Importance of zinc in crops and human health

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Introduction

Zinc is one of the 17 essential elements necessary for the normal growth and development of plants. It is among eight micronutrients essential for plants. Zinc plays a key role in plants with enzymes and proteins involved in carbohydrate metabolism, protein synthesis, gene expression, auxin (growth regulator) metabolism, pollen formation, maintenance of biological membranes, protection against photo-oxidative damage and heat stress, and resistance to infection by certain pathogens (Alloway 2008). Zinc deficiency in plants retards photosynthesis and nitrogen metabolism, reduces flowering and fruit development, prolongs growth periods (resulting in delayed maturity), decreases yield and quality, and results in sub-optimal nutrient-use efficiency. Some of the common deficiency symptoms of zinc in plants are light green, yellow or bleached spots in interveinal areas of older leaves; emerging leaves are smaller in size and often termed as “little leaf”, and exhibit rosetting, ie, the internodal distance becomes so short that all the leaves appear to come out from the same point.

Similarly, zinc is an essential nutrient for human health. It is vital for many biological functions in the human body. The adult body contains 2–3 g of zinc. It is present in all parts of the body including organs, tissues, bones, fluids and cells. It is vital for more than 300 enzymes in the human body, activating growth (height, weight and bone development), growth and cell division, immune system, fertility, taste, smell and appetite, skin, hair and nails, and vision. Some of the reported symptoms due to zinc deficiency in humans, especially in infants and young children include dwarfism (growth retardation), dermatitis (alopecia), impaired neurology, decreased immune function, infections and death. In industrialized countries, cases of mild zinc deficiency can be observed. The most common symptoms include dry and rough skin, dull hair, brittle finger nails, white spots on nails, reduced taste and smell, loss of appetite, mood swings, reduced adaptation to darkness, frequent infections, delayed wound healing, dermatitis and acne (Black 2008).

Zinc deficiency in soils

Zinc has emerged as the most widespread micronutrient deficiency in soils and crops worldwide, resulting in severe yield losses and deterioration in nutritional quality (Sillanpää 1982). It is estimated that almost half of the soils in the world are deficient in zinc. Since cereal grains have inherently low concentrations, growing them on these potentially zinc-deficient soils further decreases grain zinc concentration. The Food and Agriculture Organization of the United Nations (FAO) estimates that 50% of world’s soils growing cereal grains are zinc deficient. It further estimates that agricultural production must increase by 70% by 2050 to feed over 9 billion people worldwide.

India is no exception. Analysis of over 256,000 soil samples from all over India showed that about 50% of the soils were deficient in zinc (Fig. 1) and that this was the most common micronutrient problem affecting crop yields in India. The reasons for the increase of incidences of zinc deficiency include large zinc removals due to high crop yields and intensive cropping systems, less application of organic manures, use of high analysis fertilizers (such as urea and DAP in place of AS and SSP), increased use of phosphatic fertilizers resulting in phosphorus induced zinc deficiency and the use of poor quality irrigation water. The soil conditions that commonly lead to zinc deficiency in crops are low total zinc concentrations, such as sandy soils; highly weathered parent materials with low total zinc contents, such as tropical soils; high calcium carbonate contents, such as calcareous soils; neutral or alkaline pH, as in heavily limed soils or calcareous soils; high salt concentrations, ie, saline soils; peat and muck, as in organic soils; and high phosphate status; prolonged waterlogging or flooding, as in rice soils; and high

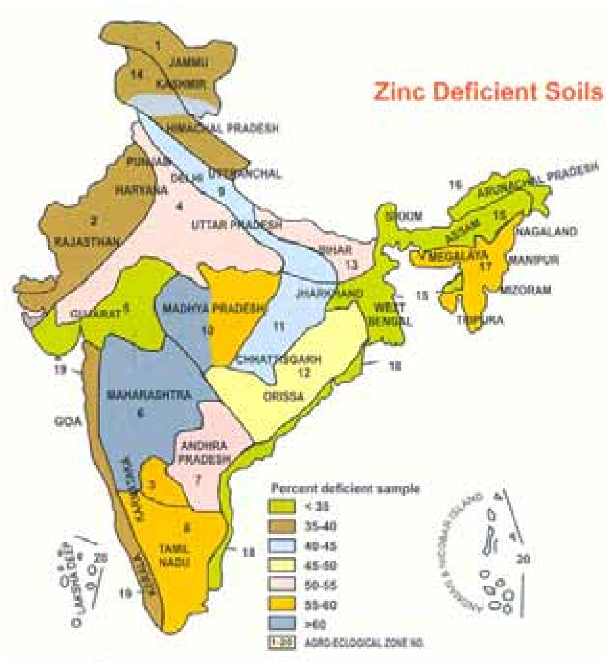

Figure 1. Extent of zinc deficiency in India (Source: Singh 2009).

magnesium and/or bicarbonate concentrations in soils or irrigation water (Alloway 2008). Zinc deficiency in India is expected to increase from the present level of around 50% to 63% in 2025 if the current trend continues. This is also because increasing areas of marginal lands are brought under intensive cultivation without adequate micronutrient supplementation.

The status of zinc deficiency in soils of India is shown in Table 1. About 50% or more soil samples tested were deficient in zinc in Maharashtra, Karnataka, Haryana, Tamil Nadu, Bihar, Orissa and Meghalaya. Increased cropping intensity in marginal lands and less use of micronutrients in the states of Bihar, Tamil Nadu, Maharashtra, Karnataka, Chhattisgarh, Jharkhand and the hill region has further escalated the magnitude of zinc deficiency. The states of Punjab, Haryana and part of Uttar Pradesh have, however, shown a build-up of zinc status and decline in zinc deficiency. This likely is due to greater awareness and use of zinc fertilizers by the farmers. This success story needs to be replicated elsewhere in the country.

Zinc deficiency is also widespread in soil types and climatic regions where primarily dryland/rainfed farming is practiced (Rego et al. 2005, Sahrawat et al. 2007, ICRISAT 2009). In these rainfed areas, farmers' fields found to be deficient in zinc were: 82% (out of 1926 samples) in Andhra Pradesh, 82% (out of 82 samples) in Gujarat, 74% (out of 1260 samples) in Karnataka, 18% (out of 28 samples) in Kerala, 100% (out of 73 samples) in Madhya Pradesh, 15% (out of 179 samples) in Rajasthan and 61% (out of 119 samples) in Tamil Nadu. These data show that zinc deficiency is widespread in the rainfed fields of the Indian semi-arid tropics. In a survey of soils across 21 districts, zinc deficiency was widespread. More than 75% soil samples were found to be deficient in zinc in 43% districts (Sahrawat et al. 2007).

There is a high degree of correlation between zinc deficiency in soils and that in human beings (Fig. 2). It is estimated that about one-third of the world's population suffers from zinc deficiency.

Zinc deficiency in humans

Zinc deficiency, especially in infants and young children under five years of age, has received global attention. Zinc deficiency is the fifth leading cause of death and disease in the developing world. According to the World Health Organization (WHO), about 800,000 people die annually due to zinc deficiency, of which 450,000 are children under the age of five. Globally, around 2 billion people are affected by zinc deficiency. It is also estimated that 60–70% of the population in Asia and Sub-Saharan Africa could be at risk of low zinc intake (Prasad 2006). Global cause of death in children below five years is depicted in Figure 3. It may be surprising to note that

Table 1. State-wise zinc deficiency in soils of India[1].

State	No. of soil samples	Deficient samples (%)
Andhra Pradesh	8,843	46.8
Bihar	19,257	54.0
Punjab	18,590	46.1
Gujarat	30,296	23.9
Haryana	21,968	60.5
Madhya Pradesh	33,505	44.2
Tamil Nadu	28,402	58.6
Uttar Pradesh	26,126	45.7
Maharashtra	545	83.0
Orissa	16,653	52.5
Meghalaya	95	57.0
Pondicherry	4,108	8.0
West Bengal	6,547	36.0
Rajasthan	183	21.0
Assam	2,165	34.0
Delhi	201	20.0
Himachal Pradesh	155	42.0
Jammu and Kashmir	93	12.0
Karnataka	27,860	72.8
Kerala	650	34.0
All India	256,355	48.8

1. Source: Singh (2009).

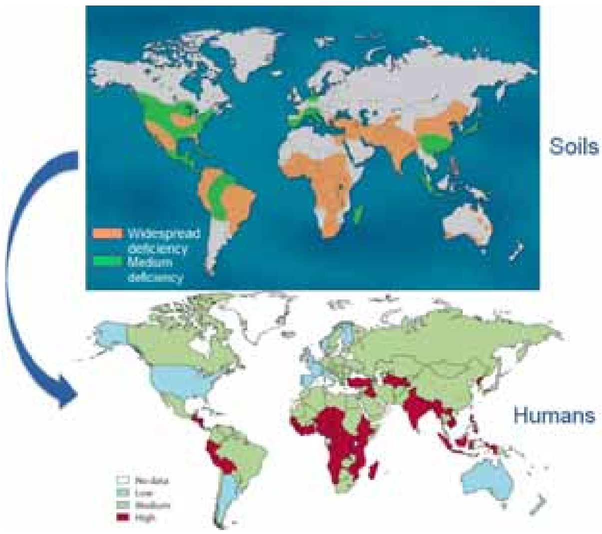

Figure 2. Worldwide zinc deficiency in soils and humans (Source: Alloway 2008, Black 2008).

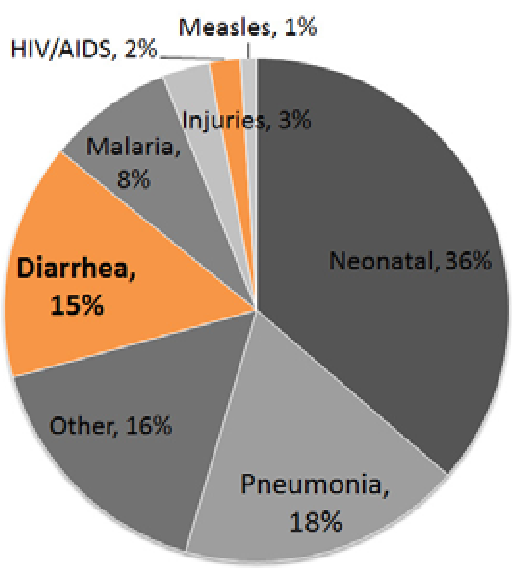

Figure 3. Global causes of death in children below five years (Source: UNICEF 2012).

Table 2. Response of crops to zinc in field experiments[1].

Crop	Field trials	Mean response to Zn	
		kg ha^{-1}	Percent
Chickpea	15	360	24
Groundnut	83	320	18
Pearl millet	236	190	13
Sorghum	83	360	41
Finger millet	47	350	14

1. Source: Tandon (2013).

15% of infant deaths are caused by diarrhea, compared to 2% by HIV/AIDS. Globally, 1.5 million deaths could be attributed to diarrhea alone. Country-wise deaths from diarrhea and pneumonia in children under five are illustrated in Figure 4, which clearly depicts that the casualty in India is alarmingly high. Zinc supplementation could prevent most of the deaths of children due to diarrhea and pneumonia (UNICEF 2012). Some typical symptoms related to zinc deficiency in humans are shown in Figure 5.

Everyone needs zinc. Children need zinc to grow, and adults need zinc to maintain health. Growing infants, children and adolescents, pregnant women and lactating mothers, athletes, vegetarians and the elderly often require more zinc. The primary source of zinc is food. The major sources of zinc are (red) meat, poultry, fish and seafood, whole cereals and dairy products. Zinc from meat is most available to the human body. The bioavailability of plant-based foods is generally lower due to dietary fiber and phytic acid, which inhibit the absorption of zinc. A balanced diet is the best way to provide the body with zinc.

Dietary sources of zinc to meet human health needs along with their average zinc content are oysters (25 mg $100g^{-1}$), meat (especially red meat) (5.2 mg $100g^{-1}$), nuts (3 mg $100g^{-1}$), poultry (1.5 mg $100g^{-1}$), eggs (1.3 mg $100g^{-1}$), milk products (1.2 mg $100g^{-1}$), cereals and bread (1 mg $100g^{-1}$), fish (0.8 mg $100g^{-1}$), sugars and preserves (0.6 mg $100g^{-1}$), canned and green vegetables (0.4 mg $100g^{-1}$), potatoes (0.3 mg $100g^{-1}$) and fresh fruits (0.09 mg $100g^{-1}$) (Black 2008).

Zinc deficiency – possible way out

The possible solutions to correct zinc deficiency in humans may be food supplementation, food fortification or biofortification. The former two programs require infrastructure, purchasing power, access to market and health care centers and uninterrupted funding, which have their own constraints. In addition, such programs will most likely reach the urban population, which is easily accessible, especially in the developing countries. Alternatively, the latter program, biofortification – fortification of crops (especially cereals) with zinc – is the best option for alleviating zinc deficiency. It will cater to both the rural and urban populations. It could be achieved through two approaches: (1) genetic biofortification; and (2) agronomic biofortification. There is a developing field of research on biofortification of plant foods with zinc. This involves both the breeding of new varieties of crops with the genetic potential to accumulate a high density of zinc in cereal grains (genetic biofortification) and the use of zinc fertilizers to increase zinc density (agronomic biofortification). Although the

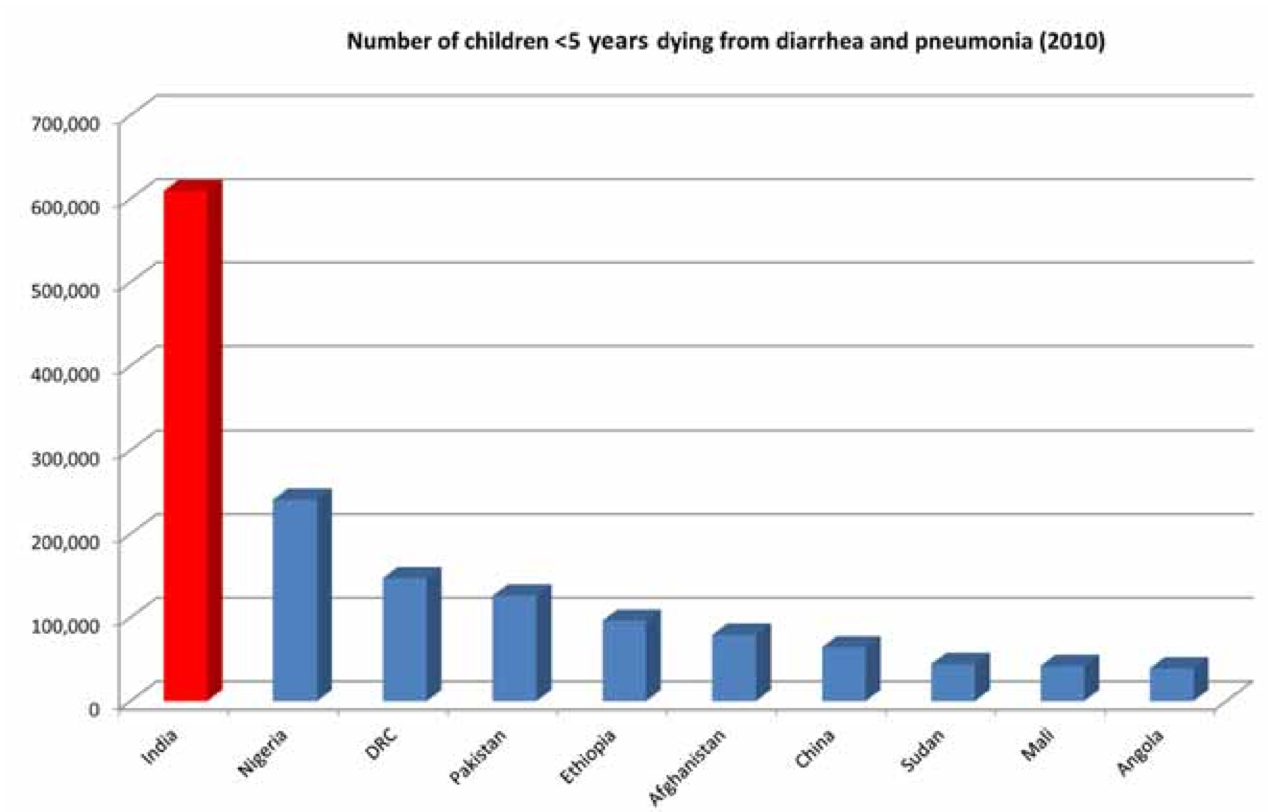

Figure 4. Deaths from diarrhea and pneumonia in children below five years (Source: UNICEF 2012).

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 zinc density in diets. In order to replenish the zinc taken up by the improved cultivars, higher and sustainable use of fertilizers is inevitable.

Crop response to application of zinc fertilizers

Crop response to zinc has been observed in all crops under almost all types of soils and agroclimatic zones. Extent of the crop response depends on the status of zinc in that soil. The higher the zinc deficiency in soils, the higher the crop response would be to applied zinc. The effect of zinc on crop yields has been well documented. Since zinc deficiency is widespread, impact of zinc application on increasing crop yields has been recorded on most crops, both under irrigated and rainfed conditions (Table 2).

Figure 5. Symptoms of zinc deficiency in humans (clockwise from top left): dermatitis, retarded mental growth, acne and white spots on nails (Source: Black 2008).

Table 3. Zinc fertilizer recommendations for some crops in India[1].

State	Crop	Zinc recommendation
Andhra Pradesh	Groundnut	Apply 25 kg ha^{-1} $ZnSO_4$ before sowing. Alternatively, spray 0.2% $ZnSO_4$ solution 35 days after sowing (DAS) and again 45 DAS.
Tamil Nadu	Pearl millet	Apply 12.5 kg ha^{-1} of Agricultural Department's micronutrient mixture mixed with sand just before or after sowing. If mixture is not available, add 25 kg ha^{-1} $ZnSO_4$.
	Sorghum	Apply 12.5 kg ha^{-1} of Agricultural Department's micronutrient mixture mixed with sand just before or after sowing and add over the furrows or mix 25 kg ha^{-1} $ZnSO_4$ with sand and apply.
	Groundnut	In zinc deficient soils, apply 25 kg ha^{-1} $ZnSO_4$ or foliar spray with 0.5% $ZnSO_4$.
Karnataka	Finger millet	Prepare a paste of 12.5 g $ZnSO_4$ with 4–6 tablespoons of water and mix with 2–2.5 kg seed. Keep overnight and sow the seeds next day or apply 300 g $ZnSO_4$ in 150 m^2 of nursery area to plant one hectare field.
Maharashtra	Groundnut	Apply 50 kg ha^{-1} $ZnSO_4$ as basal (in the Vidharba region).
Gujarat	Groundnut	Apply 25 kg ha^{-1} $ZnSO_4$ every three years or 8–10 kg ha^{-1} every year on zinc deficient soils.
Rajasthan	Groundnut	In zinc deficient soils, apply 30 kg ha^{-1} $ZnSO_4$ as basal.
Madhya Pradesh	Pigeonpea	If soil is deficient in zinc, apply 25 kg ha^{-1} $ZnSO_4$ in light soils and 50 kg ha^{-1} in medium heavy soils.
	Groundnut	Where zinc deficiency is a problem, apply 25 kg ha^{-1} $ZnSO_4$ as basal.

1. Source: Tandon (2013).

Zinc fertilizer use

A fast and cost-effective way of addressing zinc deficiency in soils, crops and humans is to apply zinc fertilizers to crops. There are many zinc fertilizers and products available in the market. The fertilizers containing zinc, mentioned in the Fertiliser Control Order under Schedule 1, Part A, 1 (f): Micronutrients are – Zinc Sulphate Heptahydrate (21% Zn), Zinc Sulphate Monohydrate (33% Zn) and Chelated Zinc (Zn-EDTA) (12% Zn); 1 (g) Fortified Fertilizers – Zincated Urea (2% Zn), Zincated Phosphate (suspension) (17.6% Zn), DAP with 0.5% Zinc (18:46:0:0.5), NPK with 0.5% Zinc (10:26:26:0.5) and NPK with 0.5% Zinc (12:32:16:0.5); 1 (h): Water soluble complex fertilizers – NPK with 3.5% Zinc-EDTA (7.6:23.5:7.6:3.5); Clause 20 A: Micronutrient Mixture – Crop Specific; and Clause 20 B: Customized fertilizers (total 31 grades).

Zinc fertilizer recommendations are based on crop–soil–climate specific situations. However, wherever situation-specific recommendations are not readily available, blanket recommendation of 25 kg ha^{-1} $ZnSO_4$ heptahydrate, equivalent to 5 kg ha^{-1} zinc is generally advocated for every year or alternate years for soil application. For foliar spray, 0.5% $ZnSO_4$ is advocated. In India, agriculture is a state subject. Therefore, fertilizer recommendations are advocated by the Department of Agriculture, State Government. Zinc fertilizer recommendations for some crops in the semi-arid region of India are given in Table 3.

Challenges in zinc fertilizer use

Major challenges faced by farmers towards use and promotion of zinc fertilizer products are:

- Unavailability of zinc fertilizers at the time of need of the farmers
- Poor quality of zinc fertilizers available in the market
- Zinc fertilizers under highly unorganized and fragmented sector
- Lack of awareness of the extension and promotional workers
- Lack of awareness of the farmers – last mile delivery

Fertilizer policy in India

The Planning Commission of India had well accomplished the strategic plan for the fertilizer industry keeping in view the industrial growth in the context of the Eleventh Five-Year Plan (2007–2012). The Government of India has been concerned with the problem of imbalanced use of plant nutrients, declining crop response ratio, stagnant crop productivity and rising subsidy bill. Switchover to the Nutrient Based Subsidy Scheme as proposed in the Union Budget for 2009–10 by the Finance Minister of India provided the direction for future fertilizer policies.

Keeping in view the agricultural situation and widespread soil degradation, the time was ripe for ushering in nutrient based subsidy to promote balanced and efficient use of plant nutrients. Such policies encouraged development and use of customized fertilizers. Nutrient based subsidy rather than products based subsidy allows all fertilizers covered under the Fertiliser Control Order to get the subsidy as per their nutrient content. This encourages development and use of new fertilizer products in the country depending upon the requirement of different soils and crops.

Consequently, large fertilizer players have joined the customized fertilizer business in India. Companies like Tata Chemicals Ltd., Nagarjuna Fertilizers & Chemicals Ltd., Coromandel International Ltd., Deepak Fertilizers & Petrochemicals Corporation and Indo Gulf Fertilizers have entered into the foray of customized fertilizers.

In addition, the large fertilizer players are also coming forward into zinc sulfate manufacturing and marketing. The Indian Farmers Fertiliser Cooperative Limited (IFFCO) has shown the way by commissioning 30,000 tons capacity of zinc sulfate monohydrate plant at Kandla, Gujarat. It is generally felt that entering of the larger players into zinc fertilizer business will open up new vistas in the field of zinc fertilizer manufacturing, marketing and usage.

Under the Nutrient Based Subsidy Scheme, the role of zinc has been specially targeted through additional subsidy for zinc fortified products at ` 500 per ton. The Government of India (GOI) is also promoting the use of zinc under the National Food Security Mission and providing an additional subsidy to the farmers at ` 500 per hectare for use of micronutrient fertilizers. Inclusion of urea in the Nutrient Based Subsidy Scheme is under consideration by the GOI. Such steps will lead towards balanced fertilization resulting in higher productivity and efficient use of fertilizers. Use of zinc fertilizer is likely to witness an upward trend in the near future.

International Zinc Association in addressing zinc deficiency

The International Zinc Association (IZA) was founded in 1991 and is a non-profit organization headquartered at Brussels, Belgium. IZA has regional offices in China, India, Europe, Latin America, North America, the Middle East and Southern Africa. It has 41 Full Members, 149 Affiliate Members and 52 Associate Members worldwide. IZA is the only global industry association dedicated exclusively to the interests of zinc and its users. Operating internationally and locally through its regional affiliates, IZA helps sustain the long-term global demand for zinc and its markets by promoting such key end-uses as corrosion protection for steel and the essentiality of zinc in human health and crop nutrition. IZA helps grow and protect the global markets for zinc by promoting zinc's essentiality in present and potential applications, human health and crop nutrition and by highlighting zinc's contribution to sustainable development. IZA's main program areas are technology and market development, environment, health and sustainability, and communications.

There are a number of global initiatives in which IZA is actively involved. Some of these are Zinc Saves Kids Initiative – an initiative of the IZA to improve the survival, growth and development of undernourished children by funding UNICEF supported zinc programs around the world; Mining Compact for Child Health – an initiative in support of United Nation's Every Woman, Every Child campaign; IZA India program (ZNI) is a member of the Task Force for Demand Generation of Zinc – ORS; HarvestPlus Zinc Fertilizer Programme – seeks to explore and test fertilizer use to improve the zinc concentration in various staple food crops, particularly wheat and rice. Used in concern with breeding approach, the application of zinc fertilizers to soil and/or foliar application further encourages and ensures crops to produce zinc-enriched seed and contributes to yield; International Zinc Symposium – an international scientific conference to review the latest knowledge and best agricultural practices in addressing zinc deficiency and its impact on global crop production and human health; and IZA-FAI Award – for "Promoting the Use of Zinc in Indian Agriculture" to increase awareness of the importance of zinc fertilizers in view of the increasing level of zinc deficiency in crops and humans in India.

The Zinc Nutrient Initiative is a program of the IZA which addresses zinc deficiency in soils, crops and humans through increased use of zinc fertilizers. The objectives of this global initiative, with the Head Office in USA and focus in India, China and Brazil, are to improve crop yield, improve nutritional value of crops, improve human nutrition, increase farmers' incomes and improve food security. Some of the key ZNI activities initiated in India are conferences, symposia, workshops, training programs, communication activities and IZA stall display.

Conclusions and way forward

- Correcting zinc deficiency will improve crop yields and farmers' incomes, while improving nutritional quality of crops and thus human nutrition.
- Balanced fertilizer use with micronutrients including zinc is necessary for higher crop yields.
- Urgent need to increase awareness among farmers and extension workers for increased use of zinc fertilizers.
- Future research strategy should be 'Soil–crop–animal–human continuum study on zinc'.

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