Part 2 Zinc Fertilizer Strategy For Improving Yield

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

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Summary: *Improving zinc (Zn) nutritional status of food crops by applying soil and/or foliar Zn fluid fertilizers offers a practical and rapid solution to the well-documented Zn deficiency problem in human populations. In target countries with high incidence of Zn deficiency, new fertilizer policies should be developed to promote the application of Zn-containing fertilizers to the soil and/or foliar application for a quick biofortification of food crops with Zn.The returns associated with Zn fertilization of food crops are expected to be very high with significant impacts on humanity and also crop production.*

A short-term and complementary solution for improving yield and grain Zn concentrations is required if we are to alleviate Zn deficiency-related problems in human populations. In this regard, employing sound agronomics (e.g., fertilizer strategy) offers quick and effective ways to biofortify food crops with Zn at desirable levels. Fertilizer strategy simultaneously also contributes to better yield, depending on the severity of soil Zn deficiency. There are several factors affecting the solubility and root uptake of Zn in soils as discussed below briefly.

Chemical solubility. Increasing chemical solubility of Zn in the rhizosphere by adding different organic amendments into soils, shifting from mono-cropping into inter-cropping systems, and applications of Zn fertilizers to soil are well-documented agricultural strategies that can significantly contribute to root uptake and grain density of Zn.

Organic materials. It has been well documented that addition of different organic materials into soils as compost or farmyard manures greatly contributes to solubility and spatial availability of Zn and also the total amount of plant-available Zn concentrations (e.g., DPTA-extractable Zn) in soils. Existence of a strong, positive relationship between soil organic matter and soluble Zn concentrations in rhizosphere soil was found in 18 different soils collected in Colorado, indicating the importance of organic matter in improving spatial availability of Zn to plant roots.

Intercropping dicots. In the case of bio-fortification of dicots with micronutrients, intercropping dicots together with cereal species is a very useful practice as presented in Figure 1. Iron concentration in different parts of peanut plants is significantly increased by intercropping with maize plants, possibly due to the root-induced changes in solubility of micronutrients and/or increases in biological activity in the rhizosphere.

Source selection. Application of Zn fertilizers or NPK fertilizers containing Zn represents a useful and quick approach to improving concentrations of Zn in food crops. Zinc can be directly applied to the soil as both organic and inorganic compounds. Zinc sulfate (ZnSO4) is the most commonly applied inorganic source of Zn due to its higher solubility and lower cost. Zinc can also be applied to soils in the form of ZnO and Zn-oxysulfate. A factor affecting the selection of the source of Zn fertilizers is how uniformly they can be applied to the soil. To ensure uniform application of Zn into the soil, Zn can be incorporated into, or coated on the granular nitrogen, phosphate and potash (NPK) fertilizers. In India, urea is the most commonly applied N fertilizer and a good option for enrichment with Zn. In various field tests conducted with wheat and rice in India, it has been demonstrated that enriching urea fertilizer with Zn up to 3 percent improved significantly both grain yield and grain Zn concentration (Table 1). In these experiments, ZnO and ZnSO4 have been used to enrich urea with Zn, and both Zn sources were similarly effective in improving grain Zn concentrations, although ZnSO4 always tended to be better than ZnO in increasing grain Zn and improving yield.

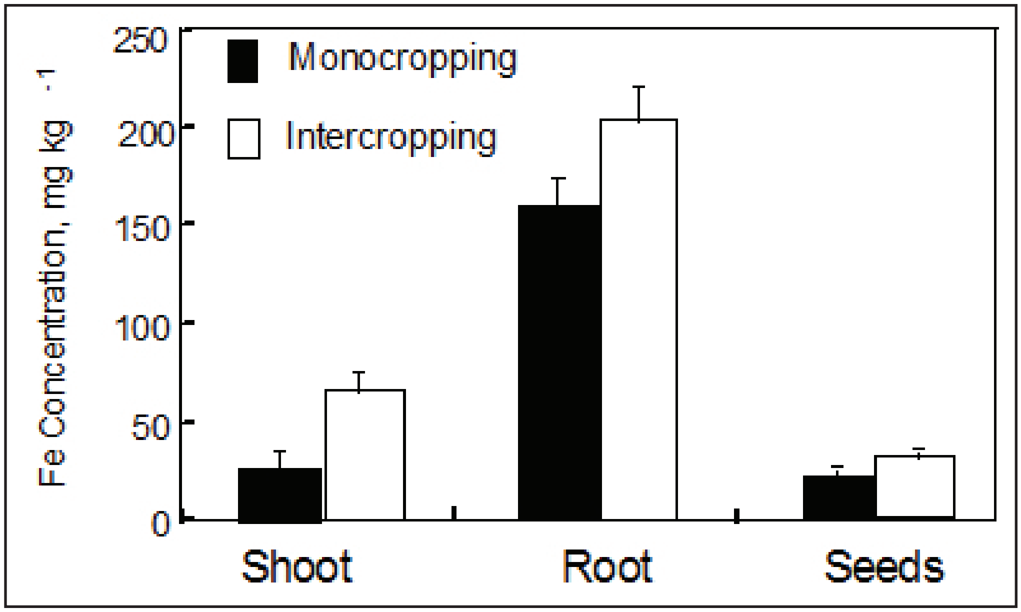

Figure 1. *Effect of intercropping peanut with maize plants on Fe concentration of shoot, roots, and seeds of peanut plants grown on a calcareous soil (Zuo and Zhang, 2009).*

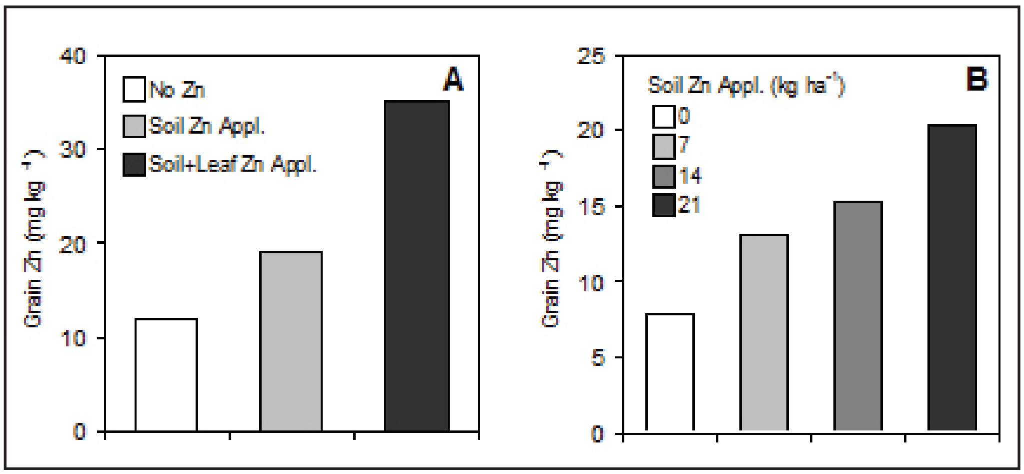

Figure 2. *Grain Zn concentrations of durum wheat treated by foliar application of ZnSO4 (A) and increasing amount of Zn fertilization into soil (B) grown on a highly Zn-deficient calcareous soil under field conditions in Central Anatolia (Cakmak et al., 2010a)*

Foliar application. In Central Anatolia, where Zn deficiency is a well-documented problem in Turkey, soil application of Zn fertilizers significantly increased both grain yield and grain concentrations of Zn (Figure 2). However, combined application of soil and foliar Zn fertilizers is more effective in enhancing grain Zn concentration, and causes increases in grain Zn concentration up to three-fold. The effect of soil-applied Zn fertilizer on grain Zn concentration is not sufficiently high in soils with an adequate amount of plant available Zn. Under such conditions, foliar application of Zn fertilizers is an essential practice in order to improve grain Zn concentration of cereal crops at adequate amounts for better human nutrition. Recent studies report 0.5 to 1.0 kg Zn ha-1 as the most commonly used rates of Zn in foliar applications to correct Zn deficiency in plants. Foliar application of Zn fertilizers can be performed by using either ZnSO4 or chelated forms of Zn (e.g., Zn-EDTA). Our recent results show that ZnSO4 is a better Zn source in increasing grain Zn concentration when compared to ZnEDTA and ZnO when foliar sprayed on wheat.

Timing of Zn spray on foliage plays an important role in the effectiveness of the foliar-applied Zn fertilizers in increasing grain Zn concentration. Particular increases in Zn deposition into grain can be achieved when foliar Zn fertilizers are applied to plants at a late growth stage. Past studies have monitored changes in Zn concentration in wheat grain during grain development and found that the highest accumulation of Zn in grain takes place during the milk stage of grain development. It has been shown that foliar spray of Zn late in the growing season in wheat (e.g., at milk and dough stage) resulted in much larger enhancement in grain Zn concentration when compared to the application of Zn at earlier growth stages (Table 2). Increases in concentration of whole grain Zn associated with late foliar Zn applications were also well reflected in various fractions such as embryo, aleurone, and endosperm. The increases found in the concentration of endosperm Zn through Zn spray during the reproductive growth stage were particularly impressive (Figure 3). These increases in endosperm Zn concentration may have important impacts on human nutrition because the endosperm part is the most commonly eaten part of wheat in a number of countries where Zn deficiency incidence in human population is very high.

“High zinc concentrations ensure good root growth”

Nutritional status. Nitrogen nutritional status of plants has also positive impacts on grain concentration of Zn. Increase in grain Zn concentration by applying soil and/or foliar Zn fertilizers is maximized when the N nutritional status of plants is improved either by soil or foliar application of N fertilizers (e.g., urea). It seems that N and Zn act synergistically in improving grain Zn concentration in wheat when Zn and N are sufficiently high in growth media or plant tissues. Most probably, improving N nutritional status of plants contributes to better root Zn uptake and/or Zn accumulation in grain by affecting at least one of the following processes:

1. root exudation of compounds contributing to solubility and uptake of Zn (e.g., phytosiderophores)
2. root growth and morphology
3. abundance and expression of transporter proteins mediating uptake and transport of Zn in root cells
4. nitrogenous compounds

contributing to mobility and transport (and re-translocation) of Fe and Zn by chelation (e.g., nicotianamine, amino acids)

5. increasing amount of seed proteins that bind/store Zn.

The positive impacts of N nutrition on grain Zn indicate that increasing attention should be paid to N management in cultivation of food crops and in establishing breeding programs for an effective biofortification of grains with Zn.

Agronomic benefits

Increasing seed concentration of micronutrients by soil and/or foliar applications of Zn also provides additional positive impacts in terms of seed vitality and seedling vigor. Earlier reviews show that when seeds with low concentration of Zn are sown, the ability of the new crop to withstand environmental stresses at the early growth stages is greatly impaired. Plants emerging from seeds with low Zn have poor seedling vigor and field establishment on Zn-deficient soils. Under rain-fed conditions, wheat plants derived from seeds containing 1.5μg Zn per seed had better seedling establishment and two-fold higher grain yields than wheat plants that emerged from seeds containing only 0.4μg Zn per seed. Similarly, another study showed that increasing seed Zn contents from 0.25μg per seed to 0.70μg per seed significantly improved root and shoot growth of wheat plants under Zn deficiency. Priming seeds in Zn-containing solutions is an alternative way to increase seed Zn prior to sowing. High Zn concentrations in seeds ensure good root growth and contribute to better protection against soilborne pathogens.

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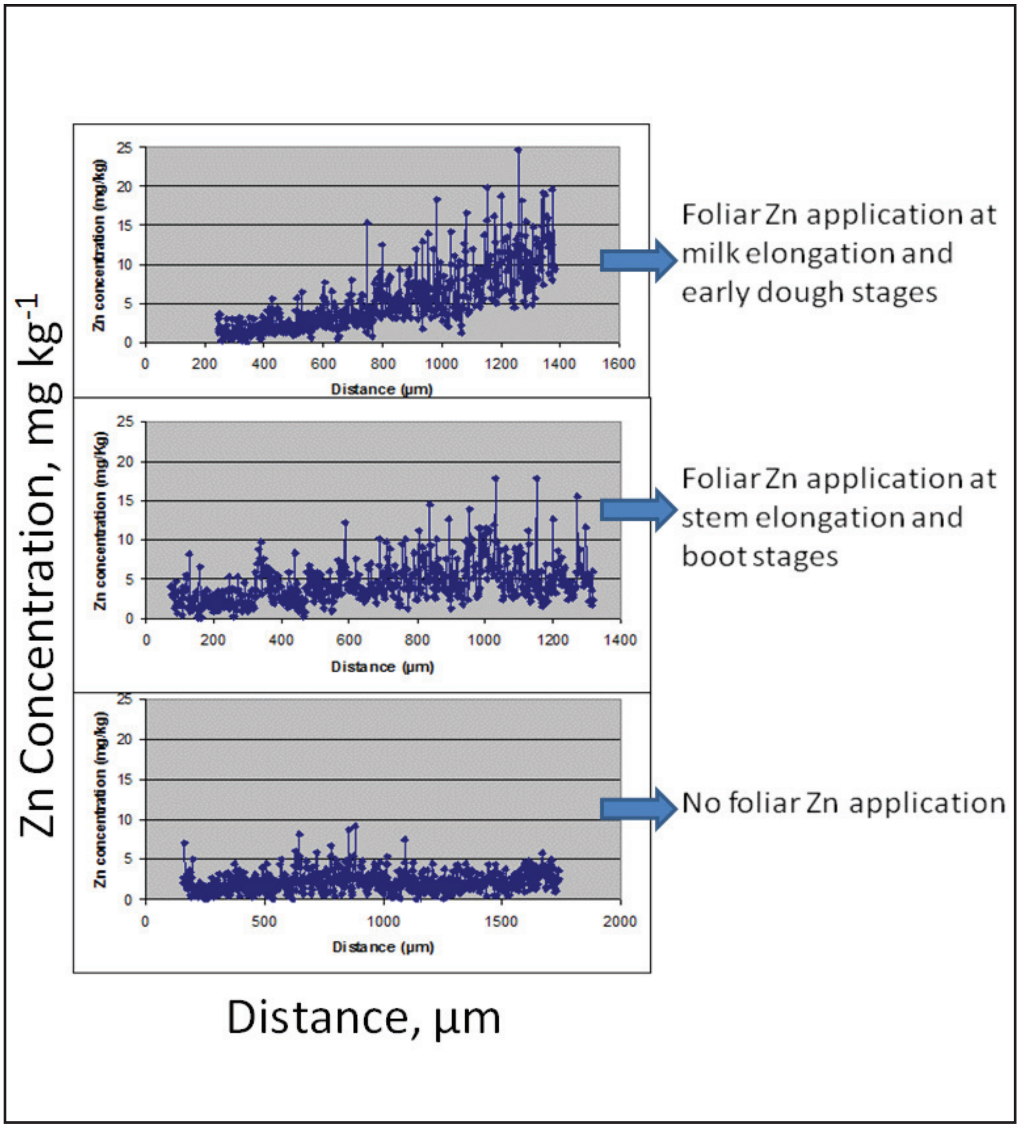

Figure 3. *Changes in Zn concentrations of endosperm part of bread wheat grains harvested at the Adana locations in Turkey. For further details see Cakmak et al. 2010b.*

Table 1. Effect of Zn-enriched urea (ZEU) on grain yield and grain Zn concentrations of aromatic rice grown under field conditions in India, 2008.

Treatments	Zn Added	Grain Yield	Grain Zn Concentration
	(kg ha-1)	(ton ha-1)	(mg kg-1)
Prilled Urea	-	3.87	27
0.5% ZEU	1.3	4.23	29
1.0% ZEU	2.6	4.39	33
2.0% ZEU	5.2	4.60	39
3.0% ZEU	7.8	4.76	42

Table 2. Zn concentrations of the whole grain and the bran, embryo, and endosperm fractions of wheat grown under field conditions with foliar spray of 0.5% $ZnSO_4.7H_2O$ at different growth stages.

	Zn concentration (mg kg-1)							
	Konya				Adana			
Foliar Zn Treatment Stages	Whole Grain	Bran	Embryo	Endosperm	Whole Grain	Bran	Embryo	Endosperm
Control (No Zn appl.)	12	20	38	8	32	42	70	11
Stem + Booting	19	28	47	10	51	72	96	15
Milk + Dough	25	41	63	15	57	88	98	16