Zinc in Fertilizers

Zinc ...essential for life

Zinc Nutrient Initiative

International Zinc Association

Belgium • Brazil • India • Peru • P.R. China • South Africa • United States

Introduction

Zinc deficiency, both in humans and in plants, has been known as a critical issue by nutritionists, medical scientists and agronomists for years. However, it has been receiving increasing attention recently by other groups as well, including economists and social scientists, with the recognition that this is a global nutritional problem with significant health, social, and economic implications. It is estimated that one third of the world's population is zinc deficient, resulting in numerous health complications including impairments in immune system and mental functions. It is also estimated that around half of the world's agricultural soils are deficient in zinc, leading to decreased crop production and nutritional value. Further, the consumption of cereal-based foods which are typically low in zinc, contributes up to 70% of the daily calorie intake in most of the devloping countries, thus resulting in the high prevalence of zinc deficiencies in these populations (Cakmak, 2008).

This direct linkage between the distribution of zinc-deficient soils and incidence of zinc deficiency in human populations can be addressed through the use of zinc-containing fertilizers. As part of a balanced soil nutrient approach, adding zinc to soils can increase crop production and nutritional status (i.e. higher zinc levels) of those crops for consumption. This can benefit all involved--from farmers who make more money from higher crop yields, to families getting more zinc in their diets.

Table 1: Relative Sensitivity of Crops to Zinc Deficiency

High	Medium	Low
Beans	Barley	Alfalfa
Citrus	Cotton	Asparagus
Flax	Lettuce	Carrots
Fruit Trees (deciduous)	Potatoes	Clover
Grapes	Soybeans	Grass
Hops	Sudan grass	Oats
Maize (corn)	Sugar beets	Peas
Onions	Table beets	Rye
Pecans	Tomatoes	
Rice		
Sorghum		
Sweet corn		
Wheat		

Modified from Alloway 2008

Zinc in crops and human health–the vital linkage

Zinc is vital for many biological functions in the human body. The adult body contains 2-3 grams of zinc, present in all parts of the body, including organs, tissues, bones, fluids, and cells. Zinc is essential for the proper functioning of a large number of proteins and over 100 specific enzymes in the human body (Andreini et al, 2006). Zinc also protects human and plant cells from damaging attack of highly toxic free radicals. The recommended daily allowance of zinc for adult women is 12 milligrams, and for adult men, 15 milligrams.

> "... it is estimated that zinc deficiency affects about one-third of the world's population...Worldwide, zinc deficiency is responsible for approximately sixteen percent of lower respiratory infections, eighteen percent of malaria, and ten percent of diarrheal disease...800,000 deaths worldwide were contributed to zinc deficiency."
>
> \- The World Health Report 2002, World Health Organization (WHO)

Zinc deficiency in early life can impair physical and neural growth and development, brain function, memory and learning ability. Severe zinc deficiency is characterized by stunting, lack of normal sexual development, poor immune response, skin disorders, and anorexia. Further, it is estimated that zinc deficiency is responsible for nearly 450,000 deaths, or 4.4% of children under the age of five worldwide. (UNICEF, Black et al, 2008). According to WHO, zinc deficiency is the fifth leading cause of death and disease in developing nations (WHO, 2002).

The global impact in terms of human health has been clearly identified by the Copenhagen Consensus , a group of eight leading economists, including five Nobel Laureates.

In 2008, the consensus stated that in terms of cost-effective solutions to the world's most pressing problems, providing zinc and vitamin A should be the first priority (out of 40). Table 3 lists the the top ten priorities as determined by the consensus. The group also concluded that zinc and vitamin A could be provided to 80% of the estimated 140 million undernourished children for $60 million annually, with resulting benefits (in terms of better health, increased future earnings, and fewer deaths) of over $1 billion–a return of $17 USD for each dollar spent.

Zinc content of the major staple foods such as wheat, rice, maize, and beans is of particular concern. For many people in developing nations, cereals are the principal source of calories, proteins and minerals. Since these are the regions with widespread zinc-deficient soils, these are also the regions with widespread zinc deficiency in humans. There is a direct and vital link between zinc deficiency in crops and human health in these areas of the world. A study conducted in India documented lower zinc levels (in blood plasma serum) in people feeding on cereal grains with lower zinc content grown in zinc-deficient soils. (Singh, 2009).

Table 3: Copenhagen Consensus 2008: Top Ten Solutions to World's Most Pressing Problems

	Solution	Challenge
1	Micronutrient supplementation for children (Vitamin A and Zinc)	Malnutrition
2	Doha development agenda	Trade
3	Micronutrient fortification (iron and salt iodization)	Malnutrition
4	Expanding immunization coverage for children	Disease
5	Biofortification	Malnutrition
6	Deworming and other nutrition programs at school	Malnutrition and Education
7	Lowering the price of schooling	Education
8	Increasing and improving girls' schools	Women
9	Community-based nutrition promotion	Malnutrition
10	Providing support for womens' reproductive role	Women

Copenhagen Consensus 2008

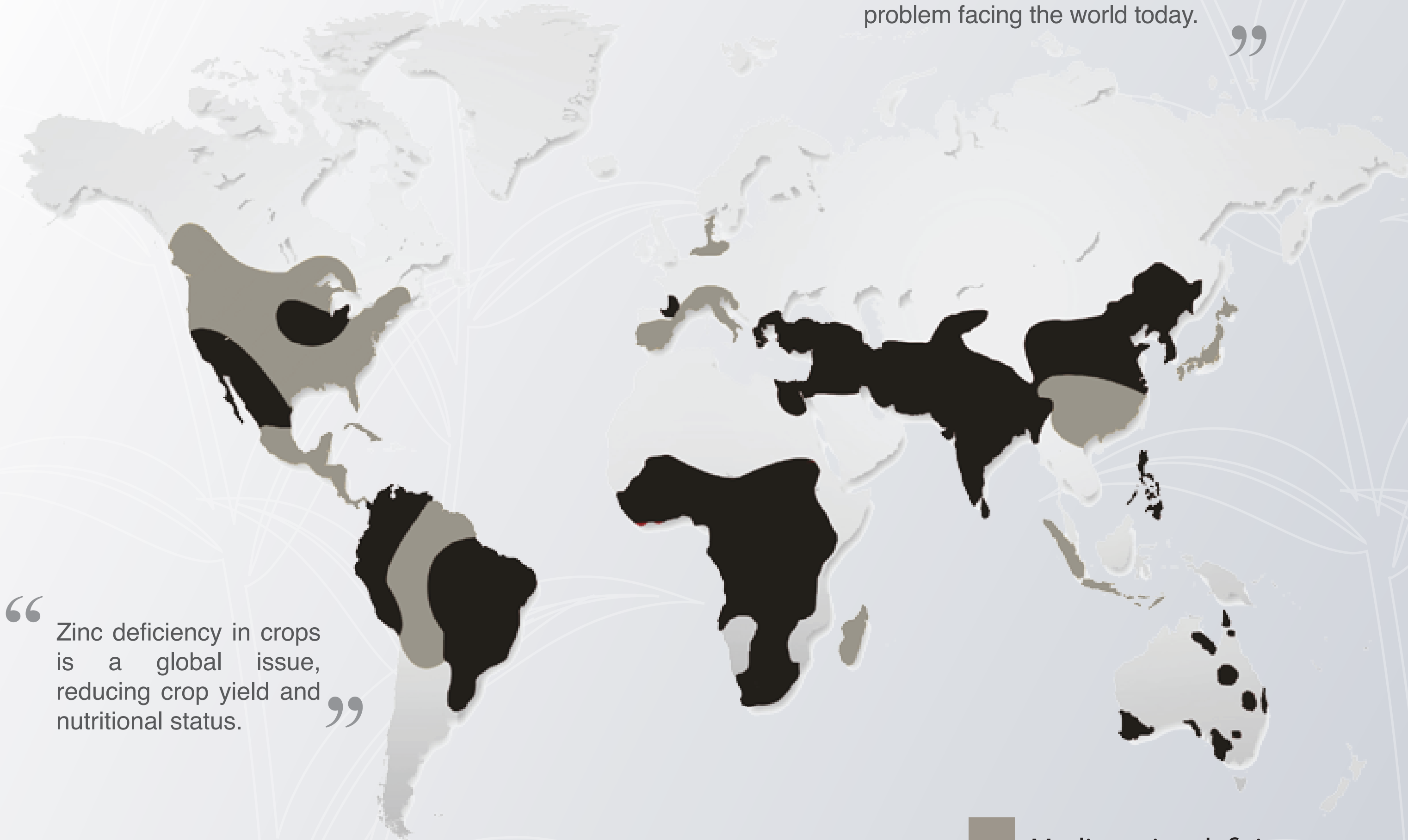
Zinc-deficient soils the root cause of zinc deficiency in crops

Zinc Deficiency in World Crops

Major Areas of Reported Problems

"Often the areas with zinc-deficient soils are also the regions where zinc deficiency in humans is the most widespread."

"According to the Copenhagen Consensus, zinc and Vitamin A can effectively treat the number one problem facing the world today."



Medium zinc deficiency

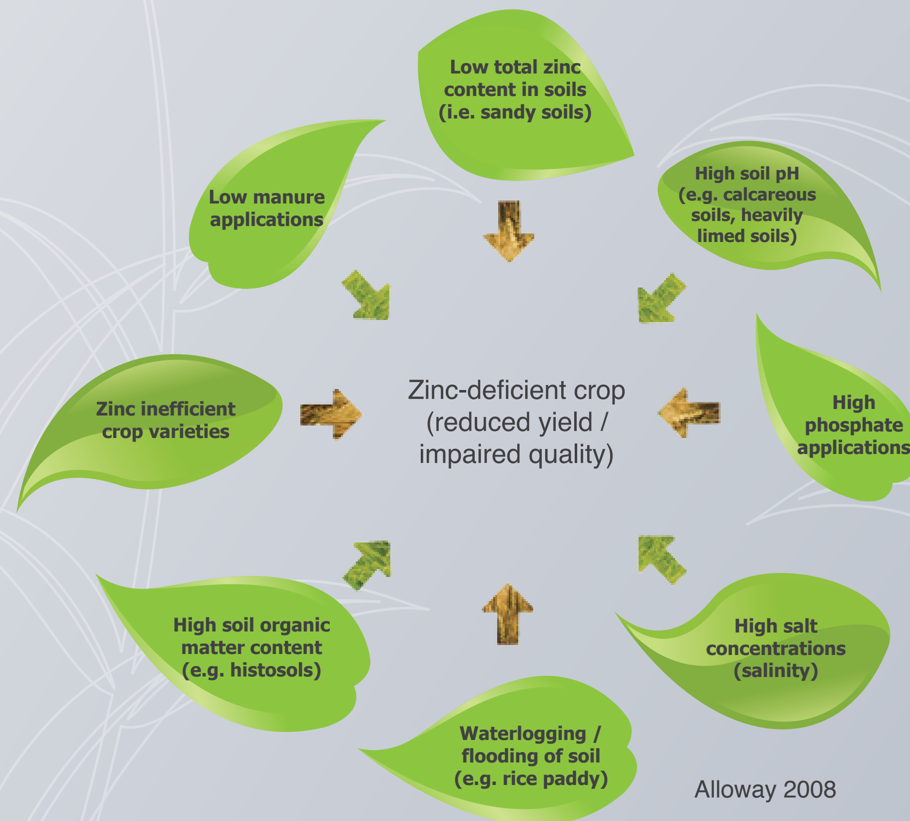
Widespread zinc deficiency

"Zinc deficiency in crops is a global issue, reducing crop yield and nutritional status."

"One-third of the world's population is at risk of zinc deficiency, ranging from 4 to 73% in different countries."

Today, it is estimated that 50% of agricultural soils devoted to cereal cultivation are potentially zinc deficient. Over two-thirds of the rice grown worldwide is produced on flooded paddy soils, which generally contain very low amounts of plant-available zinc. Wheat is typically grown on alkaline, calcareous soils with low organic matter in the semiarid (rainfed) regions of the world. These soil and climactic conditions tend to make zinc less available for uptake and use by plants. Under zinc-deficient soil conditions, plants show a high susceptibility to environmental stress factors such as drought, heat stress, and pathogenic infections, which stimulate development of chlorosis and necrosis on the leaves and cause stunted growth (Figure 2).

Figure 2: **Schematic Diagram of the Causes of Zinc Deficiency in Crops**



Alloway 2008

The high prevalence of zinc-deficient soils in major agricultural zones severely limits agricultural productivity. Zinc fertilizers can, therefore, make a significant contribution towards goals of higher crop yields in a sustainable and environmentally responsible manner. Simultaneously, zinc fertilizers can enhance grain zinc concentration and thus contribute greatly to daily zinc intake of human populations.

A study for the Food and Agricultural Organization (FAO) by Sillanpää found that zinc was the most commonly deficient micronutrient in the world. The study, which examined 190 field trials in fifteen countries, found that zinc deficiency occurred in one out of every two trials.

Zinc deficiency in food crops reduces yield capacity and lowers the nutritional value of crops. Zinc is one of the eight trace elements that plants need for normal growth and reproduction. Nearly 10% of all proteins in biological systems need zinc for their functions and structure. Plants require zinc in small but critical concentrations for several key functions, including: membrane function, photosynthesis, protein synthesis, phytohormone synthesis (e.g. auxine), seedling vigor, sugar formation, and defense against disease and abiotic stress factors (e.g. drought). Even when a plant's macronutrients of nitrogen, phosphorous, potassium, and water are met, zinc deficiency will prevent plants from reaching their full potential.

Overcoming zinc deficiency with zinc fertilizers

Zinc reduces cadmium accumulation in plants

Cadmium is a well-known metal that causes toxicity. When accumulated at high concentrations in the body, cadmium may result in severe health consequences, such as increases in the risk of bone fracture, lung damage, kidney dysfunction and hypertension. In many countries, especially in Asia, it has been shown that dietary uptake of cadmium is the predominant route for human exposure to cadmium. There are several estimates indicating that rice-originated cadmium intake is responsible for about 40-45% of the total cadmium pollution in human populations of some Asian countries. In the U.S., about 20% of the daily cadmium intake is derived from cereals. Rice, durum wheat, and potato tubers may also accumulate greater amounts of cadmium, leading to poor quality of harvested foods and threatening of their exports to other countries.

Increasing evidence is available showing that zinc significantly interferes with root uptake and transport of cadmium in plant bodies. Zinc and cadmium are chemically very similar; therefore, they compete for similar binding sites and transporter proteins in plant cells. When plants are deficient in zinc, or when growth media contain low plant-available zinc, plants absorb and transport higher amounts of cadmium. A number of reports are available showing that plants under zinc-deficient soil conditions accumulate more cadmium in grain or other edible parts.

Soil and/or foliar application of zinc is, therefore, very helpful in reducing grain accumulation of cadmium. Data from Australia, Canada and Turkey show significant decreases in root absorption and grain concentrations of cadmium after soil or foliar application of zinc fertilizers. One example is shown in Table 2. Applying zinc sulphate into soil significantly reduced cadmium accumulation in flax seeds and durum wheat grain while zinc concentrations were increasing.

Table 2: **Effect of Soil Zinc Concentration on Grain Concentrations of Zinc and Cadmium in Flax Seed and Durum Wheat**

		Grain Zn Concentration		Grain Cd Concentration	
Fertilizer Treatments*	Zinc Fertilzation	Flax Seed	Durum Wheat	Flax Seed	Durum Wheat
		(mg Zn kg-1)		(µg kg-1)	
MAP	NO	22	9	226	267
MAP	YES	39	27	136	90
MAP+Cd	NO	25	10	330	275
MAP+Cd	YES	42	31	211	165
TSP	NO	22	8	228	254
TSP	YES	41	27	138	112

* MAP: Monoammonium Phosphate; TSP: Triple Superphosphate

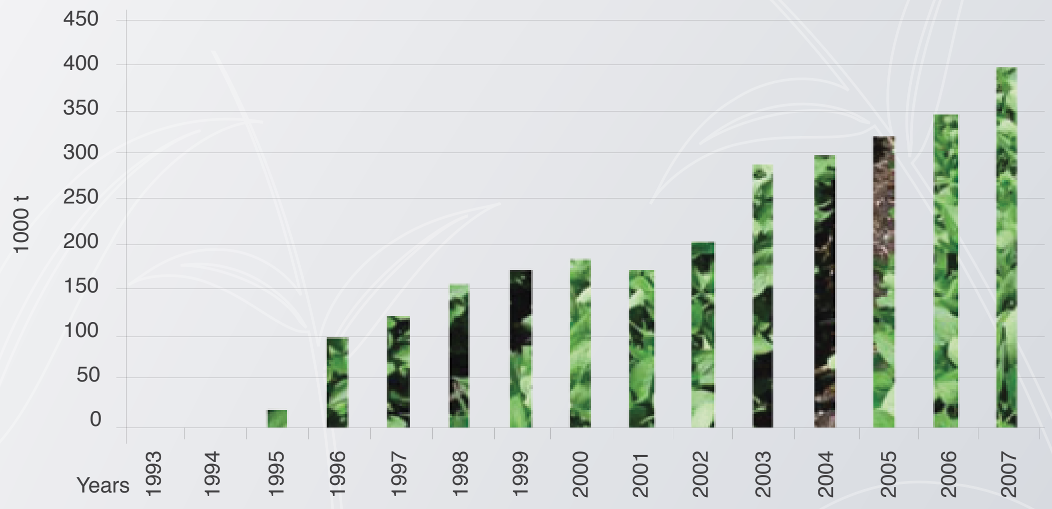
Jiao et al, 2004

Application of zinc fertilizers

Zinc deficiency is routinely corrected by soil and/or foliar applications of zinc fertilizers. Zinc sulphate ($ZnSO_4$) is the most widely applied inorganic source of zinc to soils or leaves due to its high solubility, low cost, and availability in the market. Zinc can also be applied to soils in forms of zinc oxide and Zn-oxysulphate. The well-known organic compound of zinc fertilizers is zinc EDTA (ethylenediaminetetraacetic acid). However, due to its high cost, use of zinc EDTA in practical agriculture is limited. In addition, recent results show that, in cases of leaf spray, zinc sulphate is more effective than zinc EDTA in terms of increasing grain zinc concentration.

Generally, foliar zinc spray is used at rates between 0.2% and 0.5% zinc sulphate. This type of foliar application may be repeated two or three times over the crop growth cycle, depending on the severity of zinc deficiency in plants, or depnding on the target level needed to increase grain zinc concentration for better human nutrition. Field trials with wheat showed that applying the foliar zinc spray twice at a rate of 0.5% zinc sulphate may increase grain zinc concentration by nearly 50% without any negative effect on grain yield when wheat plants are growing on zinc-deficient soils.

Figure 2: Use of Zinc-Containing NP and NPK fertilizers in Turkey

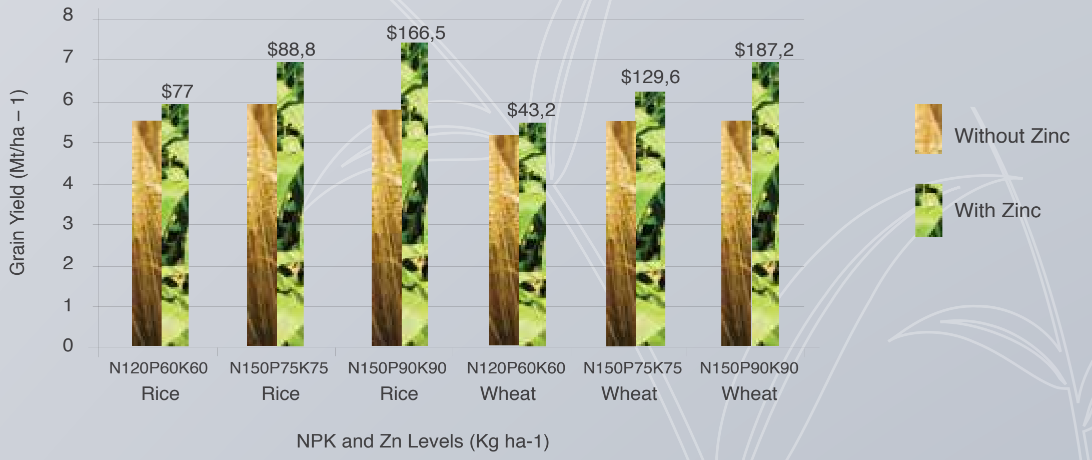


Cakmak 2008

An important factor affecting the application of zinc fertilizers into soil is uniformity of application. In order to help ensure a uniform application of zinc into soil, zinc can be incorporated into, or coated onto, the commonly available N-P-K fertilizers. Currently, either zinc-incorporated (into granule) or zinc-coated (onto granule) N, NP, or NPK fertilizers are available in different countries. For example, zinc-containing NP or NPK fertilizers have been produced and applied in South Africa for 25 years and in Turkey for 15 years, with annual amounts of about 500,000t and 400,000t respectively (Figure 2). In South Africa, the fertilizers used are 0.5% zinc, in Turkey, 1% zinc. When adding zinc into NP or NPK fertilizers, either zinc sulphate or zinc oxide is used. In most cases, zinc sulphate and zinc oxide are applied at rates between 20 and 100kg per hectare, depending on soil tests.

For farmers to achieve high-yielding, high-quality crops, they should manage a total crop production system. This includes applying a balanced fertilizer approach using optimum nutrient levels in balance with each other. For example, as shown in Figure 3, there is a good yield responses to the application of NPK fertilizer, but the highest yield was obtained only when balanced with zinc.

Figure 3: Productivity and Extra Value of Rice and Wheat with NPK Fertilizer and NPK-Zn in India



Department of Soil Sciences and Agricultural Chemistry, TNAU, Coimbatore (1994)

Examples of cost benefits of zinc fertilizer

Several published reports are available showing significant cost-benefit effects of zinc fertilizers for resource-poor farmers, especially in regions where soil zinc deficiency is of particular concern, such as India (as seen in Table 4), Turkey, Pakistan, and China.

- Nearly 50% of Indian soils are zinc deficient. Analysis of about 250,000 soil samples and 25,000 plant samples collected in India indicated that approximately 50% of the soil samples and 45% of the plant samples contained deficient levels of zinc (Singh, 2007). According to Singh, 325,000 tons of zinc should be applied annually by 2025 in order to maintain an adequate zinc nutritional status of crop plants in India.
- Field trials in Pakistan showed that enrichment of seeds with zinc resulted in marked increases of yield and seed concentrations of wheat and chickpea. According to the calculations, increasing seed zinc concentration was very cost-effective and resulted in net benefit-to-cost ratios of 75 for wheat and 780 for chickpea (Harris et al, 2008).

  In China, zinc fertilizers are commonly applied to maize, rice, wheat, soybean, and many horticultural crops. One study showed that when zinc was added to five different types of crops, crop yields increased between 3.6% and 35.3% in wheat, rice, soybean, and maize and up to 87.9% in oranges (Alloway, 2007).
- In field trials on four varieties of wheat grown under irrigated conditions in Turkey, the increases in yield by zinc fertilizers ranged from 29% to 355%, with an average increase in wheat yield of 58%. The average increase in value per hectare of the four wheat varieties was $477. If calculated at a 20% yield increase, which may be a more realistic long-term yield benefit of using zinc fertilizer, the farmer could expect to make an additional $123 per hectare (Phillips, 2006).

Table 4: Zinc in Cereals and Cotton in Farms in India Yield Improvement and Value Increase

Improvement Level	Zn Rate kg/ha	Zn Cost (USD/ha-1)	Yield Increase (kg/ha-1)	Value Increase (USD/ha-1)	Benefit-to-Cost Ratio
Wheat*					
Lowest	2.10	5.0	420	134.2	21:1
Average	5.47	13.1	970	139.0	11:1
Best	5.25	12.5	3050	780.4	62:1
Rice*					
Lowest	5.00	12.0	573	137.0	11:1
Average	6.70	16.1	889	118.0	7:1
Best	8.40	20.2	1110	268.4	13:1
Maize*					
Lowest	5.00	12.0	350	79.0	7:1
Average	5.65	13.6	936	112.0	8:1
Best	6.30	15.1	1521	380.3	25:1
Cotton*					
Lowest	5.25	12.6	215	43.3	3:1
Average	5.42	13.0	323	132.0	10:1
Best	5.60	13.4	430	98.4	7:1

* Assumes: Wheat = $144/t, Rice = $133/t, Maize = $120/t, and Cotton = $411/t
Compiled from: Rattan, R.K., Datta S.P., Saharan Neelam, and Katyal, J.C., Fertilizer News. 42 (12): 75-89 (1997)

Conclusion

Zinc is an essential micronutrient for normal growth, development, and health of plants and human beings. Large areas of agricultural land are now known to be deficient in zinc, causing severe limitations in crop productivity and nutritional quality of the food crops. Still, in many countries, zinc deficiency is unrecognized or underestimated and untreated. Therefore, there is an urgent need to understand and address zinc deficiency in these countries in order to contribute to both crop production and human health. Zinc is also particularly important to help crop plants better tolerate various stress factors such as drought, heat, and salinity.

Applying zinc fertilizers to soil and/or onto plant leaves offers a simple and highly effective solution to zinc deficiency problems in crop plants and to increasing zinc concentrations of foods. This strategy greatly prevents unnecessary loss of food production and helps improve public health. For example, enrichment of rice and wheat grain with zinc may save the lives of up to 48,000 children in India annually (Stein et al, 2007).

For millions of people around the world, a few extra milligrams of zinc each day can make the difference between illness or death and a healthy, productive life. By ensuring that crops have an adequate supply of zinc, we can help address this global problem by providing significant health, social, and economic benefits.

Acknowledgments

IZA thanks Professor Ismail Cakmak of Sabanci University, Istanbul for his general contributions and work that served as a source of material for this effort.

References

1. Alloway, B.J. 2008: Zinc in Soils and Crop Nutrition. IZA Publications. International Zinc Association, Brussels.
2. Andreini, C, Banci, L. and Rosato, A. 2006: Zinc through the three domains of life. Journal of Proteome Research 5: 3173-3178.
3. Black R.E. 2008: Zinc deficiency, infectious disease and mortality in the developing world. Journal of Nutrition 133: 1485-1489.
4. Cakmak, I. 2008: Enrichment of soil grains with zinc: agronomic or genetic biofortification? Plant and Soil 302: 1-17.
5. Cakmak et al. 1999: Field Crops Research 60: 175–188.
6. Department of Soil Science and Agricultural Chemistry, 1994: TNAU Coimbatore.
7. Fisher, Nigel 2008: Mining to Enrich Human Potential. International Zinc Association, London.
8. Harris et al, 2008: "On-farm" seed priming with zinc in chickpea and wheat in Pakistan. Plant and Soil 306: 3-10.
9. Jiao et al, 2004: Journal of the Science of Food Chemistry 84: 777-785.
10. Phillips, M.R. 2006: Economic Benefits from Using Micronutrients for the Farmer: 5-6.
11. Sillanpaa, M. 2006: Micronutrients and the Nutrient Status of Soils: A Global Study.
12. Singh, M.V. 2007: Micronutrient Deficiencies in Global Crop Production: 93-125.
13. Singh, M.V. 2009: Micronutrient Nutritional Problems in Soils of India and Improvement for Human and Animal Health. Indian Journal of Fertilizers: 11-26.
14. Stein et al, 2007: Publication of Health Nutrition 10: 492-501.
15. World Health Organization (WHO), 2002: The World Health Report.

Zinc Nutrient Initiative

The Zinc Nutrient Initiative is a program launched by IZA that is dedicated to promoting the use of zinc nutrients to correct zinc deficiency in soils and crops.

Zinc ...essential for life

The International Zinc Association (IZA) is a non-profit organization that promotes zinc's essentiality in present and potential product applications, human health, and crop nutrition, and highlights zinc's contribution to sustainable development.

International Zinc Association
1822 E. Highway 54, Suite 120, Durham, NC, USA 27713 • Tel: +1-919-361-4647 • Fax: +1-919-361-1957
168 Avenue de Tervueren/Box 4, B-1150 Brussels Belgium • Tel: +32-(0)2-776-0070 • Fax: +32-(0)2-776-0089
Email: info@zinc.org • Web: www.zinc.org