

Part 1 Zinc: A Key Nutrient in Crop Production

Zinc deficiency represents a common micronutrient deficiency problem in human populations.

Dr. Ismail Cakmak

The Fluid Journal • Official Journal of the Fluid Fertilizer Foundation • Fall 2011 • Vol. 19, No. 4, Issue # 74

Summary: *It is estimated that zinc (Zn) deficiency affects, on average, one-third of the world's population and is known to be the major reason for high incidence of micronutrient malnutrition in human populations. Soil Zn deficiency is also an important constraint to crop production and nutritional quality of grains. Based on a range of studies, the average concentration of Zn in whole grain wheat in various countries ranges between 20 to 35 mg Kg⁻¹, which is inadequate for human nutrition. Evidence is available showing that seedlings derived from seeds with low concentrations of Zn are highly susceptible to biotic and abiotic stress conditions during seed germination and early growth stages. These results indicate that improving Zn concentration of seeds/grains is also important for better agronomic performance of seedlings. Additionally, biofortification of food crops with Zn is considered a useful intervention against problems in human nutrition by using agricultural tools such as breeding and fertilization. Biofortification strategy is also proving highly promising as a cost effective and long-term solution to Zn deficiency in human populations. Developing new Zn-dense genotypes by using plant breeding, however, takes a long time. The success of a breeding program depends on a sufficient amount of readily available pools of Zn in soil solution.*



Zinc has particular physiological functions in all living systems, such as:

- Maintenance of structural and functional integrity of biological membranes
- Detoxification to highly toxic oxygen-free radicals
- Contribution to protein biosynthesis and gene expression.

Among all metals, Zn is needed by the largest number of proteins. Zinc-binding proteins make up nearly 10 percent of the proteomes in eukaryotic cells, indicating that at least 2,800 proteins are Zn dependent. About 36 percent of the eukaryotic Zn proteins are involved in gene expression. Its deficiency, therefore, results in diverse impairments in biological systems.

Zinc deficiency represents a common micronutrient deficiency problem in human populations, resulting in severe impairments in human health. Major health complications caused by Zn deficiency include:

- Impairments in brain function
- Weakness in immune system to deadly infections
- Alterations in physical development.

Zinc deficiency is known to be responsible annually for deaths of nearly 450,000 children under age five. Analyses under the 2008 Copenhagen Consensus identified Zn deficiency, together with vitamin A deficiency, as the top priority global issue.

It is estimated that Zn deficiency affects, on the average, one-third of the world's population, ranging from 4 to 73 percent in different countries. Low dietary intake is known to be the major reason for the high incidence of Zn deficiency in human populations, particularly in those regions where soils are low in available Zn and cereal grains having low Zn concentration are the major source of calorie intake.

Soil Zn Deficiency

Soil Zn deficiency represents an important constraint to crop production and nutritional quality of grains. Nearly half of the cultivated soils are affected by low levels of plant available Zn, especially calcareous soils of arid and semi-arid regions. Major soil factors resulting in adverse impacts on solubility of Zn in soils include high pH, low organic matter, low soil moisture, and high metal oxides with large fixing capacity for Zn (Figure 1).

Concentration. Since food crops,

particularly cereal crops, are inherently low in grain Zn concentration, growing them on potentially Zn-deficient soils further reduces Zn concentration of food crops and thus dietary intake of Zn by human populations. Based on a range of reports and survey studies, the average concentration of Zn in whole grain wheat in various countries ranges between 20 to 35 mg kg⁻¹, which is not adequate for human nutrition with Zn. Same situation applies to rice and maize, which contain even less Zn than wheat. In the case of Zn deficient soils, the reported Zn concentrations for wheat are much lower and range between 5 to 15 mg kg⁻¹. These values indicate high urgency of biofortification of food crops with Zn.

Yields. Soil Zn deficiency has severe impacts on crop yields. In certain regions with very low plant-available Zn in soils (DTPA-Zn around 0.1 mg kg⁻¹), cereal production is not economical, thus Zn fertilization is necessary to obtain a proper yield. As shown in Central Anatolia, application of Zn fertilizers in such soils enhances grain yield by a factor of 6 to 8 to around 2,000 kg ha⁻¹. In general, soils containing less than 0.5 mg DTPA-extractable Zn are considered

potentially Zn deficient that may respond well to Zn fertilizers. Low concentration of Zn in seeds also has negative impacts on growth of plants in Zn deficient soils. Evidence is available showing that seedlings derived from seeds with low concentrations of Zn are highly susceptible to biotic and abiotic stress conditions during seed germination and early growth stages.

These results indicate that improving Zn concentration of seeds/grains is also important for better agronomic performance of seedlings. Seeds with high nutrient density, especially with micronutrients, contribute greatly to better agronomic performance of seedlings, besides its positive impacts on human nutrition. In the future, particular attention should be paid, therefore, to routine seed analyses for composition of mineral nutrients. Harvesting seeds with high nutrient density represents an important challenge for both better human nutrition and better seedling vigor.

Problem solving

Supplements. Currently, various strategies are being discussed to alleviate Zn deficiency as it relates to problems in human nutrition. Giving Zn supplements to the target populations or fortification (artificial enrichment) of foods with Zn is considered one useful intervention against the problems. Although these approaches are effective in reducing the extent of the problem, these are not always affordable long-term nor easily accessible to target populations living in rural areas of developing countries.

Plant breeding. Alternatively, agriculture offers simple and cost-effective solutions to the problem. Plant breeding and agronomy represent cost effective strategies to alleviate micronutrient malnutrition problems by increasing grain concentrations of micronutrients and their daily intake through diets. It is well-documented that plant genotypes are highly different in use of poorly soluble sources of micronutrients in soils and translocation of micronutrients into grain. For example, in case of Zn, genotypes of a given crop species show impressive genetic variation for Zn accumulation in grain, especially wild and primitive forms of food crops. Such large natural variations in seed concentrations of Zn can be exploited under breeding programs to improve modern cultivars with high concentrations of Zn (e.g., genetic biofortification). The genetic biofortification strategy is a highly

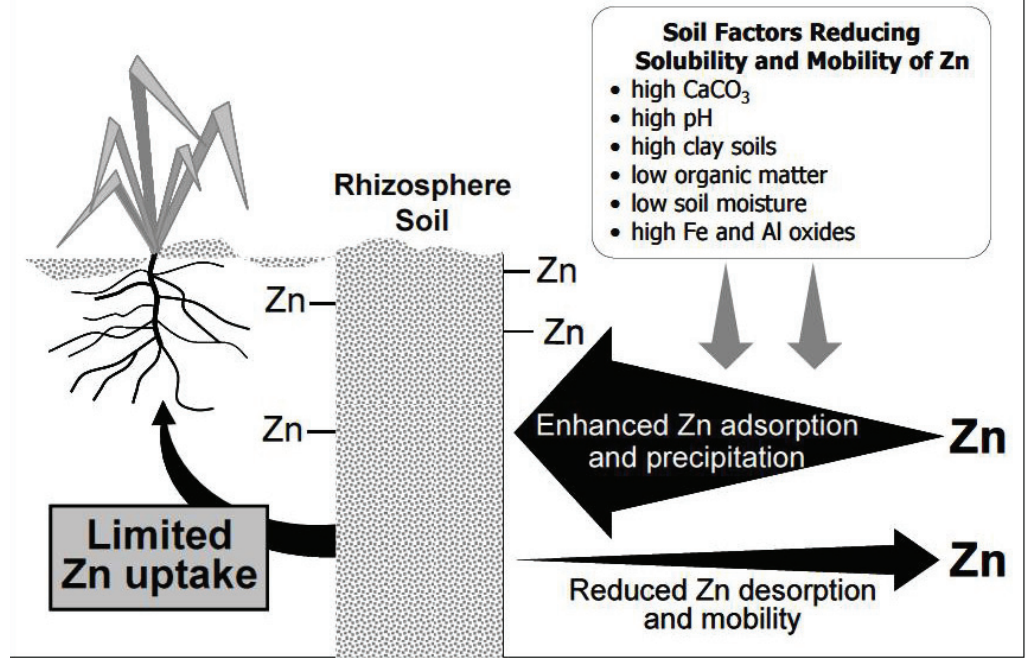


Figure 1. Main soil factors affecting solubility and root uptake of Zn in soils (Cakmak, 2008).

promising, cost-effective and long-term solution to Zn deficiency problems in human populations. Currently, impressive progress is being made under different breeding programs in improving stable food crops with high concentrations

“Improving zinc concentration improves seedling performance.”

of micronutrients, especially under the HarvestPlus program (www.harvestplus.org), which is established under the Consultative Group on International Agricultural Research. The Harvest Plus program uses plant breeding tools to improve stable food crops with Zn, Fe, and vitamin A, and to contribute to human health globally. The main sponsor of this global program is the Bill and Melinda Gates Foundation.

Cultivars. Developing new genotypes by using the plant breeding approach takes a long time however, plus the success of a breeding program depends on a sufficient amount of readily available pools of Zn in soil solution. High Zn deficiency incidence in human populations is observed mainly in the regions where soils are very low in plant-available (chemically soluble) Zn. The majority of cereal-cultivated soils globally has a number of adverse soil chemical factors (i.e., high pH values, low soil moisture, and low organic matter) that can potentially diminish the expression

of high grain Zn trait and limit the capacity of newly developed (biofortified) cultivars to absorb adequate amounts of Zn from soils and accumulate in grain. For example, among the soil chemical factors, soil pH plays a decisive role in chemical solubility and root uptake of Zn. In a pH range between 5.5 and 7.0, Zn concentration in soil solution is decreased up to 45-fold for each unit increase in soil pH. This increases risk for inducing Zn deficiency problems in plants and leading to low yield and simultaneously low Zn concentrations in grain.

Increasing cultivation of high-yielding cultivars may further contribute to the extent of Zn deficiency in soils by progressively depleting available soil Zn pools. This depletion of available Zn pools by large off-take in agricultural produce may occur to a greater extent in soils with low Zn solubility. Intensification of farming by introducing high-yielding cultivars contributes not only to Zn depletion in the soil but also to dilution of Zn in the harvested parts of plants such as seeds/grains. Increasing evidence is available showing that selection of modern cultivars with high yield capacity over more than 100 years caused a clear decline in grain concentrations of minerals, especially micronutrients.

This is Part 1 of a two-part series. Part 2 will appear in the Winter 2012 issue and cover Zn fertilizer strategies for improving yield and grain Zn concentrations.

Dr. Cakmak is a Professor at Sabanci University, Istanbul, Turkey.