

**73<sup>rd</sup> IFA ANNUAL CONFERENCE**  
**Kuala Lumpur, Malaysia, 6-8 June 2005**

**IDENTIFICATION AND CORRECTION OF  
WIDESPREAD ZINC DEFICIENCY PROBLEM  
IN CENTRAL ANATOLIA, TURKEY**

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**“Identification and correction of widespread zinc deficiency problem  
in Central Anatolia, Turkey”**

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**Abstract**

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Previously, wheat grown in different parts of the Central Anatolia region in Turkey was low yielding and often showed chlorotic and necrotic patches on leaves. The reason for such growth disorders in wheat was not clear over many years. The role of zinc (Zn) deficiency in development of these disorders in wheat has received attention only since the early 1990s. In order to identify the importance of Zn deficiency on wheat growth in Central Anatolia, a long-term and multi-institutional project was prepared and submitted to the NATO-Science for Stability programme; the project was approved in 1993. In the present study the results obtained in the framework of this project, and also from other projects that followed, have been summarized.

Field experiments at different locations and field survey studies with extensive soil and plant sampling showed the existence of a very widespread Zn deficiency problem in the region. There were very significant increases in grain yield in response to Zn applications on different locations. In certain areas ( $DTPA-Zn \leq 0.1$  mg kg<sup>-1</sup> soil) dramatic increases were found in grain yield. In such areas, where cereal production was not previously economical, and yield was extremely low (0.25 ton ha<sup>-1</sup>), applying Zn increased grain yield up to 6- to 8-fold. The effects of Zn fertilizers on plant growth and yield became more pronounced under rainfed conditions. Plants grown on Zn-treated soils or derived from seeds with very high Zn concentrations showed much better seedling establishment and higher tolerance to environmental stress factors (“winter killing”). Soil or foliar Zn application also improved grain quality by increasing grain Zn concentration and reducing phytic acid, a compound involved in the impairment of Zn bioavailability in humans.

Such impressive improvements in plant growth and grain yield elicited a big interest in the project results amongst farmers and fertilizer industries, and in 1995, the first Zn-containing compound fertilizers were produced and tested in farmer’s fields in Anatolia. The results were so positive that fertilizer industries in Turkey, particularly TOROS Fertilizer and Chemical Industry produced increasing amounts of NP and NPK fertilizers containing 1 % Zn. Today, nearly 10 years after the Zn deficiency problem was diagnosed as a critical constraint to wheat production in Central Anatolia, the total amount of Zn-containing compound fertilizers produced and applied in Turkey reached a record level of 300 000 tonnes per annum. It is estimated that annual economic benefits associated with application of Zn-fertilizers on Zn-deficient soils in Turkey is around 100 million USD. Since Zn deficiency is also an important human micronutrient deficiency in Turkey, increases in grain Zn concentration should contribute significantly to the health and nutrition of large numbers of Turkish people.

## **Introduction**

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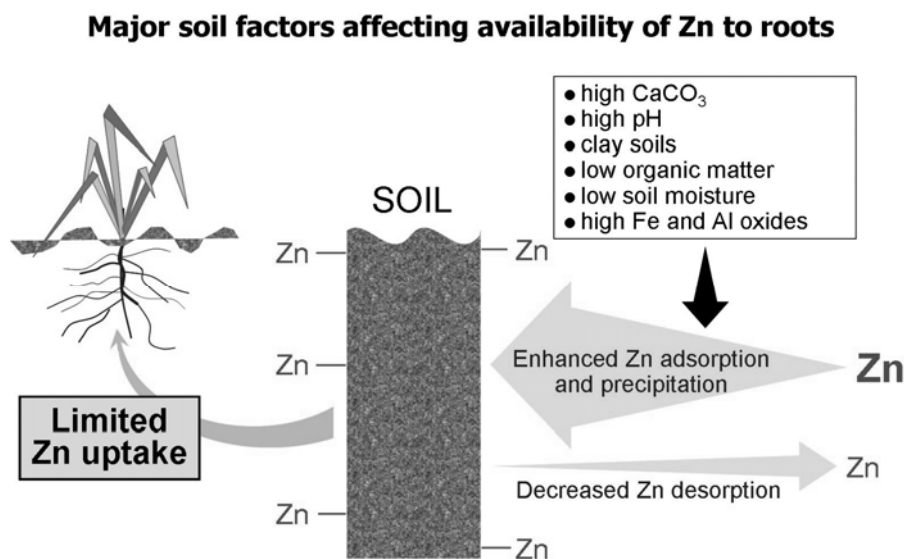
Zinc deficiency is a common micronutrient deficiency in crop plants, particularly in cereals. Increasing evidence is available showing that Zn deficiency is the most prevalent micronutrient deficiency in crop plants in the world, causing severe decreases in crop yield and quality (Alloway, 2004). According to Graham and Welch (1996), nearly 50 % of the cereal-growing areas globally are deficient in plant available Zn. Among the cereals, wheat and rice are particularly sensitive to Zn deficiency. Growing rice and wheat on Zn-deficient soils leads not only to a reduction in grain production, but also to low nutritional quality of grains. Wheat, together with rice, are predominant sources of energy and minerals for a majority of the world's population. Improving Zn nutritional status of these crops is, therefore, critically important to sustain high yields and maintain high Zn levels of grain. Several reports are available showing that Zn deficiency, together with Fe deficiency, affect the health of half the world's population, and are responsible for severe health complications, especially in developing countries (Cakmak et al., 2003; Welch and Graham, 2004).

In most cases, Zn-deficient soils are sufficiently high in total amount of Zn, but extremely low in plant available Zn concentrations. There are several soil factors that decrease the chemical availability of Zn to plant roots, such as high pH and CaCO<sub>3</sub> levels and low levels of organic matter and moisture in soils. The development of Zn deficiency in plants due to low absolute Zn levels in soils is very rare. Countries with widespread occurrence of Zn deficiency in soils include India, China, Australia, Pakistan and Iran (White and Zasoski, 1999; Alloway, 2004). In a global study initiated by FAO, it was reported that Turkish soils are the most severe Zn-deficient soils among the tested soils from 30 countries (Sillanpaa, 1982; 1990). Based on the results from 1511 soil samples, Eyupoglu et al. (1994) reported that almost 50 % of the cultivated soils in Turkey are Zn-deficient according to the DTPA-soil test (Lindsay and Norvell, 1978). Despite several reports on the existence of Zn deficiency problems in Turkish soils, the role of Zn fertilizers on growth and yield of crop plants has not been studied under field conditions on a large scale, especially in Central Anatolia. Central Anatolia is the driest region in Turkey and covers 50 % of the wheat production areas (4.5 million ha).

Previously, wheat grown in different parts of the Central Anatolia region often showed necrotic and chlorotic patches on leaves and poor growth. Interestingly, the role of Zn deficiency in the development of these symptoms and the resulting poor growth in wheat did not receive attention until the early 1990s. At that time, several biotic and abiotic stress factors (including pathogens, drought, B-toxicity etc.) were discussed as possible underlying causes for the leaf symptoms and poor growth in wheat. To identify the factors responsible for the disorders in wheat observed over many years and to clarify the possible relationship of these disorders to micronutrient nutrition of plants (with an emphasis on Zn) a long-term and multi-institutional project was prepared and submitted to the NATO-Science for Stability programme (NATO-SFS) in 1992. The institutions involved in the project were Cukurova University in Adana, the Transitional Zone Agricultural Research Institute in Eskisehir, the Bahri Dagdas International Agricultural Research Center in Konya and CIMMYT-Ankara. In 1993, the project was approved by the NATO-SFS (Science for Stability) program to study different aspects of Zn deficiency in wheat production in Turkey, especially in Central Anatolia. The results obtained from this NATO-SFS project and from the projects that followed it have been recently reviewed by Cakmak (2004) and are summarized below.

## Soil Chemical Properties and DTPA-Extractable Zinc

Most of the project activities have been conducted in Central Anatolia where long-term annual precipitation is between 280-325 mm. Due to very low soil moisture, wheat/fallow production systems dominate in this region. Nearly 90 % of the collected soil samples around Konya and Eskisehir, the major provinces of the region, had Zn deficiency based on soil DTPA-test (Cakmak et al., 1996). By contrast, these soils are fairly high in total amount of Zn, ranging between 40 to 60 mg kg<sup>-1</sup> soil. Almost all soils were calcareous. More than 65 % of the soils in Central Anatolia contained greater than 20 % CaCO<sub>3</sub>. The organic matter content was very low, averaging 1.5 %. As presented in Fig. 1, very high levels of pH and CaCO<sub>3</sub>, together with very low levels of soil moisture and organic matter are major factors responsible for decreasing chemical availability of Zn to plant roots in Central Anatolia.



*Figure 1: Illustration of major soil factors limiting Zn solubility and uptake in soils*

High pH and CaCO<sub>3</sub>, together with low levels of organic matter, reduces chemical availability of Zn in soils by stimulating precipitation or adsorption of Zn to soil constituents (e.g., clay minerals and metal oxides). Soil moisture is also a critical factor needed for the diffusion of Zn to plant roots. In model experiments dealing with adsorption and desorption of Zn in soils under laboratory conditions we showed that the soils in Central Anatolia have extremely high Zn-adsorption capacity. Zinc added to these soils is very quickly and strongly adsorbed and held on soil constituents; consequently, the Zn in these soils is only poorly available to plant roots. In contrast to Zn, DTPA-extractable levels of Mn and Cu are at an adequate range for plants, and only 25 % of soils are potentially deficient in Fe based on DTPA-test (Cakmak et al., 1996; Cakmak, 2004).

## Wheat Response to Zinc Applications

Wheat was highly responsive to soil or foliar application of Zn-containing fertilizers. In the first field experiment conducted in the 1991-1992 cropping season by M. Kalayci and his colleagues at the Eskisehir location, it was demonstrated that among all micronutrients, only in the absence of Zn fertilizers was the yield of wheat and barley severely depressed. Grain yield of wheat and barley cultivars was increased by 58 % in response to Zn application (Table 1).

Application	Bezostaja-1	Gerek-79	Kundurur-1149	Tokak	Mean
Control (all micronutrients)	4.64	4.76	2.65	4.73	4.19
- Fe	4.36	4.37	2.38	4.53	3.91
- Mn	4.54	4.71	1.93	5.38	4.14
- Cu	3.93	4.30	2.17	4.91	3.62
- B	4.20	4.37	2.63	4.81	4.00
- Zn	2.96	3.00	1.58	3.07	2.65

**Table 1:** Effect of soil applications of different micronutrients on grain of the bread wheat cultivars Bezostaja-1 and Gerek-79, durum wheat cultivar Kundurur-1149 and barley cultivar Tokak grown in a Zn-deficient soil under field conditions in Central Anatolia (Eskisehir province). Micronutrients were applied at the rate of 5 kg ha<sup>-1</sup> (Cakmak et al., 1999).

In the following cropping seasons, several field experiments were conducted on different places in Central Anatolia with varying degree of DTPA-extractable Zn concentrations in the soil. The results obtained showed that in soils containing less than 0.4 mg DTPA-extractable Zn per kg soil, wheat (especially durum wheat) responded significantly to Zn fertilizers. There were dramatic increases in grain yield by Zn application. Due to very severe Zn deficiency in soils (DTPA-Zn:  $\leq 0.1$  mg kg<sup>-1</sup>), it was not possible in certain places to have adequate yield for farmers (grain yield less than 0.25 tons per ha). Following diagnosis of Zn deficiency in such particular areas, applying Zn eliminated necrotic patches on leaves and increased grain yield by a factor of 6 to 8 (from 0.25 tons up to 2 tons per ha) (Cakmak et al., 1996; Cakmak, 2004). Currently, several such places, which were not under cultivation before, and are now being used for production of wheat, sugar beet, vegetables etc. with the application of Zn fertilizers.

In different greenhouse and field experiments we often observed that decreases in plant growth due to Zn deficiency occur even without appearance of visual deficiency symptoms. Despite lack of visible leaf symptoms (chlorosis and necrotic patches on leaves) plants were still responsive to Zn applications. Reduction in plant growth and yield without development of visible Zn deficiency symptoms is referred to as “hidden hunger”. Since in practical agriculture, Zn fertilizers are generally applied when leaf symptoms of Zn deficiency are apparent, it is important to develop methods identifying hidden hunger associated with Zn deficiency in crop plants. As a solution to this hidden hunger, incorporation of certain amounts of Zn into regular major fertilizers (NP or NPK) could be recommended to ensure and maintain adequate Zn nutrition of crop plants.

As indicated above, Zn nutrition of crop plants is particularly impaired in arid and semi-arid regions. Plants become more sensitive to Zn deficiency under rainfed, relative to irrigated conditions, due to restricted Zn transport to plant roots by diffusion. Under rainfed conditions, topsoil drying is, therefore, a significant factor contributing to the development of Zn deficiency problem in plants. As the limited soil moisture is the most important constraint to wheat production in Central Anatolia, irrigation results in impressive increases in grain yield. However, the extent of these increases was highly dependent on the application of Zn fertilizers. In a field experiment with different cereal cultivars, increases in grain yield by Zn application became much greater under rainfed (156 %) than irrigated (102 %) conditions (Ekiz et al., 1998). Accordingly, it was found that drought tolerant genotypes are also more tolerant to Zn deficiency stress than the drought sensitive genotypes. In Central Anatolia, spike sterility is a well-known problem and attributed to high day temperatures under drought conditions. Also, the spike sterility problem is pronounced when plants suffer from Zn deficiency stress. Under drought and heat stress, improving Zn nutritional status of wheat plants is critically important in protecting plants from spike sterility. Spike sterility seems to be induced by reactive oxygen species (ROS) that cause oxidative cell damage (Selote and Khanna-Chopra, 2004), and Zn is an essential component in the protection of cells against cell damage by ROS (Cakmak, 2000).

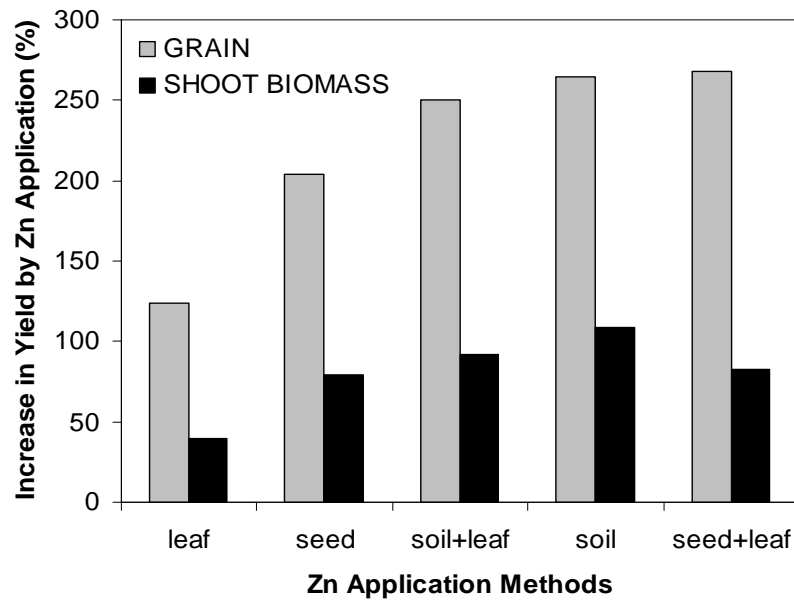
### **Zinc Application Methods**

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Several Zn application methods have been tested for their efficacy in increasing yield and grain Zn concentration. Zinc application methods tested were:

- i) control (no Zn application),
- ii) 23 kg Zn ha<sup>-1</sup> as broadcast to soil,
- iii) seed coating (1 liter 30 % ZnSO<sub>4</sub> sprayed to 10 kg seeds and then the seeds dried and sown)
- iv) foliar application (2x220 g Zn ha<sup>-1</sup> as ZnSO<sub>4</sub> in 450 liters at tillering and stem elongation)
- v) combination of the methods (ii) and (iv)
- vi) combination of the methods (iii) and (iv)

Irrespective of the method tested, application of Zn significantly improved plant growth and yield (Fig. 2). The highest increases in biomass production and grain yield were obtained with soil (265 %) and soil+leaf (250%) applications, while leaf application alone resulted in the lowest increase in grain yield (e.g., 124 %). As presented in Fig. 2, increases in biomass production by Zn applications were lower than the increases in grain yield. This result indicates that Zn is more important for generative phases (seed setting, spikelet sterility, etc.) than for the vegetative growth.



**Figure 2:** Increases in grain and whole shoot biomass production by different Zn application methods. The results represent the average values of one durum and 3 bread wheat cultivars grown in Central Anatolia on a severely Zn-deficient calcareous soil. The yield values for control (without Zn) plants: 558 kg ha<sup>-1</sup> for grain and 3114 kg ha<sup>-1</sup> for shoot biomass (Yilmaz et al., 1997).

As the Zn applied to soil has long-term residual effects (up to 3 years), soil application methods seem to be the most economical and effective long-term methods. In case of increasing Zn concentration of plants, the most effective method was soil+leaf application that resulted in a 3.5-fold increase in grain Zn concentration and a 7-fold increase in the shoot Zn concentration. The combined soil and foliar application should be considered as the most effective method if a high grain yield together with high Zn concentration in grain desired. As discussed below, enhancements in grain concentration of Zn have diverse benefits both for plant growth and human health.

### **Role of Seed Zinc in Plant Growth**

Among the soil application methods, the seed Zn-coating method was also highly effective in increasing biomass production and grain yield (Fig. 2). The increase in plant growth by using Zn-coated seeds was comparable with increases resulting from soil application of Zn. Interestingly, despite marked increases in plant growth and yield caused by the use of Zn-coated seeds, the concentration of Zn in shoot or grain was not affected. In the case of soil application, Zn concentration of plants was, however, increased by nearly 2-fold. It seems very likely that high seed Zn plays an important role during seed germination and early seedling development. Increasing evidence is available showing that plants derived from seeds with very low Zn concentration lose their vigor and cannot withstand environmental stress factors (e.g., extreme temperatures and salinity). Sowing seeds with high Zn concentration contributes to better growth and yield under Zn-deficient conditions as shown in pot (Rengel and Graham, 1995) and field experiments in Central Anatolia (Yilmaz et al., 1998).



Zinc has also protective roles against root-rotting pathogens and nematode infestation. One of the critical conditions in infection of plant tissues is the availability of exudates released from the cells into growth medium. Exudates such as carbohydrates and amino acids are major factors in attraction and rapid spread of pathogens in the tissue. The release rate of exudates from cells is dependent on the structural integrity and permeability of cell membranes. Any impairment in membrane stability can cause massive release of organic compounds from cells, representing a very suitable feeding medium for pathogens (Marschner, 1995). Zinc is essentially needed for maintenance of membrane stability and in controlling membrane permeability. Under Zn deficiency, structural integrity of cell membranes is substantially impaired, causing membranes to become leaky (Welch et al., 1982; Cakmak and Marschner, 1988). Increase in root exudation of carbon-containing compounds is very typical for Zn-deficient plants (Cakmak and Marschner, 1988). Such increases in root exudation under Zn-deficient conditions attract pathogens as found in different Zn-deficient plants (for more detail see Cakmak, 2004).

An increased amount of Zn in seeds is also important for reducing seeding rates. In many places of Central Anatolia, very high seeding rates (up to 350 kg seed per ha) are applied due to poor seedling establishment and increased “winter killing”. Due to widespread occurrence of Zn deficiency in the region, seed Zn concentrations are very low, and the plants derived from such seeds are very sensitive to adverse soil and environmental conditions at early growth stages causing poor seedling development and poor field establishment.

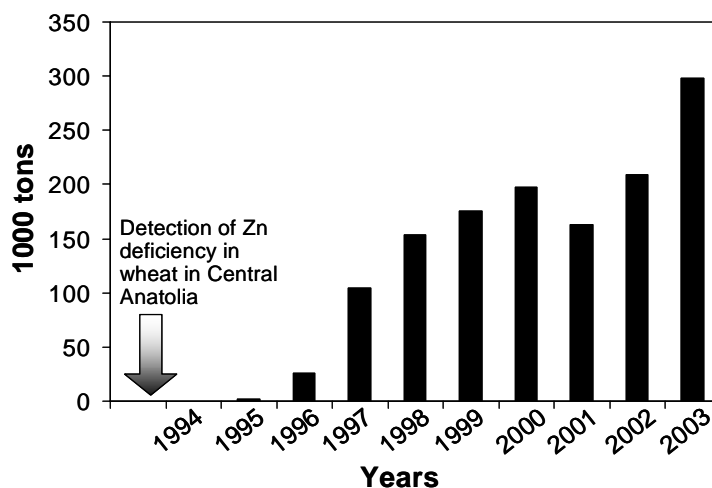
This might be one major reason for higher seeding rates in Central Anatolia. It is estimated that by use of Zn-enriched seeds, seeding rate can be very significantly reduced and at least 500 000 tons of seed per year can be saved in Central Anatolia, leading to an annual economic benefit of at least US\$50 million.

### **Development of Zinc-Containing Compound Fertilizers**

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Spectacular increases in plant growth and yield either by applying Zn fertilizers or sowing Zn-enriched seeds elicited a growing interest in the project results from the farmers and fertilizer industries. Among the fertilizer industries in Turkey, TOROS Fertilizer and Chemical Industry was the first fertilizer producer who responded quickly to the project results, and started to produce NP and NPK fertilizers containing 1 % Zn. In 1995, the first 4 000 tonnes of Zn-containing compound fertilizers was produced and distributed to farmers to test their reaction to the new Zn-fertilizers. The reaction of farmers to the new Zn-containing fertilizers was so positive that in the following years increasing amounts of Zn-containing fertilizers have been produced and applied, not only in Central Anatolia but also in other regions of Turkey. The Turkish Government made Zn-containing compound fertilizers eligible for state subsidies in 1997. This was the first state subsidy given a micronutrient – containing fertilizer in Turkey. In 2003, nearly 10 years after the Zn deficiency problem was solidly identified as a critical constraint to wheat production in Central Anatolia, the total amount of Zn-containing compound fertilizers applied in Turkey has reached a record level of 300 000 tons (Fig. 3). The fertilizers amended with Zn and their production amounts in 2003 were as follows:

20-20-0-Zn (210 000 tons),  
15-15-15-Zn (42 000 tons),  
10-25-20-Zn (29 000 tons) and  
10-15-25-Zn (18 000 tons).

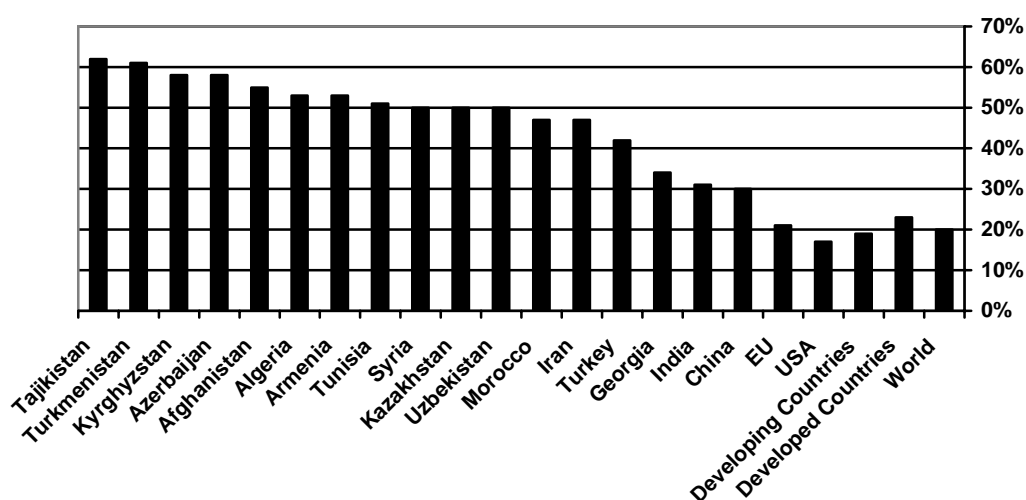


**Figure 3:** Consumption of Zn-containing fertilizers in Turkey (Source: Turkish Fertilizer Producer Association, 2001; Turkish Ministry of Agriculture, 2004).

Application of 300 000 tones of Zn-containing NP and NPK fertilizers represents an annual turnover of about 70 million USD. In Turkey, increased amounts of ZnSO<sub>4</sub>, ZnO and Zn-containing foliar fertilizers are also being applied, but as yet there is no statistics available showing total amount of such Zn-fertilizers applied in Turkey. The Ministry of Agriculture and CIMMYT-Ankara estimate that the annual economic benefits resulting from Zn-dependent increases in grain yield is around 100 million USD.

### Human Nutritional Aspects

As Zn deficiency is an important micronutrient deficiency in humans in Turkey, increases in grain Zn concentration by using Zn fertilizers should have obvious implications for human health. In Turkey, a majority of the population relies on wheat as an important source of caloric intake (Fig. 4). On average, wheat alone provides nearly 45% of the daily caloric intake nationally.



**Figure 4:** Daily calories intake from wheat in different countries and regions (Source: FAO Database 2003; compiled by H.J. Braun, CIMMYT-Turkey).

This ratio is possibly much higher in the rural regions. When grown in potentially Zn-deficient regions, wheat can produce grains with very low Zn concentration, and monotonous and extensive consumption of cereal-based foods derived from such grains with low Zn concentration can induce occurrence of Zn deficiency problems in humans. Any increase in grain Zn concentration by applying Zn-enriched NP or NPK fertilizers is therefore important for human health and nutrition. As shown in different field experiments in Central Anatolia, soil or foliar application of Zn to wheat increased grain Zn concentration up to 2- to 3-fold.

Improving Zn nutritional status of plants is also associated with reductions in grain phytic acid and Cd concentrations. By binding Zn, phytic acid impairs absorption of Zn in the body (Cakmak et al., 2003). Decreased concentration of phytic acid in grains of Zn-treated plants is related to reduced uptake and translocation of P by adequate Zn supply (Cakmak and Marschner, 1986). Zinc and Cd are chemically very similar, and their root uptake is possibly maintained by similar transport proteins (Cakmak et al., 2000). Consequently, Zn and Cd compete for uptake and transport in plants. In agreement with this, improving Zn nutritional status of plants significantly reduced uptake and transport of Cd in durum wheat (Cakmak et al., 2000). Also, foliar application of Zn substantially reduced Cd transport from leaves into grains (unpublished results). Sowing seeds with very high levels of Zn was also effective in reducing Cd concentration in seedlings and reducing Cd toxicity at early growth stages (unpublished results).

## **Conclusions**

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Zinc deficiency is a critical constraint to wheat production in Central Anatolia. Development and application of Zn-containing NP and NPK fertilizers were very successful in reducing Zn-deficiency related problems in wheat production. The project described in the present study should be a model for large number of countries where Zn deficiency in soils and crop plants are widespread. Currently, in many regions, farmers and scientists are still not aware of the losses in plant growth and yield caused by Zn deficiency. Through this project, scientists in different countries around Turkey were alerted about the importance of Zn deficiency for crop production under rainfed conditions. Increasing amount of Zn-containing fertilizers is now being applied in neighboring countries such as Iran (Dr. M. J. Malakouti, personnel communication).

The “Zn-project” described in the present study is also one of the first examples in the world of using agricultural intervention to address public health. Today, nearly half of the world’s population suffers from Zn and Fe deficiencies. These deficiencies affect mainly children and women, and are responsible for the development of severe health problems (Cakmak et al., 2003; Welch and Graham, 2004). By affecting vitality, cognitive abilities and quality of life, micronutrient deficiencies also impair programs to control population growth, societal stability and sustainable national development efforts (Cakmak et al., 2003). Very recently, in the “Copenhagen Consensus” (<http://www.copenhagenconsensus.com>), supplying adequate amounts of micronutrients to human-beings was identified as one of the 4 major solutions in ensuring global welfare, particularly in developing countries.

The results of the Copenhagen Consensus were achieved by an expert panel of the world's most distinguished economists (including 3 Nobel laureates). To achieve the goals identified in the "Copenhagen Consensus", new plant genotypes should be developed with high genetical capacity to accumulate micronutrients in the edible parts of food crops (Bouis, 2003; Grusak and Cakmak, 2005). Alternatively, as shown in the present study, increasing micronutrient concentration of edible parts of crop plants (e.g., seeds) by applying Zn-enriched NP and NPK fertilizers could be considered as a rapid solution in the fight against micronutrient deficiency in human beings worldwide. This approach is cost-efficient, sustainable and reaches all the people who are at risk of developing micronutrient deficiencies.

## **Acknowledgements**

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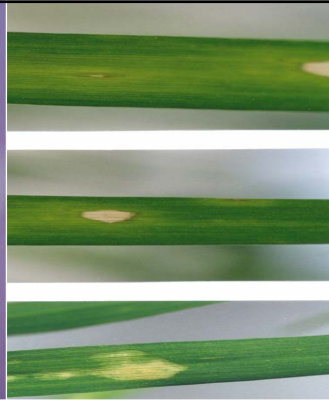
## Identification and correction of widespread zinc deficiency problem in Central Anatolia

"success story"

Ismail Cakmak

Sabanci University, Istanbul-Turkey

**Leaf Symptoms caused by "Drought, Heat, Pathogen, Boron Toxicity, Micronutrient Deficiency (Zn??)" ??????**



**Wheat Fields in Central Anatolia in 1992**

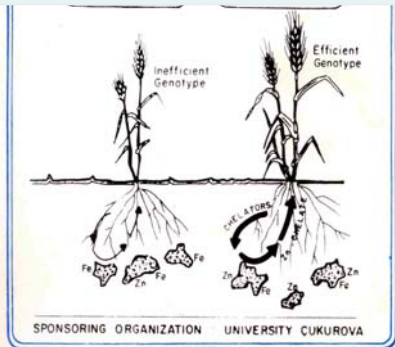
-poor growth and necrotic patches on leaves-







**Year 1993, March:**  
**Approval of “Zinc-Project in Anatolia”**  
**by NATO-Science for Stability Programme**



**Participating Institutions:**  
Cukurova University-Adana  
Ministry of Agriculture  
CIMMYT-Ankara

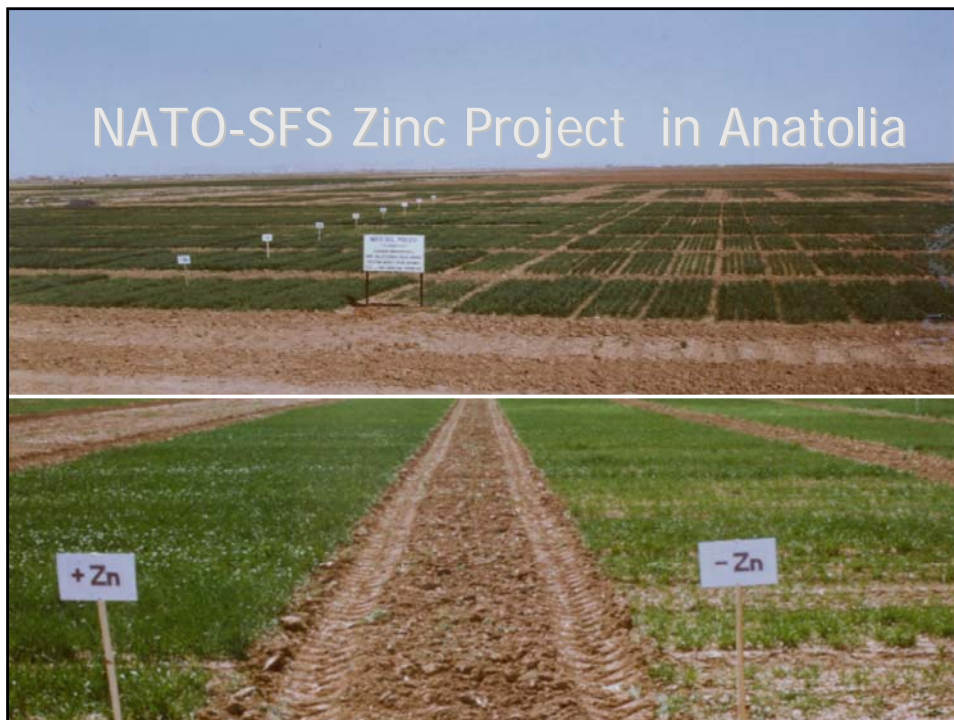


**Effect of soil applications of different micronutrients (5 kg ha<sup>-1</sup>) on grain yield of cereal species. Experiment was conducted by Mufit Kalayci in Eskisehir (YEAR 1992)**

**Cereals**

<u>Applications</u>	<u>Barley</u>	<u>Bread Wheat</u>	<u>Durum wheat</u>
	<b>(tons grain ha<sup>-1</sup>)</b>		
Control (all micro)	<b>4.73</b>	<b>4.64</b>	<b>2.65</b>
-Fe	4.53	4.36	2.38
-Mn	5.38	4.54	1.93
-Cu	4.91	3.93	2.17
-B	4.81	4.20	2.63
<b>-Zn</b>	<b>3.07</b>	<b>2.96</b>	<b>1.58</b>

Details of results available in [Cakmak et al., 1999, Field Crops Res.](#)





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



**Effect of soil Zn application on grain yield of wheat in different locations with varying levels of DTPA-Zn in Central Anatolia.**

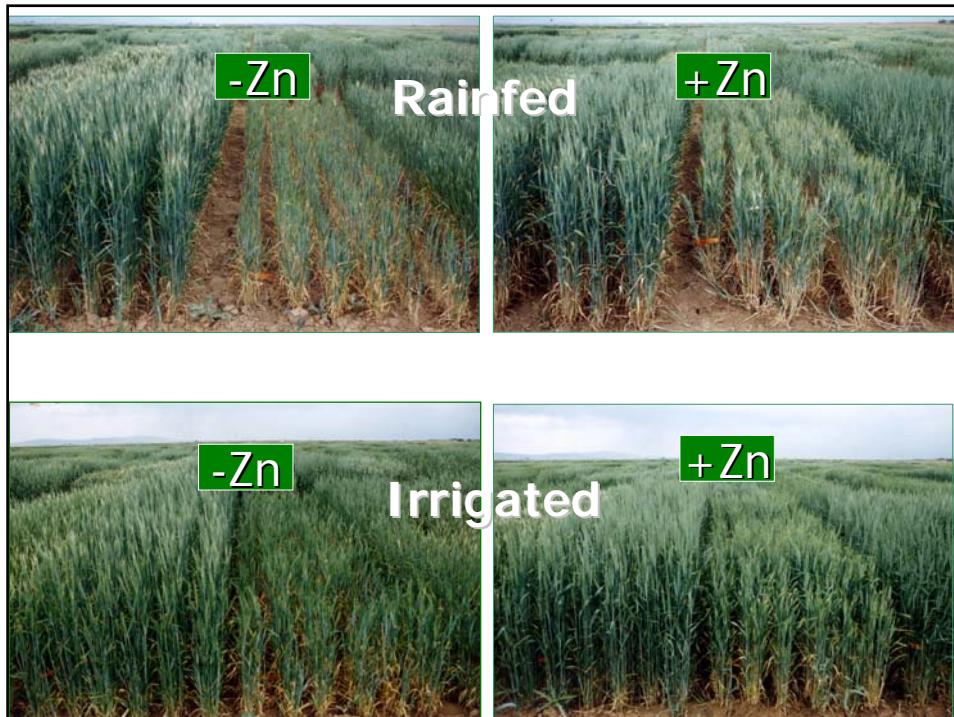
Location	DTPA-Zn	Grain yield		
		-Zn	+Zn	increase by Zn
		(t ha <sup>-1</sup> )		(%)
Konya (centrum)	0.13	2.8	5.9	111
Konya (Comakli)	0.11	0.2	1.4	600
Eskisehir	0.15	2.5	3.3	32
Sarayonu (Cesmelisebil)	0.25	1.1	2.3	109
Sarayonu (Gozlu)	0.38	1.1	1.5	36
Cumra	0.64	5.4	5.6	4
Mean	0.28	2.2	3.3	53

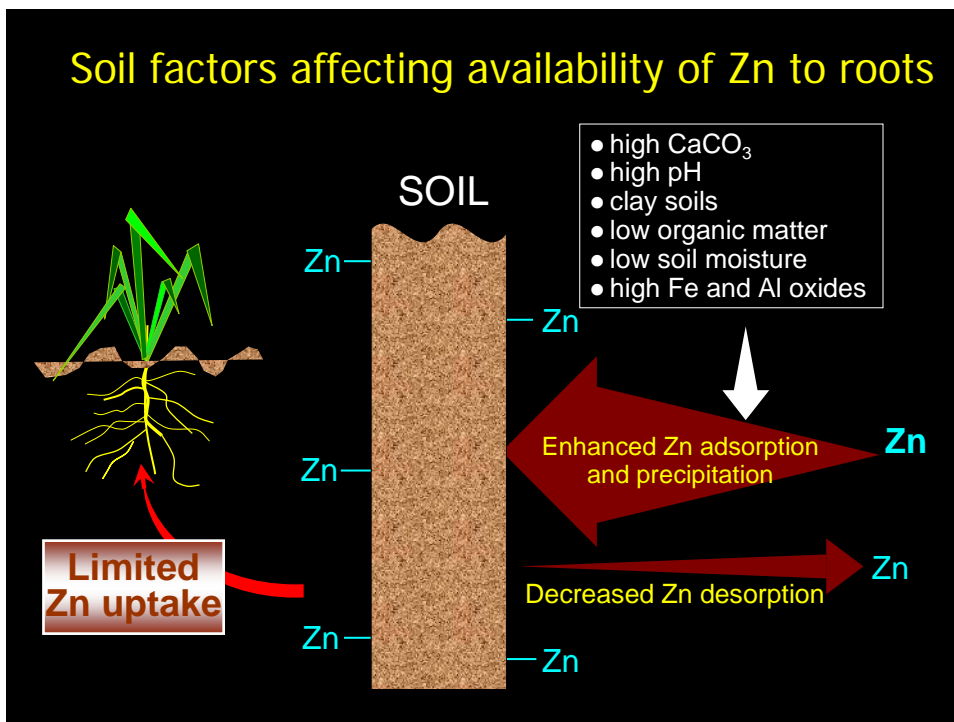
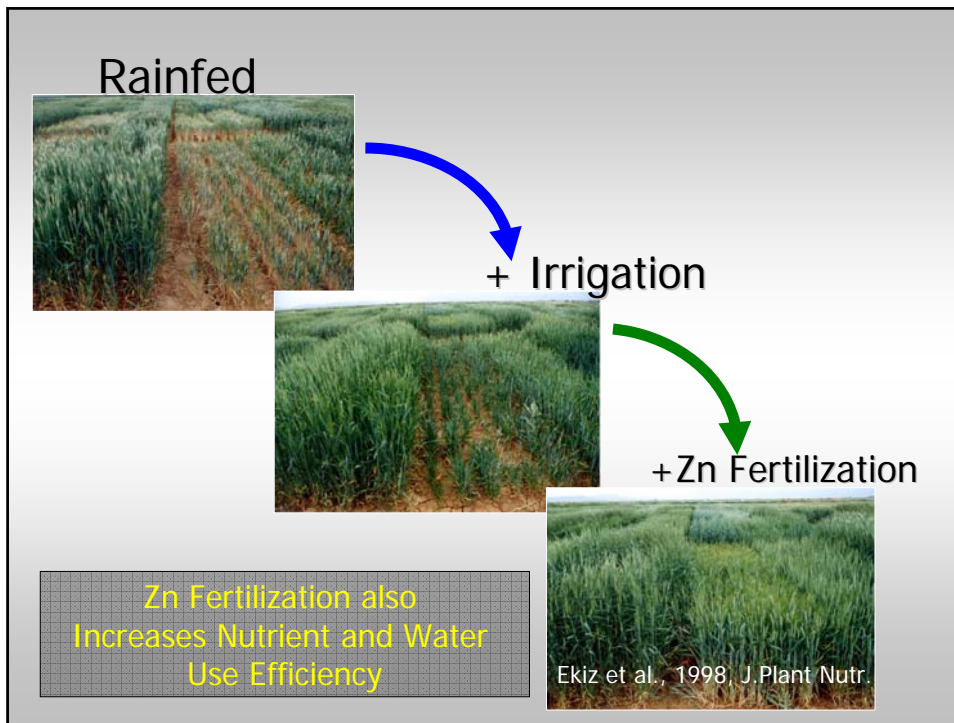
Cakmak et al., 1996, Plant and Soil



## Foliar Application of Zn on Barley Field

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

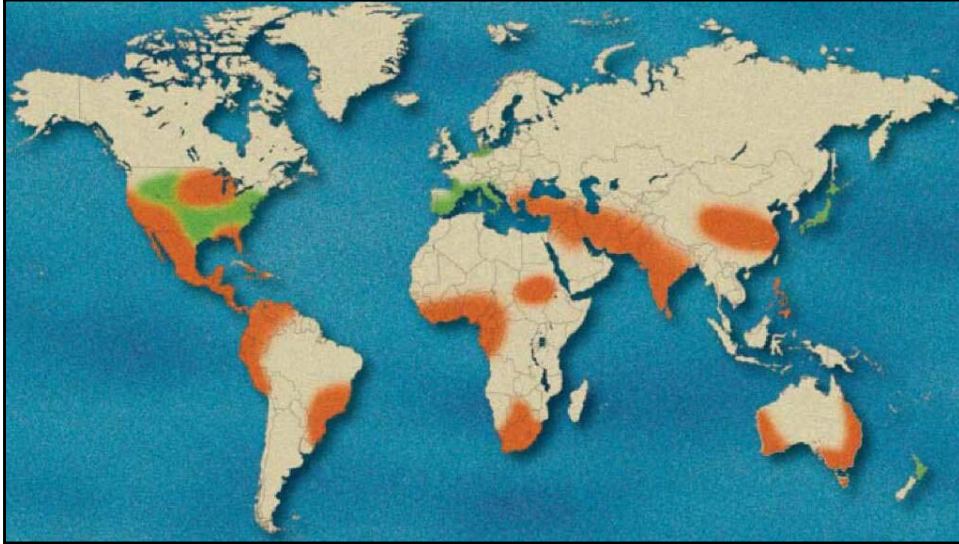






Geographic distribution of severe (red) and moderate (green) zinc deficient soils in the world

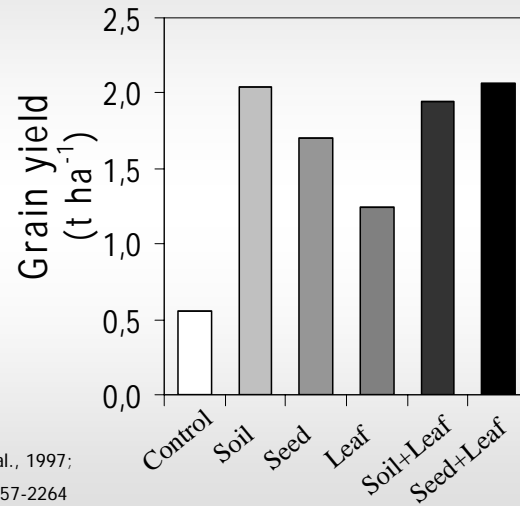
(Alloway, 2004, In: Zinc in soils and Crop Nutrition. IZA Publications, Brussels)



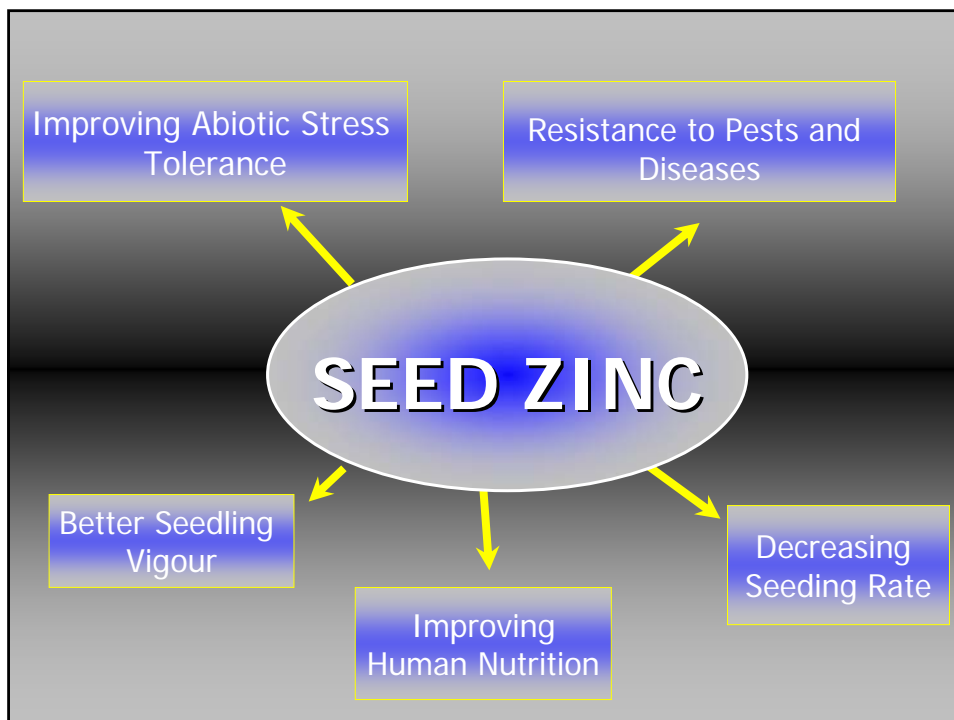
Role of Seed-Zn in Improving Wheat Production Under Zn-Deficient Conditions

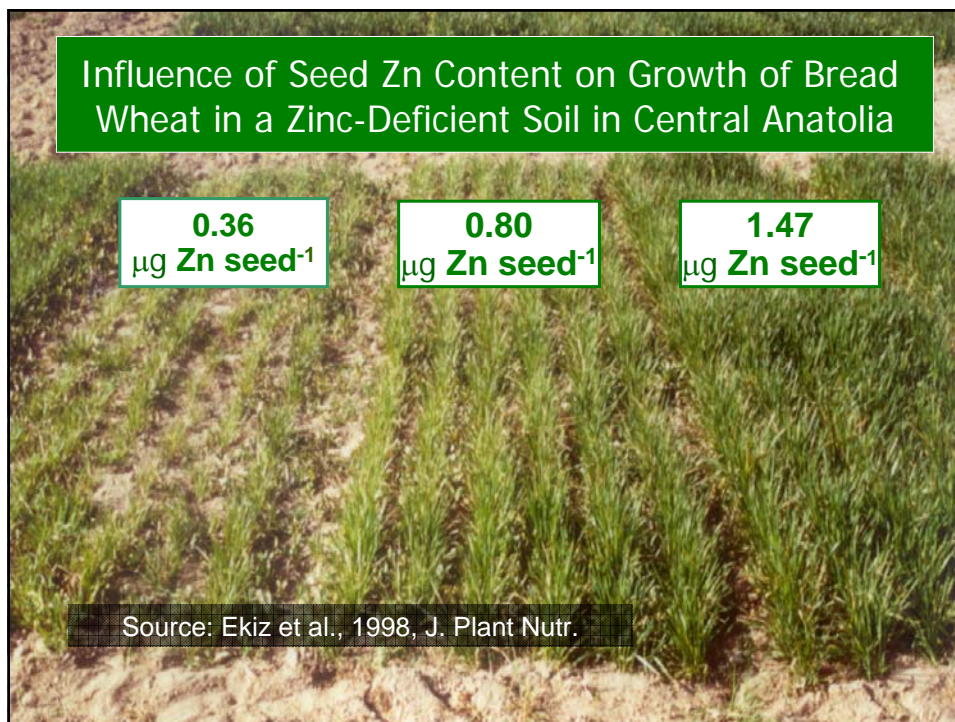


## Effect of Different Zn-applications on grain yield and grain Zn concentration



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





## **Project results were rapidly shared with**

- scientific community,
- industry, and
- especially end users (farmers)



# Zinc in Turkish Press

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

Zinc Alarm in Soils

NATO-Aid to Our Soils

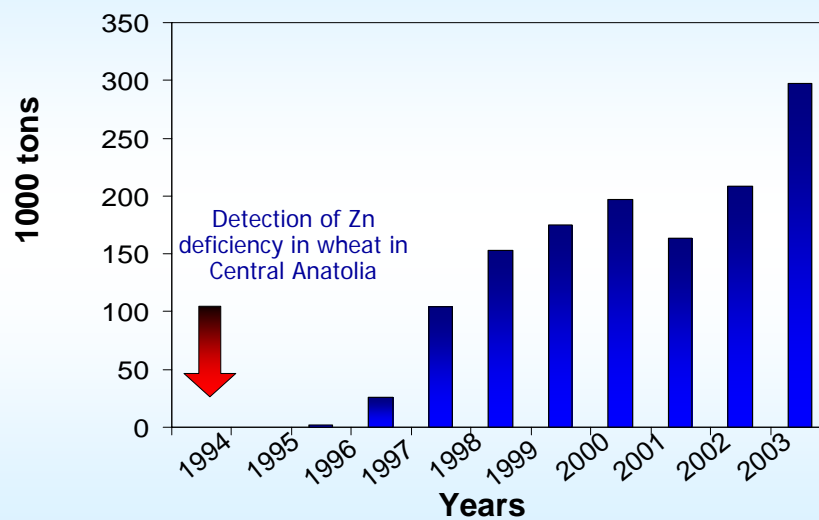


# Production of Zn-Containing Compound Fertilizers



Zn containing  
Compound  
Fertilizers in Field

Use of Zn-Containing NP and NPK Fertilizers in Turkey following “Zinc NATO-Project”



Sources: Turkish Fertilizer Producer Association, 2001  
Turkish Ministry of Agriculture, 2004



### Use of Zn-containing NP and NPK Fertilizers in 2003

Fertilizer	Tonnes
20-20-0 + Zn	210,000
15-15-15 + Zn	42,000
10-25-20 + Zn	29,000
10-15-25 + Zn	18,000
<b>Total</b>	<b>299,000</b>

**Annual turnover:  
70 Million USD**

Ministry of Agriculture and CIMMYT-Ankara estimates put annual economic benefits from the Zn fertilization at 100 million USD.

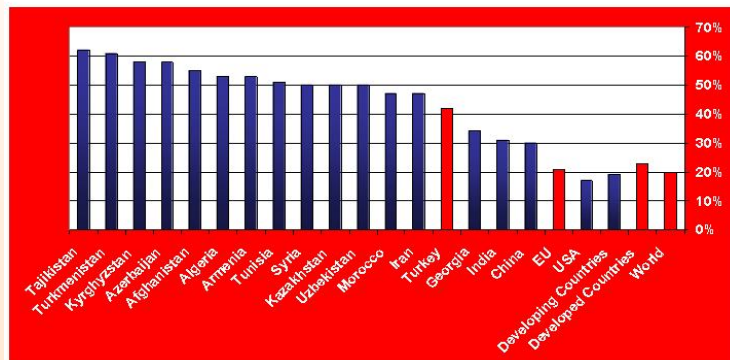
## Social and Health Benefits

Generally, the regions with most severe Zn-deficient soils are also the regions where Zn deficiency in human-beings is very common, especially in developing countries.

In Turkey, together with Fe deficiency, Zn deficiency is a common micronutrient deficiency problem in human beings

Extensive consumption of cereal based foods is one major reason for widespread occurrence of Zn deficiency in human beings in Turkey and in many other countries

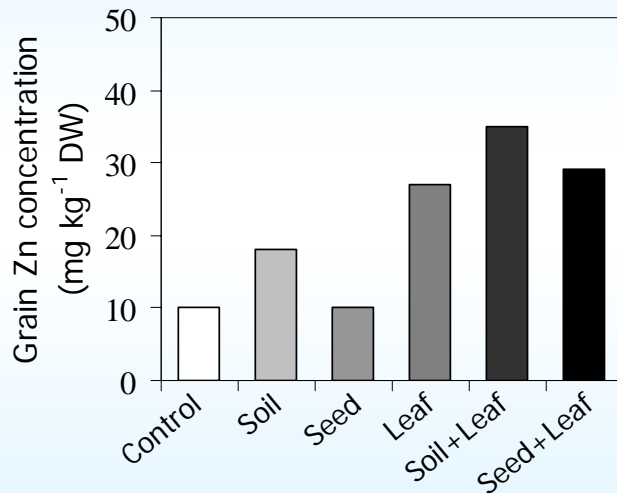
### % daily Calories from Wheat



Source: FAO Database, 2003;

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

Applying Zn to wheat can increase grain Zn concentration up to 2- or 3-fold.



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

## Conclusions

- As shown in Turkey, applying Zn-enriched mineral fertilizers could be a rapid solution to Zn deficiency-related problems in crop production and human health. Currently, zinc deficiency together with Fe deficiency affects health of 3 billion people.
- The success of this “zinc-project” could be a model for many countries where zinc deficiency is a severe health problem in their populations and an important constraint to crop production.

# Thank you...



Explanation: Potassium deficiency induces photooxidative damage (bleaching) in leaves. Partial shading of leaves (IFA) prevents development of bleaching.