Zinc Deficiency in Indian Soils is Associated with Low Crop Productivity and Crop Quality

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SUMMARY

Zinc deficiency is widespread in soils and crops worldwide. Almost half of the soils in the world are deficient in Zn and India is no exception. About 40% of soil samples analysed for available Zn were found deficient in India. Significant improvement in crop yield and quality through balanced application of Zn has been reported across India. Adequate Zn application to crops is important for the food and nutritional security of India.

KEYWORDS:

human health; crop quality; micronutrients

ABBREVIATIONS AND NOTES:

Zn = zinc; N = nitrogen; P = phosphorus; K = potassium; S = sulphur

Zinc deficiency in plants delays photosynthesis and N metabolism, reduces flowering and fruit development, and prolongs growth periods. All of these factors result in delayed maturity, lower yield, poor produce quality, and sub-optimal nutrient use efficiency. Some of the common deficiency symptoms of Zn in plants appear as light green, yellow, or bleached spots in interveinal areas of older leaves; small size of the emerging leaves, often termed as "little leaf"; and in case of severe deficiency, small inter-nodal distances so that all the leaves appear to come out from the same point, termed as "rosetting." It is estimated that almost half of the soils in the world are deficient in Zn (Alloway, 2008). Since cereal grains have inherently low concentrations of Zn, growing these crops on potentially Zn-deficient soils further decreases grain Zn concentration.

Zinc is considered the fifth most important yield-limiting nutrient (following N, P, K, and S) in India's upland crops, and in lowland crops like rice, it is second only to N. About 40% of soil samples analysed for available Zn in India were found to be deficient (**Figure 1**). Zinc plays a key role in plants as both a structural constituent and a regulatory co-factor for a wide range of different enzymes and proteins in various biochemical pathways. These pathways include carbohydrate metabolism, photosynthesis, conversion of sugars to starch, protein metabolism, auxin (growth regulator) metabolism, pollen formation, maintenance of the integrity of biological membranes, and resistance to infection by certain pathogens.

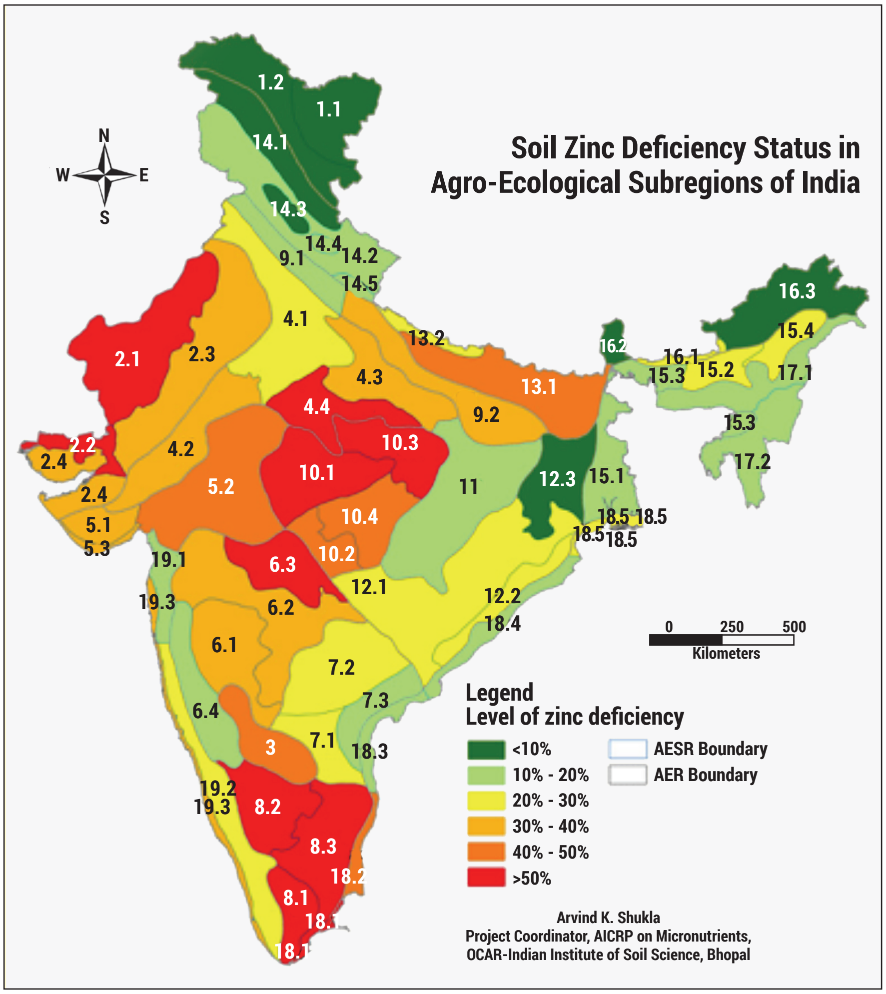

Figure 1. Soil zinc deficiency status in India (Shukla and Tiwari, 2016).

There are multiple reasons for the increasing incidences of Zn deficiency in India, including large Zn removals due to high crop yields and intensive cropping systems, lesser application of organic manures, use of high analysis fertilizers, increased use of phosphatic fertilizers resulting in P-induced Zn deficiency, and the use of poor quality irrigation water with high calcium carbonate content.

The critical level of Zn in Indian soils is 0.6 ppm and there is a growing concern that it should be increased to 1.2 ppm, or higher, as the intensity of crop production increas-

Table 1. Refined critical limit of Zn for some soils and crops at different locations.

Location	Crop	----- Zn, mg/kg ----- Soil	Plant
Akola, Maharashtra	Soybean	0.65	24.3
Coimbatore. Tamil Nadu	Maize	0.90	24.8
Pantnagar, Uttarakhand	Lentil	1.20	9.6
Pantnagar, Uttarakhand	Chickpea	1.20	19.2
Nainital, Uttarakhand	Soybean	1.24	22.3

Shukla and Tiwari, 2016.

Table 2. Response of different crops to Zn application.

Crop	Location	On-farm trials	Grain yield, t/ha Zn 0	Zn 5 / Zn 10*	% Response Zn 5 / Zn 10
Rice	Assam	43	5.1	5.6	12
Rice	Jharkhand	46	3.8	4.0	9.3
Rice	West Bengal	6	4.8	5.3	10
Chickpea	Maharashtra	5	1.0	1.1	9.4
Cotton	Maharashtra	25	1.3	1.5	9.8
Maize	Maharashtra	5	2.6	2.9	10
Soybean	Maharashtra	36	1.1	1.2	8.8
Wheat	Maharashtra	16	3.9	4.2	8.8
Cabbage	Tamil Nadu	2	39.5	42.5	7.3

*Zn application of 5 or 10 kg/ha. Shukla and Tiwari, 2016.

Table 3. Effect of different sources and mode of Zn application on grain yield (t/ha) and grain Zn content (mg/kg) in rice.

Treatment	Grain yield, t/ha	Grain Zn content, mg/kg
No Zn	6.3	19
2.5 kg Zn/ha ($ZnSO_4$)	7.2	21
5.0 kg Zn/ha ($ZnSO_4$)	7.4	22
2 Foliar Spray (0.5% $ZnSO_4$)	6.5	25
2 Foliar Spray (0.5% Zn-EDTA)	8.0	24
2.5 kg Zn/ha ($ZnSO_4$) + 1 Foliar Spray (0.5% $ZnSO_4$)	6.7	26
5.0 kg Zn/ha ($ZnSO_4$) + 1 Foliar Spray (0.5% $ZnSO_4$)	8.5	27
2.5 kg Zn/ha ($ZnSO_4$) + 1 Foliar Spray (0.5% Zn-EDTA)	7.7	24
5.0 kg Zn/ha ($ZnSO_4$) + 1 Foliar Spray (0.5% Zn-EDTA)	6.7	26

Shukla and Tiwari, 2016.

es. At present, about 40% of soils in India are classified as Zn deficient on the basis of the existing critical Zn limit. However, crop response to applied Zn has been observed in soils above the critical limit and it is generally believed that critical concentrations of Zn are site specific and one critical limit may not represent every soil type or crop. Shukla and Tiwari (2016) suggested that the critical limit of Zn may vary widely depending upon the soil types and crops grown, and it could be as high as 1.24 mg Zn/kg for soybean in Uttarakhand (**Table 1**).

Crop Response to Zinc Fertilizers

Crop response to Zn has been observed in most crops in almost all types of soils and agro-climatic conditions. While the response was found to be higher in grain crops like rice and maize, fruit and vegetable crops also responded well to applied Zn. Singh (2008) summarized the range of crop response to Zn based on over 15,000 on-station field trials in India:

Cereals: 420 to 550 kg/ha (16 to 23%)
Pulses: 170 to 460 kg/ha (7.3 to 28%)
Oilseeds: 110 to 360 kg/ha (11 to 40%)
Fodders: 90 to 4620 kg/ha (5 to 34%)

Shukla and Tiwari (2016) reported the response of Zn application on cereals (rice, wheat, and maize), pulses (chickpea), oilseeds (soybean), fiber crops (cotton), and vegetable (cabbage) based on a large number of experiments and on-farms trials in different states of India. Zinc application resulted in a 9 to 12% increase in rice yield at different locations. A similar range of responses were also observed for chickpea, cotton, maize, soybean, wheat, and cabbage at different locations (**Table 2**).

A field trial on source and method of Zn application in kharif rice in Nadia, West Bengal, showed that basal application of 5 kg Zn/ha through zinc sulfate solution ($ZnSO_4$•$7H_2O$), along with one foliar spray of 0.5% $ZnSO_4$ at the time of maximum tillering, increased the grain yield of rice to 8.5 t/ha and increased the grain Zn content by 47% (27 mg/kg) over no Zn application (**Table 3**). Field experiments on rice and wheat in India showed that application of Zn-enriched urea (up to 3% Zn) significantly enhanced both grain Zn concentration and grain yield in rice and wheat (Shivay et al., 2008).

Application of Zn not only increases the crop yield, but also improves its quality. For potato it increased ascorbic acid in tubers, reduced phenol content and enhanced reducing sugars, sucrose, and total sugar. Zinc was also found to increase the phenol tannin content of leaves, kernels, and seed coat of cotton. An increase in the energy value, as well as total lipids, crude protein, and carbohydrate content in rice, maize, wheat, mustard, chickpea, and blackgram were attributed to Zn application. Improvement in amino acids in cereals and sucrose recovery and juice quality in sugarcane were also reported (Kalwe et al., 2001).

A recent study (Myers et al., 2014) highlighted reduction in nutritional quality of grains due to climate change impact. Field trials in wheat, rice, maize, and soybean showed that high ambient CO_2 concentration significantly reduced Zn concentration in wheat grains by as much as 9.3%. Similarly, foliar Zn application increased water use efficiency

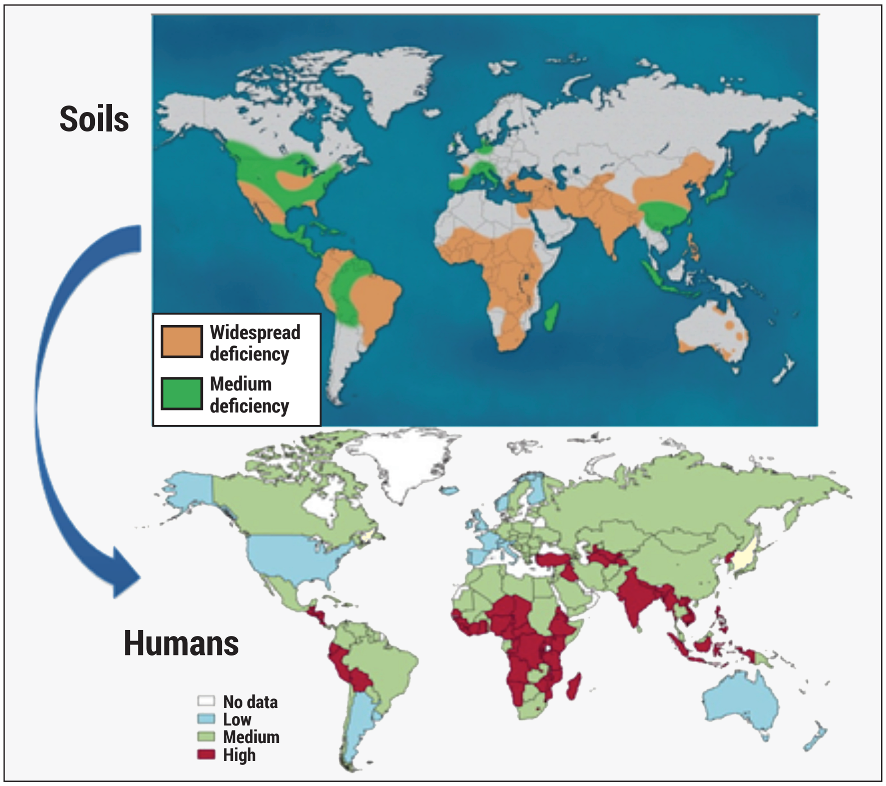

Figure 2. Worldwide Zn deficiency in soils and humans (Alloway, 2008).

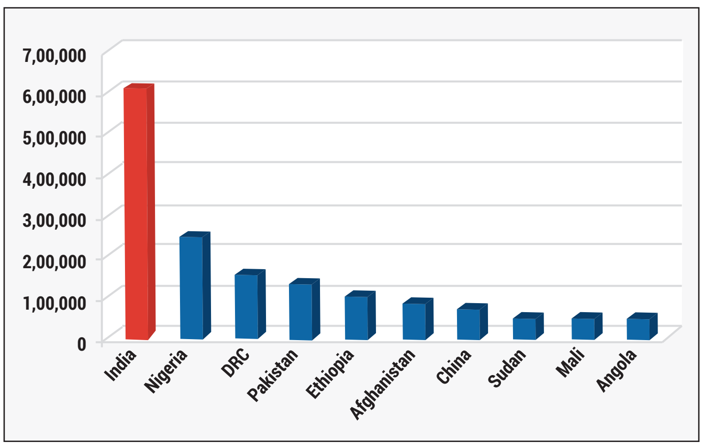

Figure 3. Deaths from diarrhoea and pneumonia in children under 5 (UNICEF, 2012).

and thereby reduced the negative effects of drought stress. Results support that appropriate Zn application could improve wheat growth under drought stress (Yavas and Unay, 2016). Therefore, adequate Zn application in crops would be necessary to alleviate climate change impacts on crop yield and nutritional quality.

Zinc in Human Health

It is estimated that about one third of the world's population suffers from Zn deficiency (Cakmak, 2008). Zinc deficiency, especially in infants and young children under five years of age, has received global attention. According to the World Health Organization, about 800,000 people die annually due to Zn deficiency including 450,000 that are children under the age of five. It is estimated that 60 to 70% of the population in Asia and sub-Saharan Africa could be at risk of low Zn intake. In absolute numbers, this translates into about 2 billion people in Asia and 400 million people in sub-Saharan Africa (Prasad, 2006). There is a high degree of correlation between Zn deficiency in soils and that in human beings (**Figure 2**).

Some of the reported symptoms of Zn deficiency in humans, specifically in infants and young children, are diarrhoea, pneumonia, stunted growth, weak immune system, delayed mental development, dwarfism, impaired cognitive function, behavioural problems, memory impairment, problems with spatial learning, and neuronal atrophy. Deaths due to diarrhoea and pneumonia in children under five is alarmingly high in India, higher than the sub-Saharan African countries or their neighbouring countries (**Figure 3**). This has drawn the attention from the government and policy makers in India and generated awareness on the critical role of Zn in human health. Consequently, Zn fertilizer consumption doubled over the last ten years in India (FAI, 2016).

Analysis of Zn content in soil, crop, animal, and human blood serum established a strong relationship and interdependence among the soil-plant-animal-human continuum, as depicted in **Table 4**.

Table 4. Soil Zn status vs Zn content in crops and its effect on serum Zn level in human blood.

Location	Soil Zn status	No. of people tested	Mean Zn status, ppm	
			Soil	Plant
Ranga Reddy (Andhra Pradesh)	Deficient	18	0.4	18
	Sufficient	44	0.7	27
East Godavari (Andhra Pradesh)	Deficient	16	0.4	14
	Sufficient	44	1.1	26

Singh, 2009.

Possible Solution to the Correction of Zinc Malnutrition

Ideally, cereal grains should contain 40 to 60 mg Zn/kg grain to meet the requirement of human nutrition and currently it is only 10 to 30 mg Zn/kg grain (Cakmak, 2008). Some possible solutions to the Zn malnutrition in the humans may be: i) Food supplementation, ii) Food fortification, or iii) Biofortification. The former two programmes require infrastructure, purchasing power, access to market and healthcare centres, and uninterrupted funding, which have their own constraints. Alternatively, biofortification (genetic or agronomic fortification of crops especially food crops with Zn) is the best option for alleviating Zn deficiency. This involves both the breeding of new varieties of crops with the genetic potential to accumulate a high density of Zn in cereal grains (genetic biofortification) and the use of Zn fertilizers to increase Zn density (agronomic biofortification). Although the plant breeding route is likely to be the most cost effective approach in the long run, the use of fertilizers is the fastest route to improve the Zn density in diets. In order to replenish the Zn taken up by the improved cultivars, higher and sustainable use of fertilizers is inevitable. Zinc fertilizer use efficiency is abysmally low and does not exceed 2 to 5% in crops, which continues to be a challenge. Therefore, sustained research initiatives are needed to enhance the uptake of Zn through development of innovative fertilizer sources. Nanoscale or nanostructured materials as fertilizer carriers or controlled-release products for the building of the so-called ‘smart fertilizers’ can enhance the nutrient use efficiency (Rai et al., 2015).

Economics of Zinc Fertilizer Use

Many reports show the significant cost-benefit effects of Zn fertilizers for resource poor farmers, especially in regions where soil Zn deficiency is of particular concern. **Table 5** shows that the benefit-to-cost ratio was as high as 38:1 at a lentil farm in India, revealing that Zn application was remunerative to the farmers.

Conclusions

Zinc deficiency in crops and humans is a critical issue and a global challenge. The sustainable solution is to apply an adequate and balanced quantity of Zn in crop production, so that the soil health and food and nutritional security are ensured. This could be achieved by ensuring: 1) availability of new and innovative Zn fertilizer products for higher use efficiency; 2) timely access to quality Zn fertilizers; 3) increased stakeholder awareness on Zn requirement in the soil-plant-animal-human continuum; and 4) a supportive and conducive policy environment for encouraging the balanced fertilizer use by the farmers in India. **BCSA**

Table 5. Yield increase and benefit-to-cost ratio on some key crops in India.

Crop	Zn rate, kg/ha	Yield increase, kg/ha	Value of increase, Rs	Benefit:Cost ratio
Wheat	5.25	1,430	20,735	24:1
Rice	8.40	1,102	14,987	11:1
Maize	6.30	1,521	19,925	19:1
Chickpea	10.00	855	32,063	18:1
Lentil	2.62	440	16,500	38:1
Groundnut	5.50	690	25,875	28:1
Mustard	6.30	230	8,625	8:1
Cotton	5.60	430	16,125	17:1

Rattan et al., 2008.

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