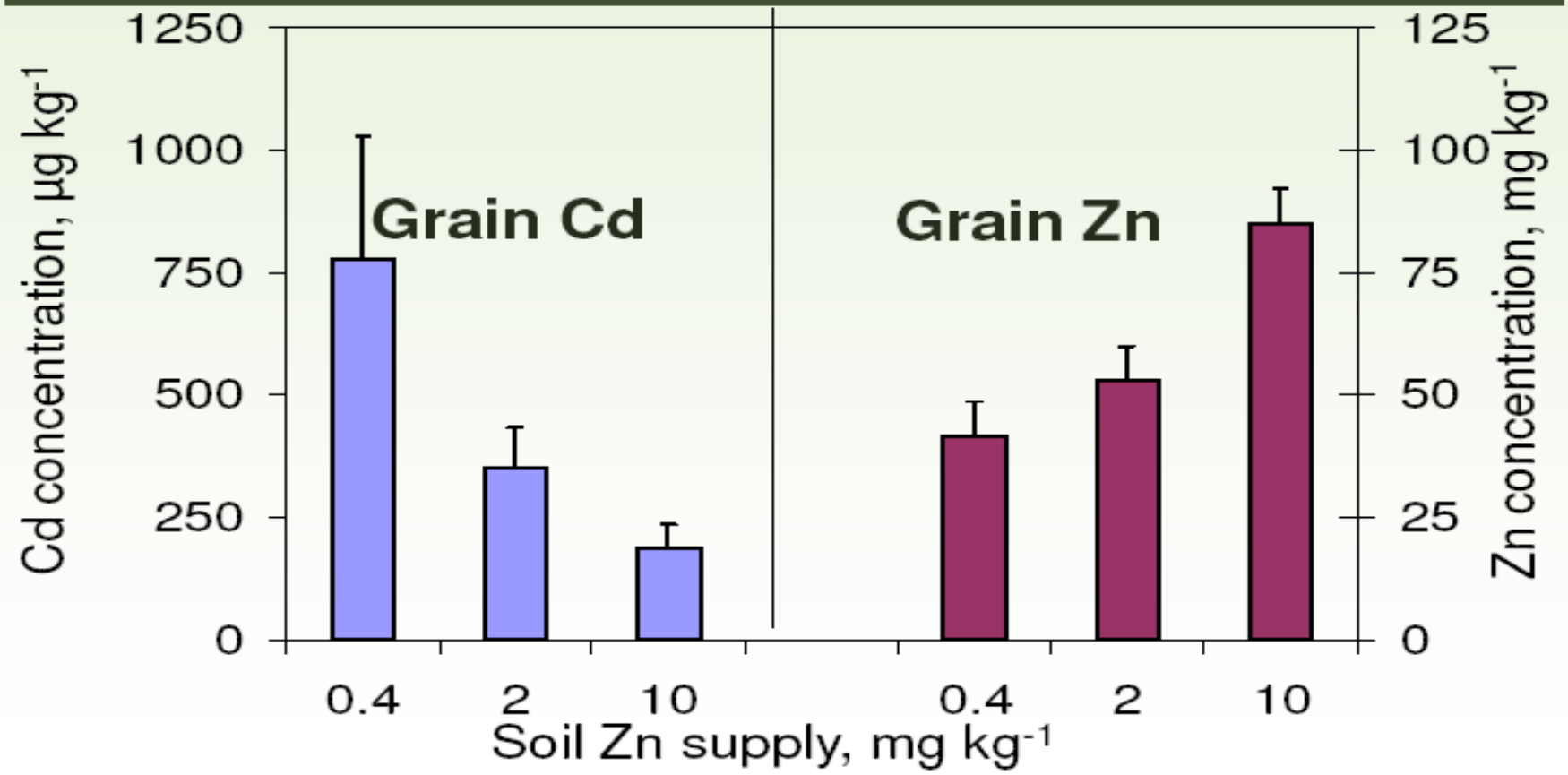
- Nearly all Zn fertilizer field trials conducted globally focused on correction of Zn deficiency problem and improving crop yield;

  **but, very little attention has been paid to Zn concentrations in edible plant parts.**

- Fertilizer-related problems/issues (e.g., fertilizer subsidy) are being discussed mainly in terms of political and economical aspects;

  **but, very rarely in terms of human health aspects**

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




(Ozkutlu *et al.*,2008)

Exposure levels of 30–50 µg Cd/d for an adult could increase the risk of bone fracture, cancer, kidney dysfunction, and hypertension (Satarug et al. 2003)

# Effect of Zn-enriched urea (ZEU)

## on grain yield and grain Zn concentrations of aromatic rice, and economics of use of Zn-enriched urea

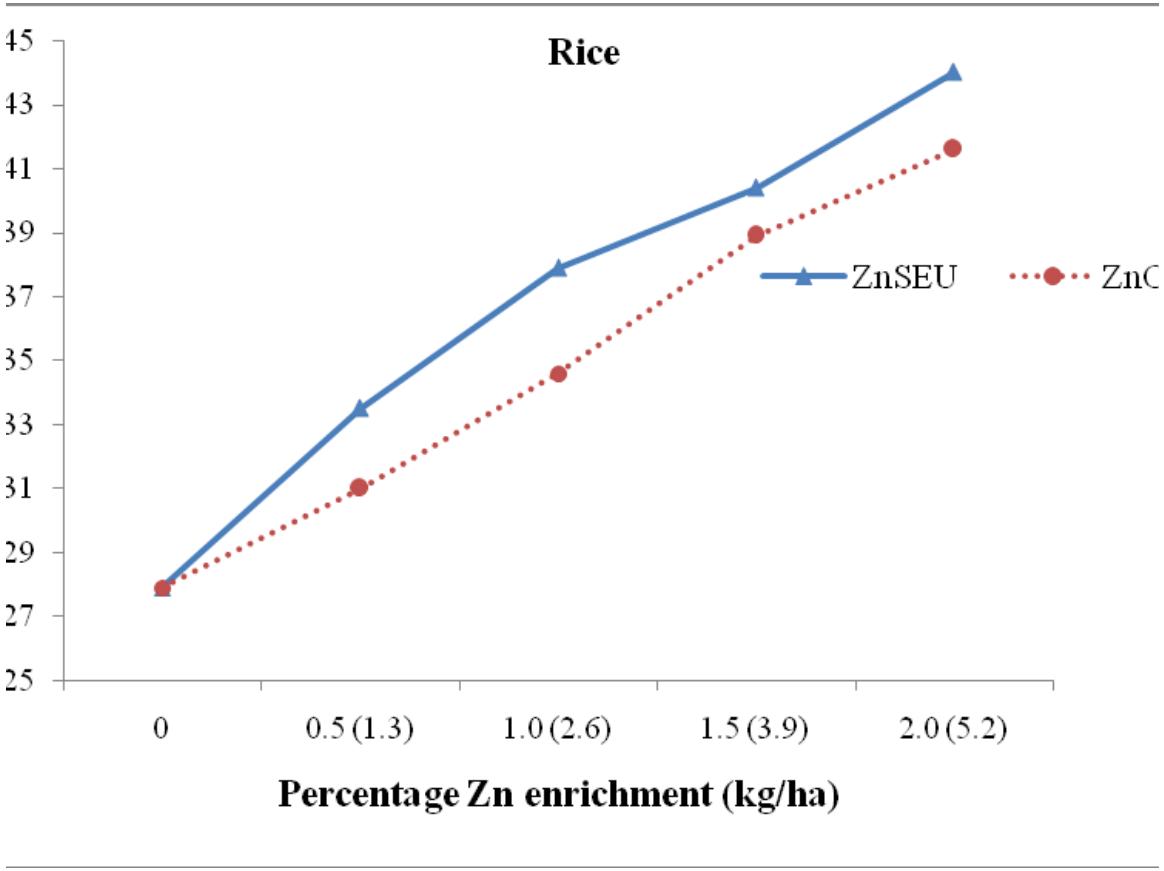
| Treatments | Zn Added | Grain Yield | Zn Concentration | Benefit | Benefit:Cost Ratio |
|---|---|---|---|---|---|
| | (kg $ha^{-1}$) | (ton $ha^{-1}$) | (mg $kg^{-1}$ DW) | (USD $ha^{-1}$) | |
| Prilled Urea | - | 3.87 | 27 | - | - |
| 0.5% ZEU | 1.3 | 4.23 | 29 | 95 | 96 |
| 1.0% ZEU | 2.6 | 4.39 | 33 | 152 | 77 |
| 2.0% ZEU | 5.2 | 4.60 | 39 | 216 | 55 |
| 3.0% ZEU | 7.8 | 4.76 | 42 | 266 | 45 |

Shivay et al. (2008) Nutr Cycl Agroecosyst

# 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. (2008) Nutr Cycl Agroecosyst




Grain Zn concentration in rice due to degree of Zn enrichment of urea. Solid lines for Zn sulphate (ZnSEU) and dotted lines for Zn oxide (ZnOEU) enriched urea

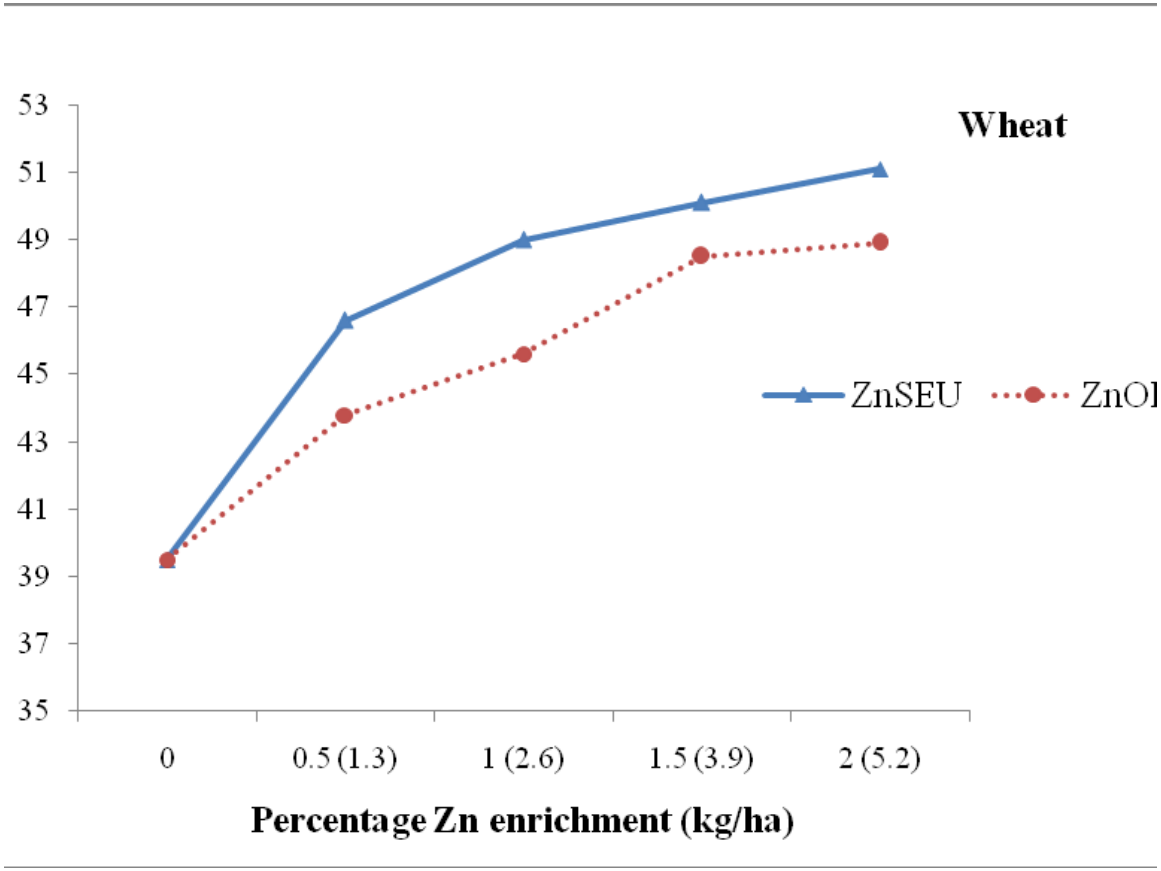
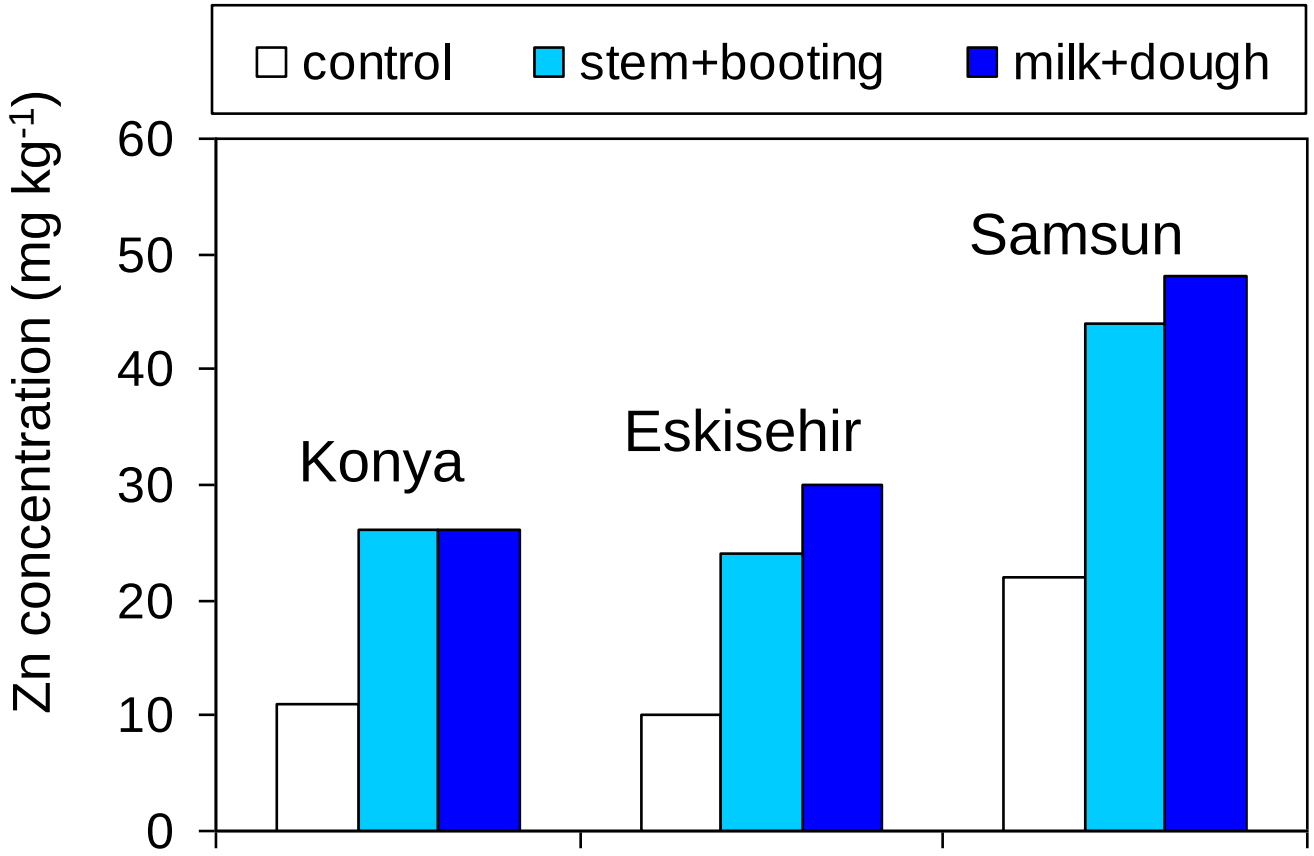



**Figure:** Grain Zn concentration in wheat due to degree of Zn enrichment of urea. Solid lines for Zn sulphate (ZnSEU) and dotted lines for Zn oxide (ZnOEU) enriched urea

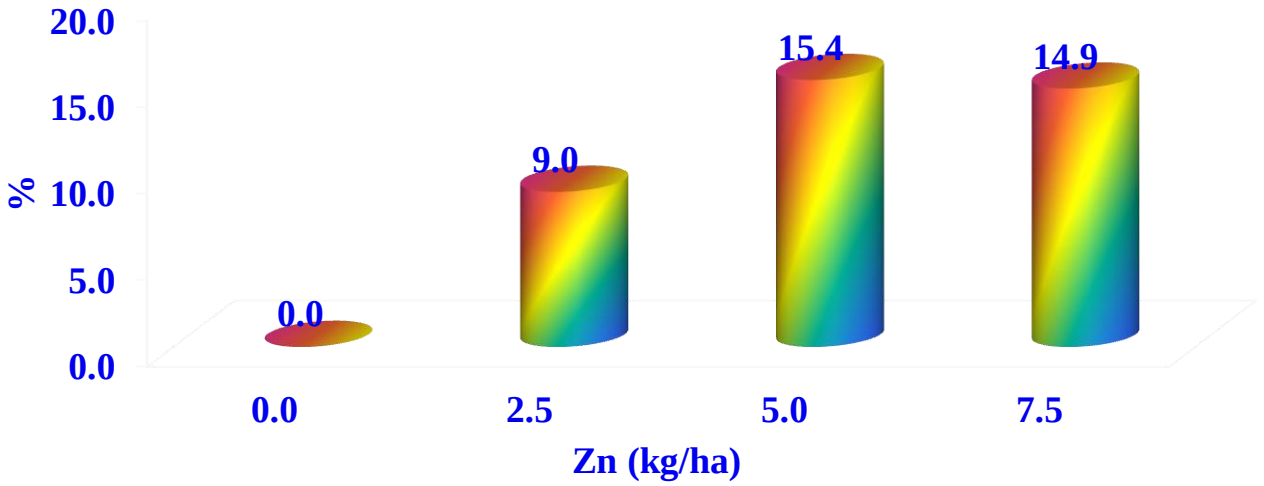
# Effect of foliar Zn application at 2 different growth stages on grain Zn concentration in 3 locations

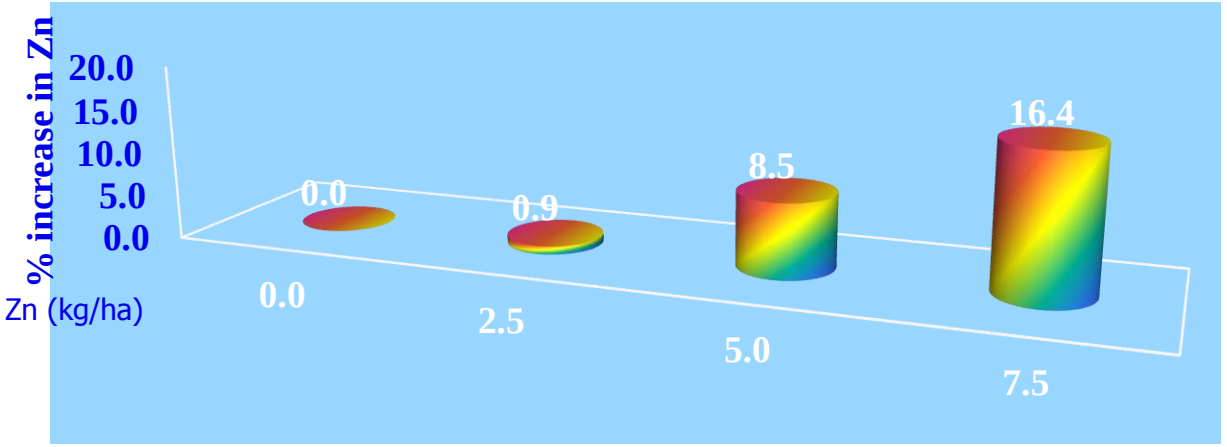



**Konya**: Zn-deficient location
**Eskisehir**: Zn-deficient location
**Samsun**: Zn-adequate location

(Cakmak, 2008: Plant Soil)

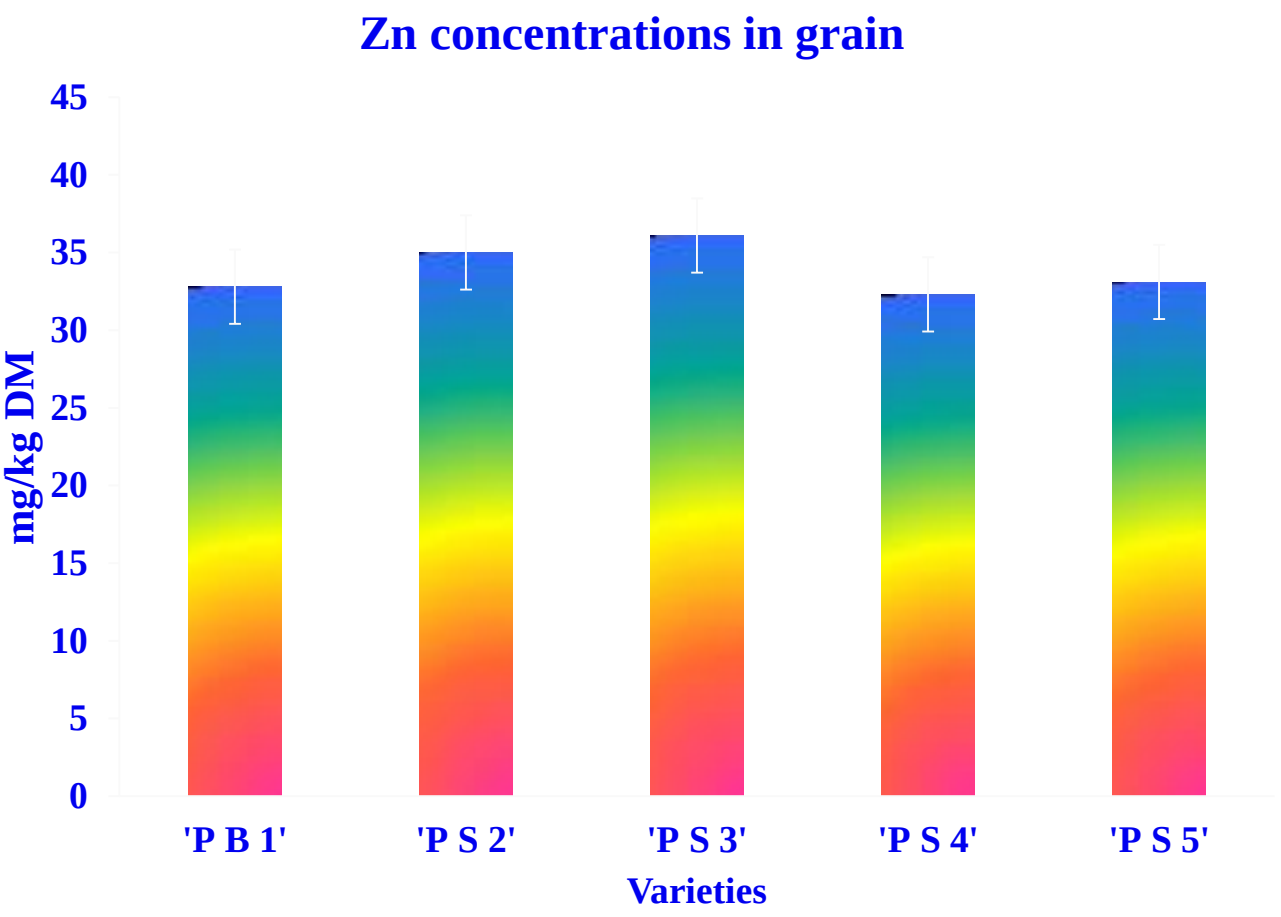
# Effect of Zn levels on percent increase in grain yields and Zn concentration in aromatic rices (means of 2 years)




(Shivay *et al*., 2008)

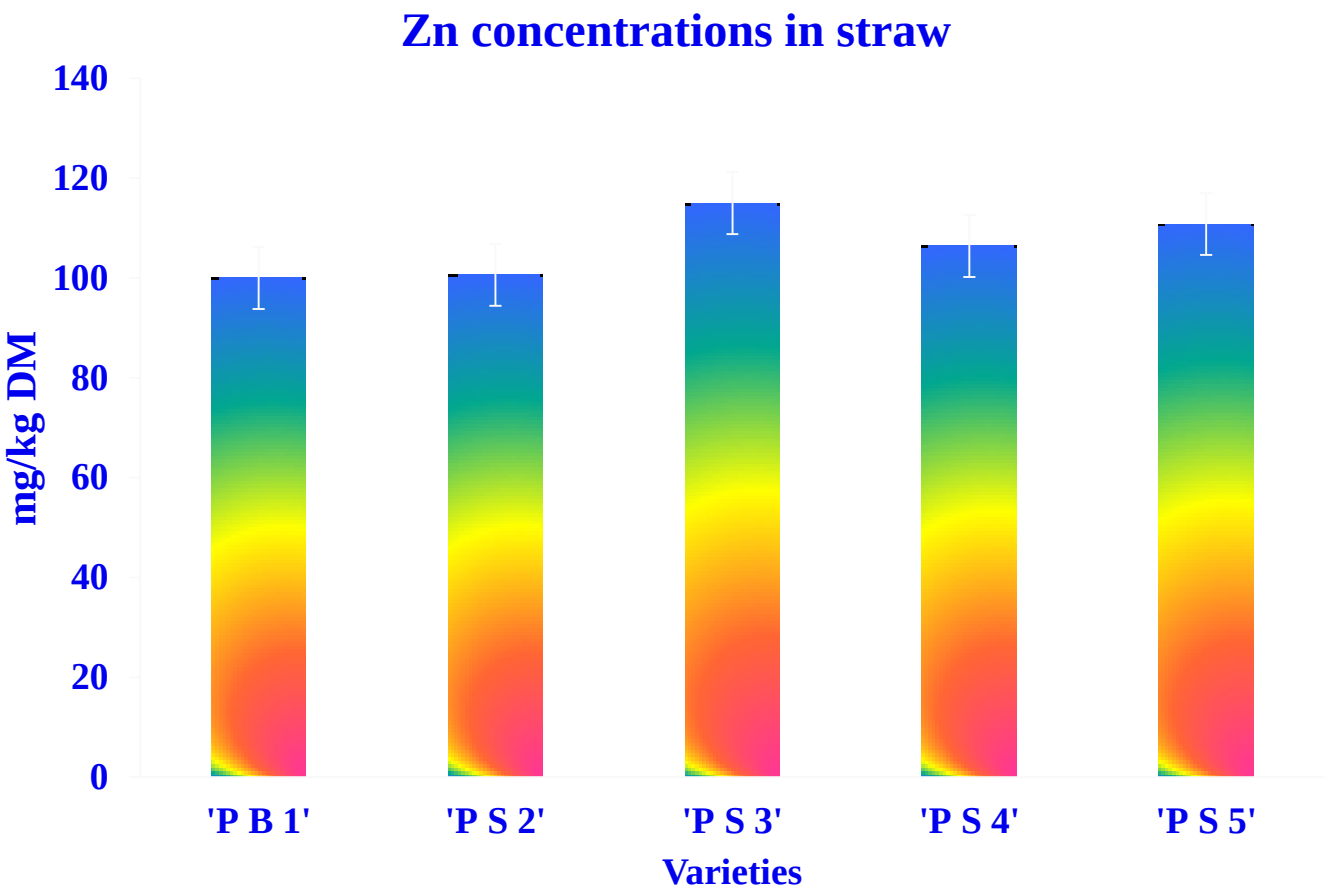
# Effect of variety on Zn concentrations in rice grain of aromatic rices (means of 2 years)




(Shivay *et al*., 2008)

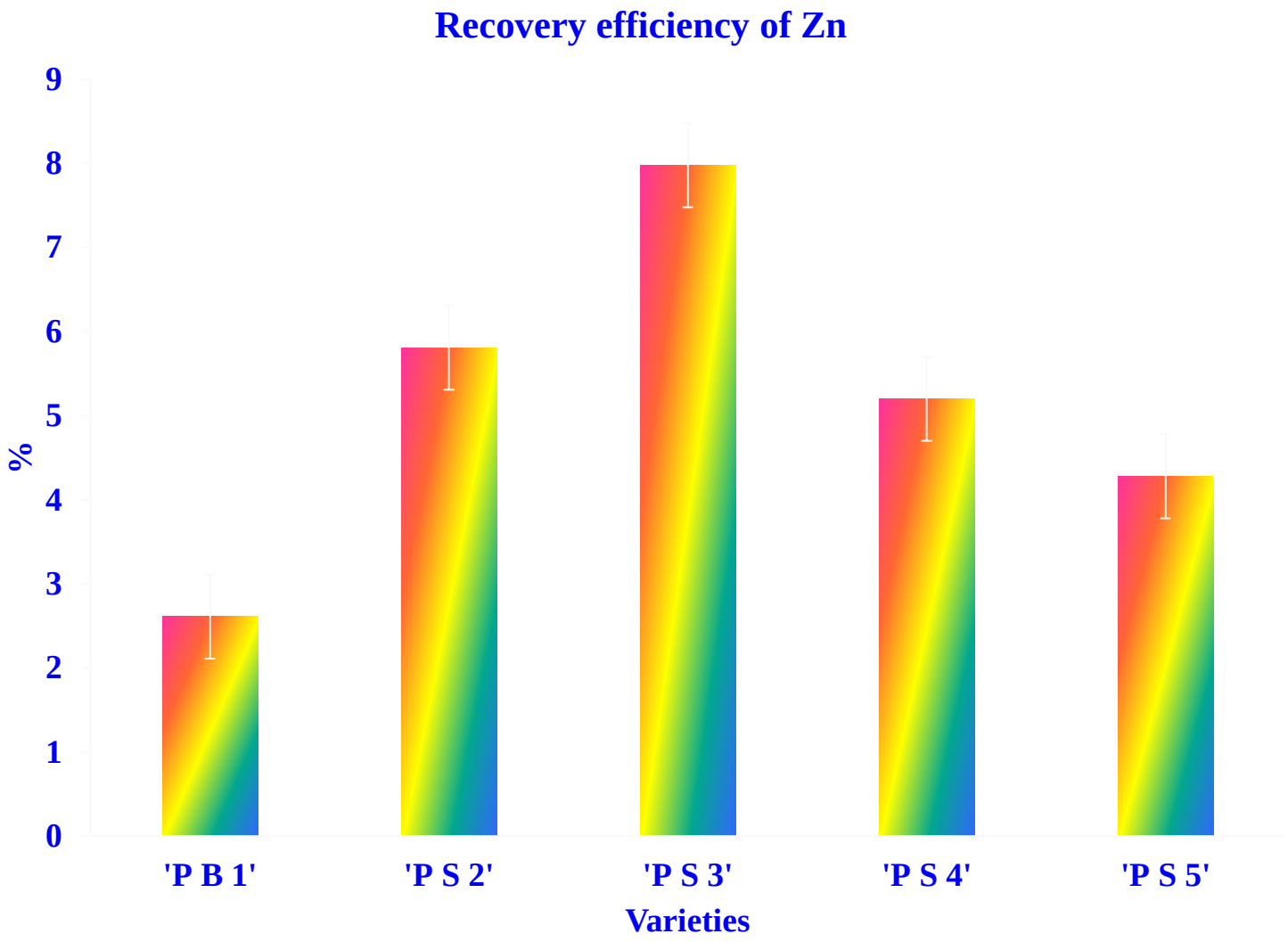
# Effect of variety on Zn concentrations in straw of aromatic rices (means of 2 years)





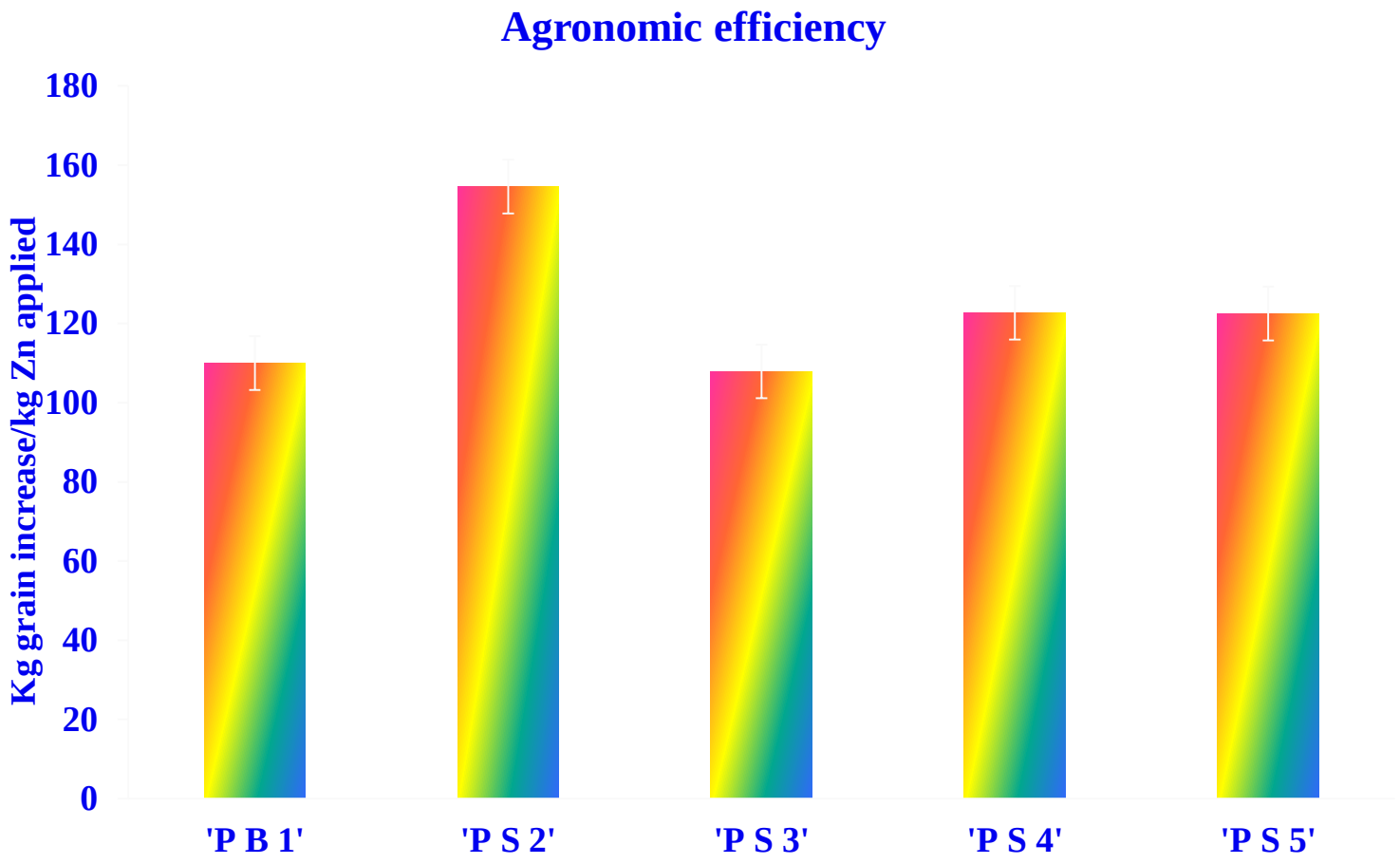

(Shivay *et al*., 2008)

# Effect of variety on Zn recovery in aromatic rices (means of 2 years)



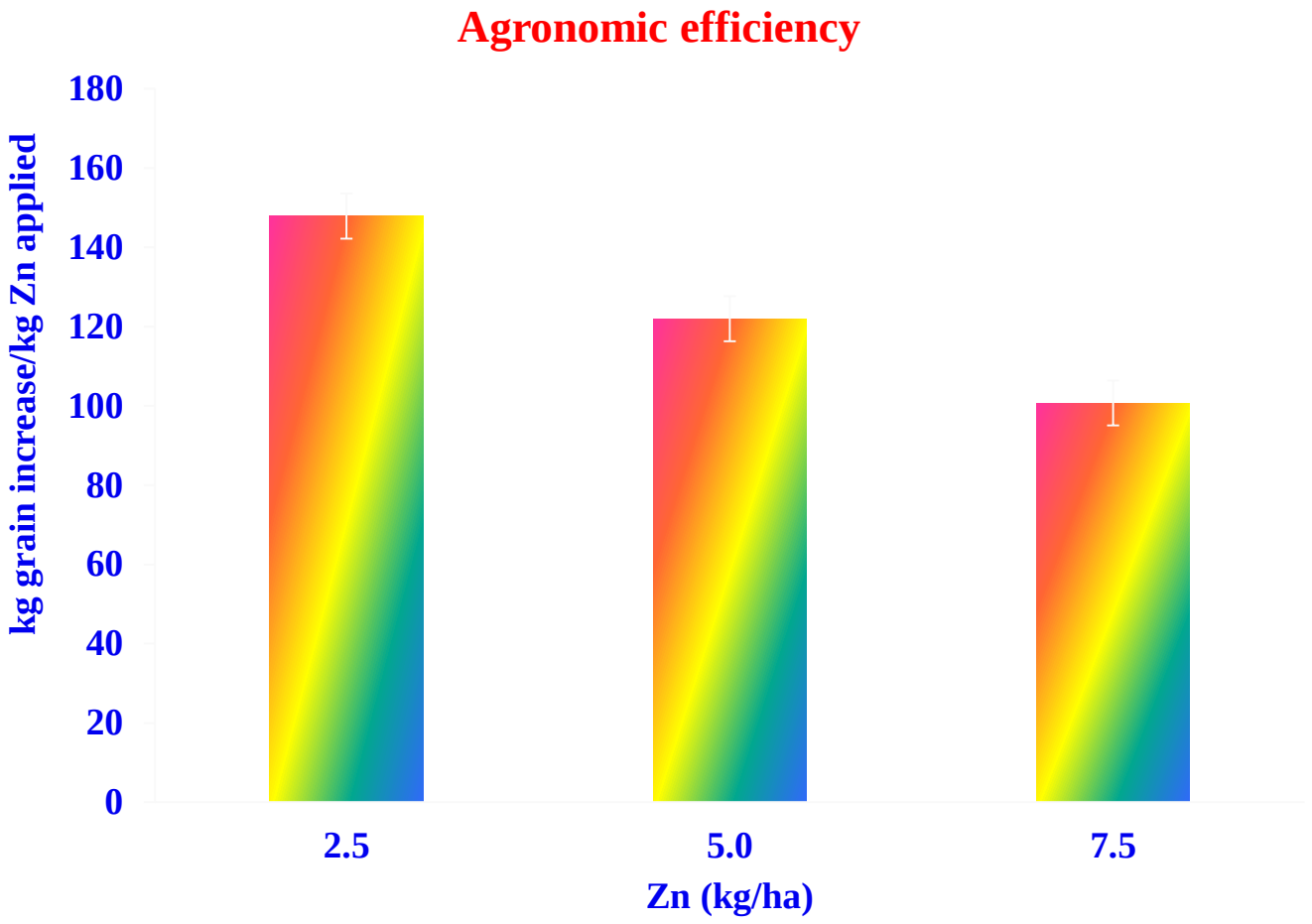

(Shivay *et al*., 2008)

# Effect of variety on agronomic efficiency of Zn in aromatic rices (means of 2 years)




(Shivay *et al*., 2008)

# Effect of rate of Zn application on agronomic efficiency in aromatic rices (means of 2 years)




(Shivay *et al*., 2008)

# Effect of Zn-enriched urea on zinc concentration in wheat grain and straw (mean over 2 years)

| Treatments | Zn added (kg $ha^{-1}$) | Zn concentration (mg $kg^{-1}$ DM) | |
|---|---|---|---|
| | | Grain | Straw |
| Prilled urea alone (no Zn) | 0 | 39.5 | 29.9 |
| 0.5% Zn (ZnO)-enriched urea | 0.65 | 43.8 | 32.1 |
| 0.5% Zn ($ZnSO_4$)-enriched urea | 0.65 | 46.7 | 34.4 |
| 1.0% Zn (ZnO)-enriched urea | 1.30 | 45.6 | 33.6 |
| 1.0% Zn ($ZnSO_4$)-enriched urea | 1.30 | 49.0 | 37.2 |
| 1.5% Zn (ZnO)-enriched urea | 1.95 | 48.5 | 33.9 |
| 1.5% Zn ($ZnSO_4$)-enriched urea | 1.95 | 50.1 | 38.3 |
| 2.0% Zn (ZnO)-enriched urea | 2.60 | 48.9 | 37.1 |
| **2.0% Zn ($ZnSO_4$)-enriched urea** | **2.60** | **51.1** | **39.4** |
| SEm± | - | 0.93 | 0.62 |
| LSD (*P*=0.05) | - | 2.80 | 1.85 |

(Shivay *et al*., 2008)

# Effect of Zn-enriched urea on Zn agronomic efficiency and apparent crop recovery of applied Zn on wheat (mean over 2 years)

| Treatments | Zn added (kg $ha^{-1}$) | Recovery efficiency (%) | Agronomic efficiency (kg grain increase $kg^{-1}$Zn) |
|---|---|---|---|
| Prilled urea alone (no Zn) | 0 | - | - |
| 0.5% Zn (ZnO)-enriched urea | 0.65 | 6.77 | 268.1 |
| 0.5% Zn ($ZnSO_4$)-enriched urea | 0.65 | **11.5** | **474.3** |
| 1.0% Zn (ZnO)-enriched urea | 1.30 | 5.47 | 355.6 |
| 1.0% Zn ($ZnSO_4$)-enriched urea | 1.30 | 8.80 | 408.9 |
| 1.5% Zn (ZnO)-enriched urea | 1.95 | 4.87 | 296.3 |
| 1.5% Zn ($ZnSO_4$)-enriched urea | 1.95 | 6.93 | 333.4 |
| 2.0% Zn (ZnO)-enriched urea | 2.60 | **4.83** | **243.4** |
| 2.0% Zn ($ZnSO_4$)-enriched urea | 2.60 | 6.07 | 308.9 |
| SEm± | - | 0.31 | 12.52 |
| LSD (*P*=0.05) | - | 0.95 | 37.98 |

(Shivay *et al.*, 2008)

# Effect of source and method of Zn application on Zn concentration in grain and stover of corn

| Treatment (All values are quantities of Zn $ha^{-1}$) | Zn concentration | |
|---|---|---|
| | Corn grain (mg $kg^{-1}$ grain) | Corn stover (mg $kg^{-1}$ DM) |
| Control (no added Zn) | 40.2 | 45.0 |
| 5 kg to soil | 44.2 | 49.2 |
| 1 kg foliar | 46.0 | 59.2 |
| **5 kg to soil + 1 kg foliar** | **49.2** | **64.5** |
| 2.83 kg through Zn-coated urea (to soil) | 45.8 | 58.2 |
| SEm± | 0.6 | 0.8 |
| LSD (p=0.05) | 2.0 | 2.7 |

**(Shivay and Prasad 2014)**

# Effect of rate, source and method of Zn application on Zn concentration in oats grain

| Treatment | Zn concentration in oats grain (mg $kg^{-1}$ grain) | |
|---|---|---|
| | 2009-10 | 2010-11 |
| Control (no Zn) | 22.0 | 22.5 |
| 2 kg Zn $ha^{-1}$ as ZnSHH*, deep placed at sowing | 25.1 (14.1)** | 25.6 (13.8)** |
| 2 kg Zn $ha^{-1}$ as ZnSHH, broadcast at final ploughing | 23.8 (8.2) | 24.3 (8.0) |
| **2 kg Zn $ha^{-1}$ as ZnSHH (used for coating onto 100 kg seed required for sowing one hectare)** | **32.0 (45.5)** | **32.5 (44.4)** |
| 2 kg Zn $ha^{-1}$ as ZnO deep placed at sowing | 24.7 (12.3) | 25.2 (12.0) |
| 2 kg Zn $ha^{-1}$ as ZnO broadcast at sowing | 22.1 (0.5) | 23.6 (4.9) |
| 2 kg Zn $ha^{-1}$ as ZnO (used for coating onto seed required for sowing one hectare) | 31.6 (43.6) | 32.3 (43.5) |
| 5 kg Zn $ha^{-1}$ as ZnSHH broadcast at sowing | 29.5 (34.1) | 30.3 (34.7) |
| 5 kg Zn $ha^{-1}$ as ZnSHH band placed before first irrigation (25 DAS) | 29.0 (31.8) | 29.5 (31.1) |
| 5 kg Zn $ha^{-1}$ as ZnSHH band placed after first irrigation (40 DAS) | 27.3 (24.1) | 27.8 (23.5) |
| 5 kg Zn $ha^{-1}$ as ZnO broadcast at sowing | 28.6 (30.0) | 29.1 (29.3) |
| 5 kg Zn $ha^{-1}$ as ZnO band placed before first irrigation (25 DAS) | 28.0 (27.3) | 28.4 (26.2) |
| 5 kg Zn $ha^{-1}$ as ZnO band placed after first irrigation (40 DAS) | 26.8 (21.8) | 27.3 (21.3) |
| SEm± | 0.65 | 0.64 |
| LSD (P=0.05) | 1.90 | 1.87 |

***$ZnSO_4.7H_2O$; **Percentage increase over control (no Zn)***

**(Shivay et al. 2013)**

**Effect of variety and zinc levels on grain yield and Zn concentrations in grain & straw of chickpea (Averaged over 2011-12 & 2012-13)**

| Treatment | Grain yield (t/ha) | Zn concentration (mg/kg grain) | Zn concentration (mg/kg straw) |
|---|---|---|---|
| *Varieties* | | | |
| 'Pusa 2024' | 2.11 | 39.9 | 33.3 |
| 'Pusa 5028' | 1.99 | 42.8 | 35.9 |
| 'Pusa 372' | 2.13 | 42.9 | 36.8 |
| SEm± | 0.007 | 0.063 | 0.089 |
| CD (P=0.05) | 0.020 | 0.244 | 0.352 |
| *Zinc levels (kg/ha)* | | | |
| 0 | 1.89 | 36.1 | 29.5 |
| 2.5 | 2.02 | 40.6 | 33.5 |
| 5.0 | 2.15 | 43.6 | 37.1 |
| 7.5 | 2.24 | 47.2 | 41.2 |
| SEm± | 0.038 | 0.54 | 0.53 |
| CD (P=0.05) | 0.147 | 1.61 | 1.51 |

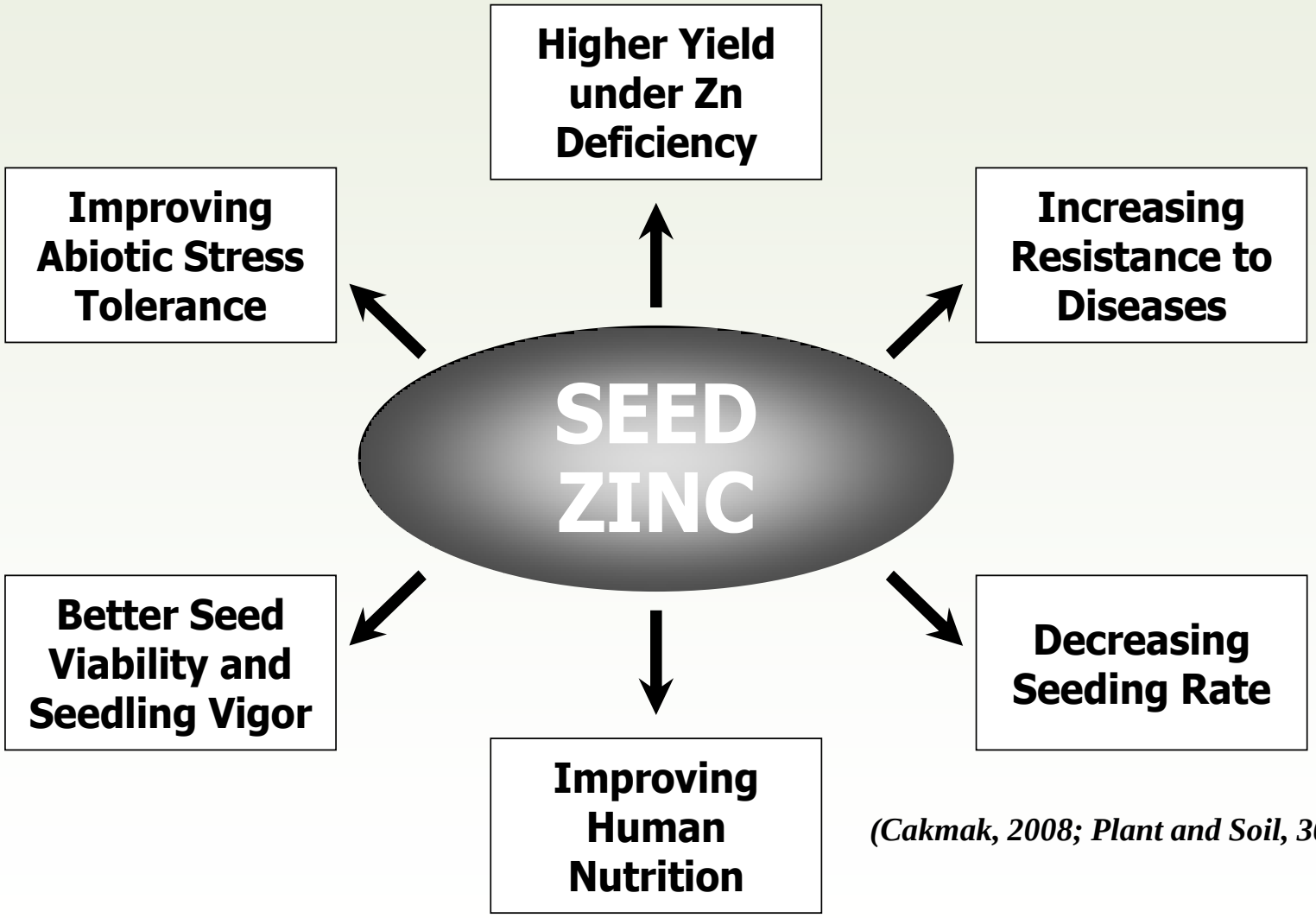
**(Shivay et al. 2014)**

**Effect of variety and zinc levels on protein concentration in chickpea grains and partial factor productivity of applied NPK (Averaged over 2011-12 & 2012-13)**

| Treatment | Protein content (%) | Partial factor productivity of applied NPK (kg grain/kg applied NPK) |
|---|---|---|
| *Varieties* | | |
| 'Pusa 2024' | 19.9 | 25.0 |
| 'Pusa 5028' | 22.7 | 23.6 |
| 'Pusa 372' | 22.6 | 25.2 |
| SEm± | 0.03 | 0.08 |
| CD (P=0.05) | 0.14 | 0.31 |
| *Zinc levels (kg/ha)* | | |
| 0 | 20.7 | 22.3 |
| 2.5 | 21.5 | 24.0 |
| 5.0 | 22.0 | 25.5 |
| 7.5 | 22.6 | 26.6 |
| SEm± | 0.09 | 0.46 |
| CD (P=0.05) | 0.26 | 1.36 |

**(Shivay et al. 2014)**

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




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

# Conclusions

- Application of Zn-containing fertilizers represents a quick and useful solution to biofortification of cereal grains with Zn;
- There is an urgent need for adoption of a new fertilizer policy to encourage and promote production and application of Zn-enriched fertilizers in India;
- Government should provide encouragement to the farmers to apply Zn-enriched fertilizers;
- **Fortification of fertilizers with Zn would be an excellent investment for humanity and for crop production in India (like in Turkey for Zn and in Scandinavian Countries for Se)**

# Enrichment of cereal grains with Zn results in huge benefits for human health

Based on the calculations made by Stein et al. (2007), biofortification (enrichment) of rice and wheat grain with Zn may prevent deaths of up to 48,000 children in India annually.

**(Stein et al., 2007, Pub Health Nutr 10:492-501)**

# Focus on *better* food, not only *more* food

**The expected rewards are high…**

# Thank you....





