Zinc in Crops and Human Health

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Abstract

Zinc has emerged as the most widespread micronutrient deficiency in soils and crops worldwide, resulting in severe yield losses and nutritional quality. Almost half of the soils in the world are deficient in zinc. Since cereal grains have inherently low concentrations, growing these on the potentially zinc-deficient soils further decreases grain zinc concentration. There is a high degree of correlation between zinc deficiency in soils and that in human beings. Zinc is an essential nutrient for human health. There is no life without zinc. 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. About one-third of the world's population suffers from zinc deficiency. The paper describes the role of zinc in crop production as well as human health. It highlights the initiatives of the International Zinc Association in addressing zinc deficiency in soils, crops and humans through increased use of zinc fertilisers.

Keywords

Crop yield • Human health • Nutritional quality • Zinc deficiency • Zinc fertilisers

3.1 Introduction

Zinc is one of the 17 essential elements necessary for the normal growth and developments of plants. It is among eight micronutrients essential for plants. Zinc plays a key role in plants as a structural constituent or regulatory cofactor of a wide range of different enzymes and proteins in

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many important biochemical pathways. These are mainly concerned with carbohydrate metabolism, both in photosynthesis and in the 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.

Zinc deficiency in plants retards photosynthesis and nitrogen metabolism; reduces flowering and fruit development; prolongs growth periods, resulting in delayed maturity; results in lower yield and poor produce quality; and results in suboptimal nutrient-use efficiency. Some of the common deficiency symptoms of zinc in plants are light green, yellow or bleached spots in the interveinal areas of older leaves, the emerging leaves are smaller in size and often termed as "little leaf", and the internodal distance in case of severe deficiency becomes so short that all the leaves appear to come out from the same point, termed as "rosetting".

3.2 Zinc Status in Soils

Zinc has emerged as the most widespread micronutrient deficiency in soils and crops worldwide (Fig. 3.1), resulting in severe yield losses and deterioration in nutritional quality. It is estimated that almost half of the soils in the world are deficient in zinc. Since cereal grains have inherently low concentrations, growing these on the potentially zinc-deficient soils further decreases grain zinc concentration.

India is not an exception. About 50 % soil samples analysed for available zinc were found deficient in India (Fig. 3.2). There is a significant response to applied zinc in the soils deficient in zinc. In India, zinc is considered the fifth most important yield-limiting nutrient after N, P, K and S in upland crops, whereas in lowland crops like rice, it is next to N.

The reasons responsible for the increase of incidences of zinc deficiency include large zinc removals due to high crop yields and intensive

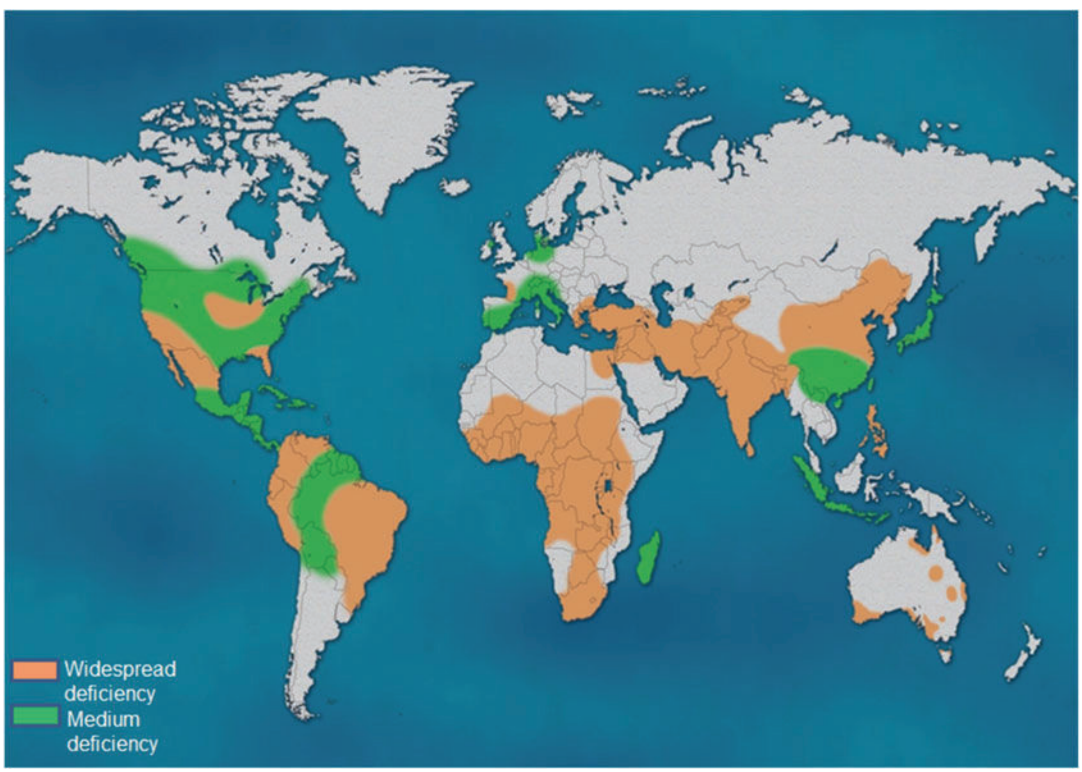

Fig. 3.1 Worldwide zinc deficiency in soils (Alloway 2008)

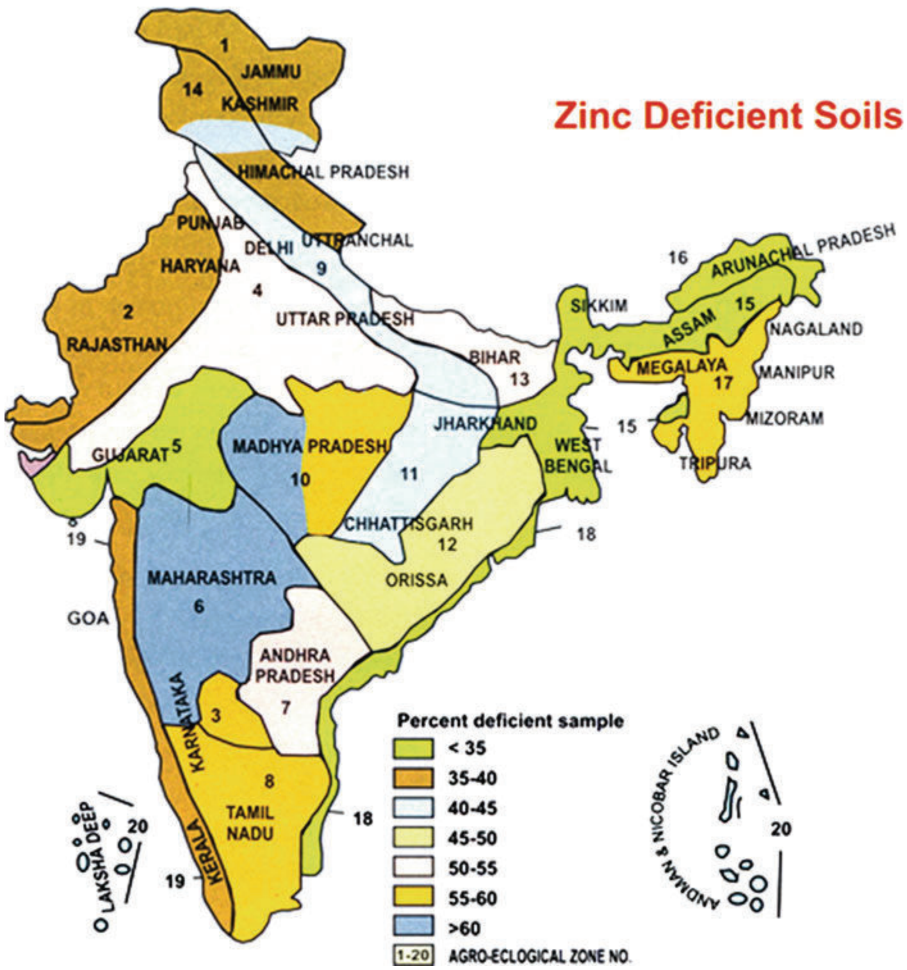

Fig. 3.2 Extent of zinc deficiency in India (Singh 2009)

cropping systems, lesser application of organic manures, use of high analysis fertilisers, increased use of phosphatic fertilisers resulting in P-induced zinc deficiency and the use of poor-quality irrigation water.

The zinc deficiency in India is expected to increase from the present level of around 50 to 63 % in 2025 if the trend continues. This is also because more and more areas of marginal lands are brought under intensive cultivation without adequate micronutrient supplementation. According to an estimate, a huge zinc deficit of about one million tonnes exists in Indian soils. Against the crop removal of about 1.2 million tonnes, the zinc fertiliser use is to the tune of only 0.25 million tonnes. Multi-nutrient deficiencies are fast emerging in many areas in India (Fig. 3.3), resulting in lower yield and quality.

3.3 Zinc: Essential for Life

Zinc is an essential nutrient for human health. There is no life without zinc. Recently, zinc deficiency – especially in infants and young children under 5 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

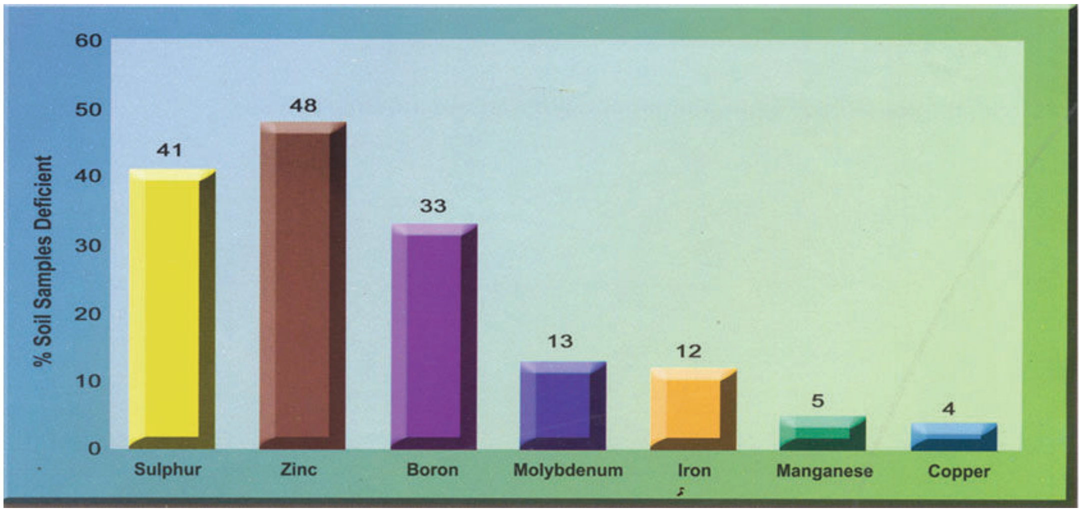

Fig. 3.3 Multi-nutrient deficiency status in India (Singh 2009)

due to zinc deficiency, of which 450,000 are children under the age of 5.

It is estimated that 60–70 % of the population in Asia and sub-Saharan Africa could be at risk of low zinc intake; in absolute numbers, this translates into about two billion people in Asia and 400 million people in sub-Saharan Africa (Prasad 2006). There is a high degree of correlation between zinc deficiency in soils and that in human beings (Fig. 3.4). It is estimated that about one-third of the world's population suffers from zinc deficiency.

Zinc 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, 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, are diarrhoea, pneumonia, stunted growth, weak immune system, retarded mental growth and dwarfism, impaired cognitive function, behavioural problems, memory impairment, problems with spatial learning and neuronal atrophy.

3.4 Zinc Malnutrition: Possible Solution is Biofortification

The possible solution to the zinc malnutrition in 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. In addition, such programmes will most likely reach the urban population, which is easily accessible, especially in the developing countries. Alternatively, the latter programme, biofortification – fortification of crops especially food crops 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, genetic biofortification and agronomic biofortification.

There is a developing field of research on the 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 fertilisers to increase zinc density (agronomic biofortification). Although the plant breeding route is

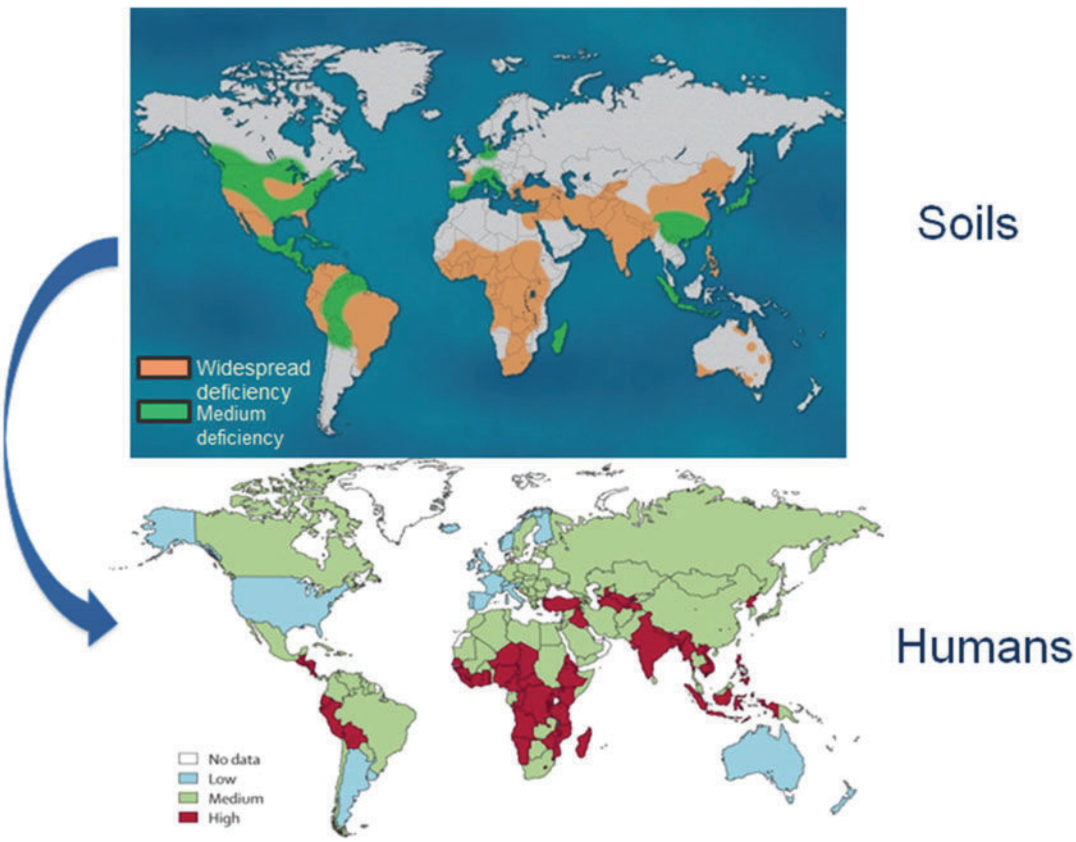

Fig. 3.4 Worldwide zinc deficiency in soils and humans (Alloway 2008)

likely to be the most cost-effective approach in the long run, the use of fertilisers 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 fertilisers is inevitable.

Ideally, the cereal grains should contain 40–60 mg zinc/kg, whereas currently, it is only 10–30 mg zinc/kg (Cakmak 2008). This needs to be rectified urgently.

3.4.1 Zinc Uptake and Removal by Crops

Zinc uptake by some pulses and oilseed crops are given in Table 3.1. The proportion of zinc absorbed by these crops which were present in the grains is also mentioned. In the pulse crops, the zinc uptake varied from 38 to 72 g ha^{-1} by pigeon pea and green gram for the corresponding grain yields of 1200 and 1000 kg ha^{-1}, whereas the zinc uptake in grain varied from 34 % to 62 % by pigeon pea and lentil for the grain yields of 1200 and 2000 kg ha^{-1}, respectively. These data show that a considerable proportion of absorbed zinc remains in the straw. Lentil and soybean seem to be able to transfer greater proportion of absorbed zinc to the seed than many other crops (Tandon 2013).

Table 3.2 shows zinc removal by pulses, cereal and oilseed-based cropping systems. The pigeon pea – wheat cropping system – removed 287 g Zn ha^{-1}, equivalent to 48 g Zn t^{-1}, for the grain yield of 6 t ha^{-1} (Prasad 2006).

3.4.2 Zinc Fertiliser Recommendations

Zinc fertiliser recommendations are based on crop–soil–climate-specific situations. However, wherever situation-specific recommendations

Table 3.1 Zinc uptake by some pulses and oilseeds and their proportions in grains

Crop	Grain yield (kg ha^{-1})	Uptake (g ha^{-1})	Uptake in grain (%)
Chickpea	1500	59	49
Pigeon pea	1200	38	34
Lentil	2000	52	62
Green gram	1000	72	58
Groundnut	1900	208	45
Mustard	1500	154	34
Sesame	1200	201	31
Soybean	2500	196	68

Table 3.2 Zinc removal by pulses, cereal and oilseed-based cropping systems

Cropping system	Grain yield (t ha^{-1})	Zinc removed (g ha^{-1})	Zinc removed (g t^{-1})
Pigeon pea–wheat	6.0	287	48
Rice–wheat	8.9	1153	129
Rice–rice	8.0	320	40
Maize–wheat	8.0	744	93
Soybean–wheat	6.5	416	64

are not readily available, blanket recommendation of 25 kg ha^{-1} $ZnSO_4$ heptahydrate, or 15 kg ha^{-1} $ZnSO_4$ monohydrate, equivalent to 5 kg ha^{-1} zinc are generally advocated for every year/alternate years for soil application. For foliar spray, 0.5 % $ZnSO_4$ is advocated. The state government recommends crop-specific zinc fertiliser doses.

3.4.3 Crop Response to Zinc

The response of pulses to soil applied Zn in 28 field trials conducted in different soils of Bihar showed that the response range varied from 33 to 860 kg ha^{-1} in lentil and chickpea, whereas the average response was from 50 to 450 kg ha^{-1} in green gram and peas, respectively (Singh et al. 2011) (Table 3.3).

Zinc biofortification trials conducted at Kanpur on pigeon pea during *kharif* 2009–2010 revealed that application of Zn enhanced the pigeon pea grain yield by 13 % over no Zn. In Bhopal, the increase in yield was 22 % with soil Zn application, whereas it was 64 % with soil + foliar Zn application (Shukla and Tiwari 2014) (Table 3.4).

Crop response to zinc has been observed in all crops under almost all types of soils and agroclimatic conditions. While the response was found to be higher in grain crops like rice, fruit and vegetable crops also respond well to applied zinc. Extent of 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. Based on over 15,000 on-station field trials conducted all over India, the overall range of crop response to zinc was of the following scale (Singh 2008):

Cereals: 420–550 kg ha^{-1} (15.7–23.0 %)
Pulses: 170–460 kg ha^{-1} (7.3–28.2 %)
Oilseeds: 110–360 kg ha^{-1} (11.4–40.0 %)
Fodders: 90–4620 kg ha^{-1} (5.0–34.0 %)

3.4.4 Zinc Content in Crops

In a multilocation study in China, India, Lao PDR, Thailand and Turkey (averaged over nine site years), Zn concentration in unhusked rice grain was about 69 % higher with foliar application than with soil application; at some centres, it

Table 3.3 Response of pulses to Zn application on farmers' fields

Crop	No. of field trials	Response range (kg ha^{-1})	Average response (kg ha^{-1})
Chickpea	9	130–860	390
Peas	2	180–710	450
Green gram	1	50	50
Black gram	6	100–520	330
Lentil	9	33–440	240
Broad bean	1	250	250

Table 3.4 Effect of Zn biofortification strategies on grain and zinc concentration in different cultivars of pigeon pea at Kanpur and Bhopal

	Grain yield (t ha^{-1})		Zinc concentration (mg kg^{-1})	
Cultivar	−Zn	+Zn	−Zn	+Zn
Kanpur				
LRG 38	1.90	2.00	49.0	63.0
JKM 7	1.80	1.90	43.0	66.0
BSMR 736	1.80	1.90	22.0	34.0
Pusa 9	2.40	2.60	18.0	23.0
Bhopal				
ICPL 87119	1.84	1.99	27.8	41.8
T 15–15	1.46	1.55	32.3	44.6
Virsa Arhar 1	1.53	1.76	32.8	38.7

Table 3.5 Relative zinc concentration in unhusked, brown and white (polished) rice

Characteristic	Control (no Zn)	Soil Zn	Foliar Zn	Soil + foliar Zn
Grain yield (t ha^{-1})	6.7	7.0	6.9	7.0
Zn in unhusked rice (mg kg^{-1})	18.7	19.1	32.3	34.7
Zn in brown rice (mg kg^{-1})	19.1	20.8	24.4	25.5
Zinc in polished rice (mg kg^{-1})	16.1	16.2	17.7	18.4

Table 3.6 Zinc content in some pulses

Crop	Grain (in %)	Straw (in %)
Chickpea	19	10
Pigeon pea	11	4
Lentil	16	10
Green gram	42	5
Black gram	29	11

was almost twice that of with soil application (Prasad et al. 2014) (Table 3.5).

An analysis of the nutrient content of some pulse crops by Aulakh (1985) shows the zinc concentration in grain and straw (Table 3.6).

3.4.5 Effect of Zinc on Crop Quality

Application of zinc not only increases the crop yield but also improves its quality. In 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 black gram, was accounted for zinc application. Improvement in amino acids in cereals was also observed. Sucrose recovery and juice quality were improved in sugarcane (Kalwe et al. 2001).

3.4.6 Interaction of Zinc with Other Nutrients

Zinc interacts positively with N and K and negatively with P. Antagonistic effect of Zn x P interaction has been the subject of intensive study in several countries. This implies that farmers should not overuse phosphatic fertilisers, or else it would lead to reduced uptake of zinc by the crops. Zinc interacts antagonistically with all three secondary nutrients S, Ca and Mg as well as other micronutrients, like, Fe, Mn, Cu and Mo.

3.4.7 Economics of Zinc Fertiliser Use

Trials carried on farmers' fields reveal that zinc application to crops is remunerative on zinc-deficient soils. Over 7000 trials carried out in cultivators' fields with cereal crops, rice, wheat, maize and barley showed an 8.3 % increase in mean grain response over NPK. The B/C ratio varied from 2.8:1 to 3.5:1, which showed that it was profitable, as B/C ratio over 2.5 is generally considered as remunerative to the farmers.

3.4.8 Zinc Fertilisers in FCO

The fertilisers containing zinc, mentioned in the Fertiliser Control Order (FCO), are enumerated below:

Schedule 1 Part A
1 (f) Micronutrients
 Zinc sulphate heptahydrate – 21 % Zn
 Zinc sulphate monohydrate – 33 % Zn
 Chelated zinc (Zn-EDTA) – 12 % Zn
1 (g) Fortified fertilisers
 Zincated urea – 2 % Zn
 Zincated phosphate (suspension) – 19 % Zn
 NPK Zn – 3.5 % Zn
Clause 20 A
 Micronutrient mixture – crop specific
 Zinc-fortified DAP/SSP/NPKs
 Zinc polyphosphate – 16 % Zn
Clause 20 B
 Customised fertilisers

3.4.9 Fertiliser Policy in India

The government is concerned with the problem of imbalanced use of plant nutrients, declining crop response ratio, stagnant crop productivity and rising subsidy bill. Switch over to the nutrient-based subsidy (NBS) scheme as proposed in the Union Budget for 2009–2010 provided the direction to the future fertiliser policies.

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

In addition, the large fertiliser players are coming into zinc sulphate manufacturing and marketing. It is generally felt that entering of the larger players into zinc fertiliser business will open up new vistas in the field of zinc fertiliser manufacturing, marketing and usage.

Under the NBS scheme, the role of zinc has been specially targeted through additional subsidy for the zinc-fortified products @ Rs. 500 per tonne. The Govt. of India is promoting the use of zinc under the National Food Security Mission also and providing an additional subsidy to the farmers @ Rs. 500 per hectare for use of micronutrient fertilisers. Of late, inclusion of urea in the NBS scheme is under consideration by the Govt. of India. Efforts are also being made to address the pricing issue of zincated urea, so that it can be considered for production and marketing by the fertiliser industry.

Fig. 3.5 Zinc Saves Kids Initiative of the International Zinc Association in support of UNICEF

Such steps will lead towards balanced fertilisation resulting in higher productivity and efficient use of fertilisers. Zinc fertiliser use has been significantly increased in the last couple of years and is bound to witness an upward trend further in the days ahead in India.

3.5 Role of International Zinc Association (IZA)

The International Zinc Association (IZA) is a non-profit organisation based in Brussels, Belgium, and was founded in 1991. IZA has regional offices in India, China, Europe, Latin America, North America, Middle East and Southern Africa.

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 the essentiality of zinc in present and potential applications, human health and crop nutrition and by highlighting contribution of zinc to sustainable development. IZA's main programme areas are Technology and Market Development, Environment and Health, Zinc for Life and Communications.

3.5.1 Zinc Nutrient Initiative (ZNI)

The Zinc Nutrient Initiative (ZNI) is a programme of the International Zinc Association (IZA) which addresses zinc deficiency in soils, crops and humans through increased use of zinc fertilisers with the objectives to raise awareness on increased crop yield, improved nutritional quality of crops, improved human nutrition, increased farmers' income and improved food and nutritional security (Das and Green 2011).

The various approaches undertaken by the initiative are coordinating crop demonstration trials; organising international, national and regional conferences, workshops and seminars; conducting training programmes; publication of communication materials; and networking with the various stakeholders in zinc sector.

There are a number of global initiatives in which IZA is actively involved. Zinc Saves Kids is one such initiative in support of UNICEF of the United Nations (Fig. 3.5).

3.6 Challenges

The key challenges in zinc in balanced fertiliser use are:

- Availability of zinc fertilisers at the time of need of farmers
- Quality of zinc fertilisers available

- Information on soil–crop–animal–human continuum study (multidisciplinary approach)
- Awareness level of the extension and promotional workers
- Lack of awareness of the farmers – last mile delivery

3.7 Conclusions

Zinc deficiency in crops and humans is a critical issue and a global challenge. The sustainable solution is increased use of zinc in balanced fertiliser use, so that the soil health, food security as well as nutritional security are ensured.

References

Alloway BJ (2008) Zinc in soils and crop nutrition. IFA, Paris and IZA, Brussels, p 135

Aulakh MS (1985) Content and uptake of nutrients by pulse and oilseed crops. Indian J Ecol 12(2):238–242

Cakmak I (2008) Enrichment of fertilizers with zinc: an excellent investment for humanity and crop production in India. In: Proceedings of FAI annual seminar, New Delhi, SII-2, pp 1–8

Das S, Green A (2011) Zinc in crops and human health – IZA initiatives. Indian J Fert 7(10):152–170

Kalwe SP, Das S, Biswas BC (2001) Role of zinc in balanced fertilisation. In: Proceedings of national conference on zinc in health and agriculture, ILZDA, New Delhi, pp 1–10

Prasad R (2006) Zinc in soils and in plant, human and animal nutrition. Indian J Fert 2(9):103–119

Prasad R, Shivay YS, Kumar D (2014) Agronomic biofortification of cereal grains with iron and zinc. Adv Agron 125:55–91

Shukla AK, Tiwari PK (2014) Micro and secondary nutrients and pollutant elements research in India. Progress report 2011–2013. AICRP – MSPE (ICAR), IISS, Bhopal, pp 1–155

Singh MV (2008) Micronutrient deficiencies in soils and crops of India. In: Alloway BJ (ed) Micronutrient deficiencies in global crop production. Springer Sciences Business Media, Dordrecht, pp 93–125

Singh MV (2009) Micronutrient nutritional problems in soils of India and improvement for human and animal health. Indian J Fert 5(4):11–26

Singh KK, Praharaj CS, Choudhary AK, Kumar N, Venkatesh MS (2011) Zinc response to pulses. Indian J Fert 7(10):118–126

Tandon HLS (2013) Micronutrient handbook – from research to application. FDCO, New Delhi, p 234