Zinc deficiency: A productivity constraint in rainfed crop production systems of India

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Introduction

India's agricultural growth after independence has moved the country from a severe food crisis of the 1960s to aggregate food surplus today. Rainfed agriculture has played an important role in this change. Most of the increase in agricultural output over the years has taken place under irrigated conditions. The opportunities for continued expansion of irrigated area are limited; so Indian planners increasingly are looking up to rainfed or unirrigated agriculture to help meet the rising demand for food projected over the next several decades. By 2030, India would need about 345 million tons of food grains (GOI 2009). The production in 2008/09 was only 230 million tons implying that about 70 million tons of food grains have to be produced from the same or lesser area, for which fertilizers will play a major role. India ranks first among the countries that practice rainfed agriculture both in terms of area and value of production. Of about 141 million ha net cultivated land in India, 85 million ha is rainfed which produces 40% of the food grains in the country, implying that rainfed agriculture in India comprises about 80% of area under coarse cereals, 85% pulses [chickpea (*Cicer arietinum*), pigeonpea (*Cajanus cajan*), black gram (*Vigna mungo*), mungbean (*Vigna radiata*), lentil (*Lens culinaris*)], 72% of oilseeds [groundnut (*Arachis hypogaea*), sunflower (*Helianthus annuus*), rape (*Brassica napus*), mustard (*Brassica* sp.), soybean (*Glyine max*)] and 64% of cotton (*Gossypium* sp.), besides supporting two-thirds of livestock population (Srinivasarao et al. 2007). Low and erratic rainfall, high temperature, degraded soils with low available water content and multi-nutrient deficiencies are important factors contributing to low crop yields in these regions. In India, the predominant production systems under rainfed agriculture are upland rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), maize (*Zea mays*), pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), cotton, groundnut and soybean besides several pulses, oilseed, coarse cereals, etc. One of the major challenges facing rainfed agriculture in India today is its sustainable development through conserving and enhancing the inherent capacity of its land and other natural resources to sustain it (Srinivasarao et al. 2013b).

Zinc deficiency: emerging nutritional constraint

Soils of drylands are highly degraded besides having low soil organic carbon. Organic carbon in soil plays a crucial role in various soil processes, nutrient dynamics, water relations and in maintaining biological and physical health of soil. Most of the dryland soils are low in organic carbon due to rapid oxidation process in dry regions of the country (Srinivasarao 2011, Srinivasarao et al. 2011a, 2011b, 2011c). The sustainable productivity of a soil mainly depends upon its ability to supply essential nutrients to the growing plants. Micronutrient deficiencies have been reported to be one of the main causes for yield plateau or even yield decline in intensified cropping systems (Katyal and Rattan 2003). Uptake of micronutrients is affected by the presence of major nutrients due to either negative or positive interactions. The problem of zinc (Zn) deficiency, especially in the developing world, has been further aggravated due to lack of information on Zn sensitivity and by growing cultivars that are highly susceptible to Zn deficiency.

Continuous use of high analysis fertilizers under intensified cropping and neglect of organic manures manifested the occurrence of widespread micronutrient deficiencies, especially of Zn in light-textured soils of India after 1960s. The Green Revolution has greatly increased the food production in India, but continuous cultivation of high-yielding varieties have led to depletion of micronutrients in soils showing signs of fatigue for higher crop production. Zinc is a trace element needed in small but critical concentrations and if the amount available is not adequate, plants will suffer from physiological stress brought about by the dysfunction of several enzyme systems and other metabolic functions in which Zn plays a part (Alloway 2008).

Diagnosis of Zn deficiency can be made based on leaf symptoms. Leaf symptoms may appear in the early seedling stage itself. The leaves may be smaller than normal. The deficient plants exhibit general bronzing of the first few leaves and often-pronounced interveinal chlorosis. Leaf thickening and cupping upward of leaf edges occurs. The chlorotic area may develop brown patches and the plant becomes bushy in nature. This delays maturity, reduces the fruit size, and ultimately affects the yield.

Zinc deficiency in India

Zinc deficiency has increased from 44% to 48%, and is expected to further increase up to 63% by 2025. Most of the marginal soils are showing higher response to added zinc (Singh 2009). In southern India, Zn deficiency is a predominant problem in 58%, 73% and 83% soils of Andhra Pradesh, Karnataka and Maharashtra, respectively, due to low organic matter, high clay and calcium carbonate. Zinc deficiency is frequently observed in swell-shrink soils in these states. In some parts of Tamil Nadu, Zn deficiency has increased from 36% in 1980 to 73.8% in 2008 because of extensive use of multi-micronutrient mixtures, mainly through foliar sprays which left little residual effect in soils compared to other states using $ZnS0_4$. Minakshi et al. (2005) reported that about 11% (39,369 ha) of the total geographical area of Patiala district of Punjab was deficient in Zn; only 4% and 5% of the area was deficient in Mn and Fe, respectively. In a recent study, geographic information system (GIS)-generated thematic maps have indicated that 10% of the total geographical area is affected by Zn deficiency (Bali et al. 2010).

Hundreds of on-farm field experiments did prove large-scale occurrences of Zn deficiency, which in extent and severity varied across soil types and agroecological zones. Coarse texture, high pH, calcareousness, diminishing organic carbon and leaching often accentuated Zn deficiency. Irrespective of these soil properties, irrigated crops whose productivity is two to three times higher than rainfed crops suffer more from Zn deficiency. Across soils and crops, lowland rice is invariably affected by Zn deficiency.

Zinc deficiency in rainfed regions

Apart from water shortages, the productivity in rainfed systems of semi-arid India is low due to poor fertility status of the soils (Sahrawat et al. 2010). In rainfed regions of India, negative balance of nitrogen (N) and phosphorus (P) (Rego et al. 2003) and widespread deficiency of Zn have been reported (Sahrawat et al. 2007).

Nitrogen is deficient in most of the cotton growing regions of India having available N less than 280 kg ha^{-1}. Analysis of soil samples from farmers' fields all over the rainfed regions of India (Fig. 1) revealed widespread deficiencies of major nutrients [N, P and potassium (K)] as well as micronutrients [magnesium (Mg), Zn, iron (Fe) and boron (B)] (Table 1). Most of the rainfed soils are degraded with loss of fertile soil in the form of runoff and low organic carbon thus resulting in emergence of deficiencies of micronutrients such as Zn, Fe, manganese (Mn), copper (Cu), B and molybdenum (Mo). While the organic matter levels and the soil mineralogy determine the micronutrient content of soils, their retention, release and availability are controlled by clay type, content, pH and lime content (Takkar 1996).

Extensive Zn deficiency in soils of semi-arid tropis of India was reported (Rego et al. 2007, Srinivasarao et al. 2008). Micronutrient deficiency especially Zn is common in most watersheds in Karnataka and ranged from 34% to 93% in farmers' fields (Table 2). Zinc deficiency was high in soil samples from cotton growing areas in Tamil Nadu (Kalaichelvi 2009). Invariably the farmers have been applying nutrients in the form of complex fertilizers wherein the application is not in accordance with the nutrients required by the crop. Similarly secondary and micronutrients are not appropriately included in nutrient management. A study was carried out to assess the contribution of nutrients with omission plot technique; the results revealed significant reduction of 8% seed cotton yield with omission of Zn (Biradar et al. 2011). To characterize the

Table 1. Emerging nutrient deficiencies in dryland soils (0–15 cm) under diversified rainfed production system of India[1].

Location	Limiting nutrient (low/deficient)
Rajkot (Gujarat)	N, P, S, Zn, Fe, B
Rewa (Madhya Pradesh)	N, Zn
Akola (Maharashtra)	N, P, S, Zn, B
Kovilpatti (Tamil Nadu)	N, P
Bellary (Karnataka)	N, P, Zn, Fe
Bijapur (Karnataka)	N, Zn, Fe
Solapur (Maharashtra)	N, P, Zn
Hisar (Haryana)	N, Mg, B
SK Nagar (Gujarat)	N, K, S, Ca, Mg, Zn, B
Bengaluru (Karnataka)	N, K, Ca, Mg, Zn, B
Ballowal-Saunkri (Punjab)	N, K, S, Mg, Zn

1. Source: Srinivasarao et al. (2006b, 2007, 2009a).

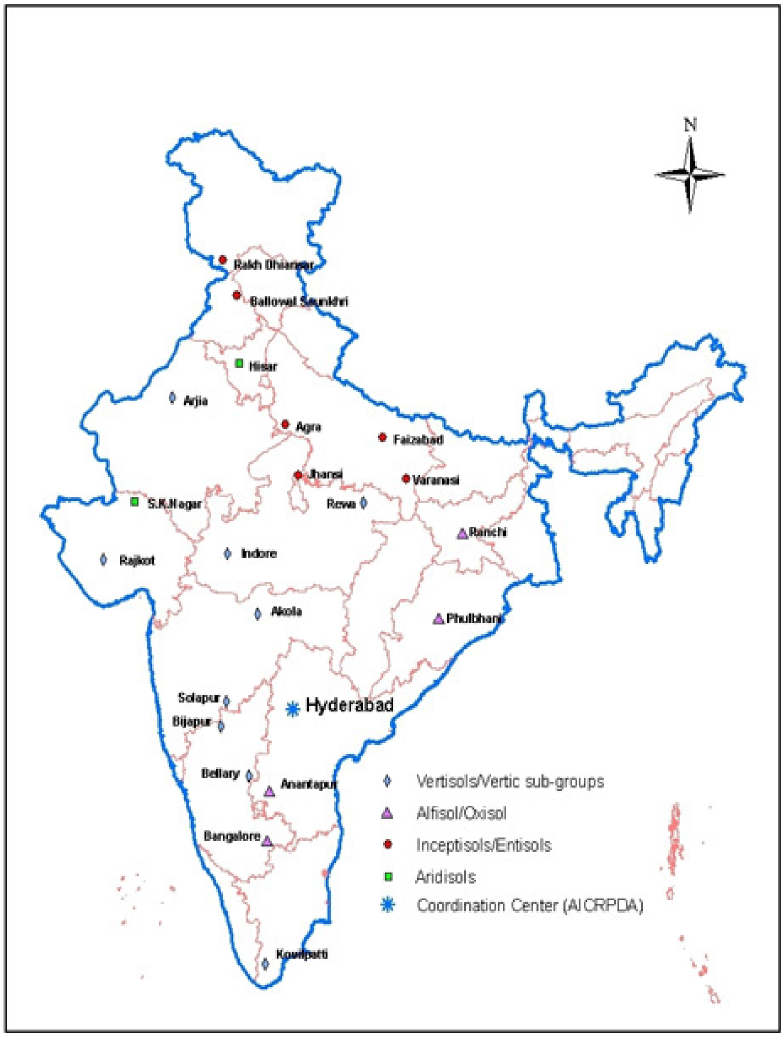

Figure 1. Profile soil samples collected for zinc analysis at different centers of All India Coordinated Research Project for Dryland Agriculture (AICRPDA).

fertility status of soils under dryland agriculture in semi-arid region of India, 3622 soil samples from Andhra Pradesh, Karnataka, Rajasthan, Madhya Pradesh, Tamil Nadu and Junagadh district of Gujarat were analyzed. The results showed that deficiency of Zn is widespread, although the extent of deficiency varied with nutrient and location in the state. Zinc deficiency ranged from 15% in Rajasthan to 98% in Madhya Pradesh (Table 3) (Sahrawat et al. 2007).

Zinc deficiency in Andhra Pradesh

Imbalanced plant nutrient management mainly N and P and lack of recycling of organic matter into soil over time, has led to the deficiency of micronutrients in soils, resulting in poor fertility in many districts of Andhra Pradesh (Srinivasarao et al. 2006b). Nutrients such as S, Mg, Zn, Fe, Mn, B and Cu are equally important to plant growth as N, P and K. When these micronutrients are not available to the plant in required quantities, growth is affected and yields are reduced. Most of the soils in Andhra Pradesh are Zn deficient (Srinivarsarao and Vittal 2007). Therefore, soil health management through balanced fertilization and site-specific nutrient management (SSNM) was promoted as key intervention for crop productivity enhancement. SSNM results in reduction in cost of inputs, higher nutrient use efficiency and protects environmental safety. For soil health management, 1850 soil samples from eight districts (Fig. 2) were collected under National Agricultural Innovation Project (NAIP) "Sustainable rural livelihoods through enhanced farming systems productivity and efficient support systems in rainfed areas" by involving farmers as participants in soil sampling. The summary of soil analysis of eight clusters showed that rainfed regions of

Andhra Pradesh are low to medium in organic carbon content and low in available N content. Zinc deficiency is a major problem and occurred in 35% to 78% of farmers' fields in eight districts (Table 4). Many farmers' fields showed Zn deficiency in soils and crops.

Diagnosis of zinc deficiency in soil and plant samples

The general critical levels of Zn deficiency in soils and crops fall in the range of 0.6–1 mg kg^{-1} (DTPA-extractant) and 10–20 mg kg^{-1} in dry matter respectively (Katyal and Rattan 2003) but vary with soils and crops. For clear prediction of possible deficiencies, their critical limits must be refined with reference to the soil characteristics and plant parts for individual crops as the soils and crops vary widely in their nutrient supplying and utilization efficiency.

Plant micronutrients were analyzed using standard wet digestion and dry ashing method. Full recovery of micronutrients (Zn and Fe) in high silica containing plant tissues [like wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), sugarcane (*Saccharum officinarum*), etc.] is not possible by dry ashing procedure. Therefore, such plant materials should be wet-digested using Di acid (HNO_3-$HClO_4$) or Tri acid (H_2SO_4-HNO_3-$HClO_4$) mixture. During plant sample collection, time of sampling and sample section (top or/bottom leaves) are important factors to be considered to enhance the accuracy of the results (Table 5).

The response of crop plants to the deficiency or sufficiency of specific nutrients has helped to generate information on the critical limits of each of the elements. The medium black calcareous soils considerably declined in available Zn; therefore, the crops respond to Zn application. There is need to establish a threshold level of Zn concentration in plants below which the crop may respond to Zn application (Table 6). In an experiment conducted on calcareous soils to determine the critical levels of Zn in soil and cotton crop, the estimated critical level of available Zn was 0.89 mg kg^{-1} in soil; concentrations of Zn in cotton in 4^{th} leaf at 30 days after sowing and at maturity in leaf were 57.5 and 24.6 mg kg^{-1}, respectively (Polara et al. 2010).

Factors affecting available zinc in soils

Soil characteristics are essential to determine the availability of micronutrients to plants, and therefore the crop yield potential and crop quality. The factors that affect the contents of such micronutrients are organic matter, soil pH, lime content, sand, silt, clay content and

Table 2. Available zinc (Zn) status of soil in different watersheds of Karnataka[1].

Location	No. of farmers' fields tested	Zn (µg g^{-1})		
		Minimum	Maximum	% deficient fields
Dharwad	135	0.28	4.72	34
Haveri	217	0.20	2.32	79
Kolar	408	0.06	5.50	64
Tumkur	269	0.14	2.34	88
Chitradurga	231	0.08	3.40	93

1. Source: Srinivasarao et al. (2009b).

Table 3. Available zinc (Zn) status in the semi-arid tropical region of India[1].

State	No. of farmers' fields tested	Zn (µg g^{-1})		
		Range	Mean	% deficient fields
Andhra Pradesh	1926	0.08–35.6	0.71	82
Karnataka	1260	0.06–5.50	0.68	74
Rajasthan	179	0.20–14.1	1.68	15
Madhya Pradesh	55	0.10–0.82	0.33	98
Gujarat	82	0.19–2.45	0.45	82
Tamil Nadu	119	0.20–5.10	0.78	61

1. Source: Sahrawat et al. (2007).

Figure 2. Soil samples collected from targeted districts in Andhra Pradesh for soil fertility analysis.

soil management factors. Many of these soil factors have potential for manipulation by farmers in order to improve crop yields. Application of acid producing amendments on alkaline and calcareous soils could decrease soil pH and consequently increase plant-available Fe and Zn (Singh et al. 1989).

The availability of micronutrients enhanced significantly with increase in organic matter because: (i) organic matter is helpful in improving soil structure and aeration; (ii) it protects the oxidation and precipitation of micronutrients into unavailable forms; and (iii) it supplies soluble chelating agents which increase the solubility of micronutrient contents.

Organic matter. Low soil organic carbon content in rainfed regions is one of the important factors that affects the availability of Zn in soils (Srinivasarao et al. 2009a). Increased concentrations of organic matter in soils can increase exchangeable and organic fractions of Zn and decrease oxide fractions of Zn in soil because of reducing conditions to enhance Zn availability. Sharma et al. (2004) observed that DTPA-extractable Zn increased with an increase in organic carbon content of the soil. Yadav and Meena (2009) reported that the DTPA-extractable Zn was significantly and positively correlated with organic carbon (r = +0.896**) content of the soil.

Phosphorus. Zinc is an active element in biochemical processes and has a chemical and biological interaction with some other elements. Phosphorus is the important element that interferes in Zn uptake, as Zn uptake by plants reduces with increased levels of P in soil (Das et al. 2005). Several studies have confirmed that Zn and P imbalance in the plant is due to excessive accumulation of P resulting in Zn imposed deficiency (Das et al. 2005). Increasing seed concentration of Zn by soil and/or foliar applications of Zn also brings several agronomic benefits for crop production. Applying Zn to plants grown under potentially Zn-deficient soils is effective in reducing uptake and accumulation of P (and thus phytate) in plants (Cakmak 2008). Phosphorus application to chickpea at sub-optimum levels showed that efficient P-utilizing genotypes perform better than others under P-deficient conditions. High levels of P application may induce Zn deficiency in plants grown on Zn-deficient soils. Twenty chickpea genotypes were evaluated for their P efficiency at varied levels of added P, and the effect of P levels on Zn (Srinivasarao et al. 2006a). Increasing P up to 13.5 mg kg^{-1} soil increased Zn concentration, while further increase led to decreased concentration. Genotypes KPG 59, BG 256, RSG 888 and JG 315 showed Zn concentrations below the critical limit of 20 µg Zn g^{-1} dry weight at the high level of P application (27 mg kg^{-1}). Results also suggest that when selecting P-efficient genotypes of chickpea, it is essential to address deficient micronutrients particularly Zn.

Zinc deficiency and yield gaps

During recent years farmers could increase agricultural production from 1 to 2 t ha^{-1} in the rainfed regions compared to attainable yields of more than 4 t ha^{-1}. The large yield gap suggests that there is much to gain by improving productivity in rainfed agriculture (CRIDA 2007). Apart from primary and secondary nutrients deficiency of Zn is now becoming widespread, particularly due to intensive cultivation (Srinivasarao et al. 2012a, 2012b). Micronutrient deficiency has become a limiting factor for crop productivity in many parts of the world. Of the microelements, Zn is the most widespread productivity constraint in rainfed production (Srinivasarao et al. 2009a). The deficiency of micronutrients may emerge when the supply of micronutrients to the soil is less compared to removal through crop harvest which in turn limits crop productivity (Shukla et al. 2009). In severe deficiency conditions, the yield loss could reach as high as 100% due to omission of micronutrients in the cropping system. Yield loss with omission of Zn fertilization was reported as 10% in India (Shukla et al. 2009). Improvement in Zn fertility during the past four decades has helped in enriching seed with higher concentration of Zn in paddy, wheat and maize from 12 to 29, 14 to 72 and 28 to 47 mg kg^{-1} seed respectively and concentration of Fe, Mn, B and S also increased in seeds and stover with micronutrient fertilization in North Indian states such as Punjab, Haryana and Uttar Pradesh.

Management of zinc deficiency in rainfed production systems

As mentioned earlier, SSNM approach was implemented in several farmers' fields based on participatory soil sampling and development of soil health cards. Based on the soil test data and crop grown, SSNM sheet was developed in each farmer's field in light-textured red soils in Dhupahad cluster of Nalgonda district of Andhra Pradesh, wherein deficient nutrients were included in nutrient recommendations instead of blanket application (Srinivasarao et al. 2012a). The farmer invested only on deficient nutrients and omitted nutrients which were in sufficient range in soils. Thus, the input cost was reduced and nutrient use efficiency improved considerably (Srinivasarao et al. 2012a).

Integrated nutrient management

Various management options are being promoted by Central Research Institute for Dryland Agriculture (CRIDA) in farmers' participatory action mode in several rainfed backward and tribal districts of Andhra Pradesh. Green leaf manuring is most promising and an important option to improve soil health and crop productivity (Srinivasarao et al. 2011d). *Gliricidia*, commonly known as *kakawate* and used as insecticide, repellent and rodenticide, can thrive in dry moist, acidic soils or even poor degraded soils under rainfed

Table 4. Zinc (Zn) deficiency in different clusters of eight districts of Andhra Pradesh[1].

Cluster (District)	Available Zn (mg kg^{-1}) Range	Mean	% deficient farmers' fields
Seethagondi (Adilabad)	0.22–2.90	0.62	74
Dhupahad (Nalgonda)	0.22–6.58	1.02	51
Tummalacheruvu (Khammam)	0.28–6.80	1.09	45
Jamistapur (Mahabubnagar)	0.30–4.68	0.96	48
Pampanur (Anantapur)	0.26–5.00	0.88	61
B.Yerragudi (YSR district)	0.24–5.20	0.61	78
Jaffergudem (Warangal)	0.26–3.88	0.96	50
Ibrahimpur (Ranga Reddy)	0.30–8.00	1.22	35

1. Source: Srinivasarao et al. (2011d).

conditions. Green leaf manuring is one of the important practices for increasing organic matter content in the soil.

About 1 to 2 t ha^{-1} *Gliricidia* leaf manure can be applied. Application of 1 t ha^{-1} *Gliricidia* leaf manure provides 21 kg N, 2.5 kg P, 18 kg K, 85 g Zn, 164 g Mn, 365 g Cu, 728 g Fe besides considerable quantities of S, calcium (Ca), Mg, B, Mo, etc. The amounts of nutrients added through 2 t *Gliricidia* ha^{-1} are 42 kg N, 5 kg P, 36 kg K, 170 g Zn, 328 g Mn, 730 g Cu and 1456 g Fe. *Gliricidia* improves mobilization of native soil nutrients in the soil due to production of carbon dioxide and organic acids during decomposition of the plant material and adds valuable nutrients such as N, P, K, Ca, Mg, Zn and Fe.

Gliricidia leaf manuring improves organic matter content in the soil, improves soil physical properties, restores and improves the soil quality, increases crop yields, allows the water to infiltrate into the soil more quickly rather than run off the surface, increases water-holding capacity of the soil and reduces soil erosion. Improvement of soil environment in the *Gliricidia* rhizosphere in the field bund soil could be due to improvement of organic carbon content and root activity and rhizodeposition (Srinivasarao et al. 2011d). The major requirement of rainfed crop nutrients (N, P, K and micronutrients) can be met through *Gliricidia* leaf (2 t ha^{-1}) manuring, if properly added.

Incorporation of horse gram biomass into soils under rainfed conditions showed increase in availabity of Zn in soil (Venkateswarlu et al. 2007). Widespread adoption of this practice at least in alternate years can restore the productivity of degraded soils and improve the yields.

Long-term study conducted in Alfisols under groundnut monocropping at Anantapur under rainfed conditions in southern India showed higher magnitude of depletion of Zn. Soil profile under the control treatment exhibited severe Zn deficiency and soils under treatments based on input of farmyard manure (FYM) exhibited relatively higher status of available Zn (Srinivasarao et al. 2013a). Incorporation of FYM exerted positive effect on the availability of nutrients, which was quite natural since it has been well established that bulky organic manures play a vital role in improving the major as well as micronutrient availability by direct contribution as well as indirectly by influencing chemical transformation reactions and microbial activity. Senthil Kumar et al. (2004) reported application of FYM or coir pith with Zn and Fe and foliar spray of these two nutrients enhanced the availability of soil Zn and increased the uptake of Zn by 64% and 114%, respectively in turmeric.

Soil test-based zinc application

Soil analysis indicated that Zn deficiency is widespread in India. Crops grown in fields having available nutrient status below the critical limits significantly responded to the application of Zn. This implies that balanced plant nutrition is essential for sustained increase in the productivity of rainfed systems in the semi-arid regions of India.

Impact of soil test-based fertilization on rainfed rice showed significant yield increase with balanced use of nutrients. Omission of Zn nutrient caused yield loss between 33% and 35% in the Terai alluvial soils of West Bengal (Mukhopadhyay et al. 2008). Hossain et al. (2011) reported while evaluating different varieties of maize that Zn fertilization resulted in increase in yields over control from 5 to 40% in hybrids and 9 to 25% in composites. Similar results were reported by Cakmak et al. (1997) in rye, triticale, bread and durum wheats; increased yields were obtained due to application of Zn in calcareous soils.

Table 5. Sufficiency range of zinc (Zn) concentration in critical stages of different crops[1].

Crop	Zn (ppm)	Stage	Parts to be sampled
Wheat	20–60	Seedling or heading stage	Fully expanded middle leaves
Oats	20–50	Seedling or heading stage	Fully expanded middle leaves
Barley	20–50	Seedling or heading stage	Fully expanded middle leaves
Maize	25–50	Tasseling or silking	Ear leaf
Sorghum	25–50	–	–
Millets	15–70	–	–
Pulses	20–40	Seedling stage	Entire aboveground plant parts
Soybean	20–60	–	–
Groundnut	10–50	Blossom stage	Fully expanded top leaves
Sunflower	20–50	Blossom stage	Fully expanded top leaves
Sugarcane	10–20	Grand growth stage (up to 4 months)	Fourth fully opened leaves from the top
Cotton	20–50	First bloom or square forming	Youngest fully expanded leaves in the main stem

1. Source: Govindraj et al. (2011).

Continuous application of Zn up to 27 kg ha^{-1} to maize crop did not induce nutrient imbalances and had no adverse effects on crop yield (Singh and Abrol 1985). In field trials conducted in Gujarat where the soils are low in Zn content, cotton responded well to soil application of Zn at 25 kg $ZnSO_4$ ha^{-1} with significantly the highest yield (3505 kg ha^{-1}) over the control (2598 kg ha^{-1}) at Orwada (Table 7). The response to individual application of different micronutrients was inexplicably low. So the combined application of Zn+Fe+B substantially improved the yield by 14.2% over control.

Wheat crop yield increased from 3.40 to 4.35 t ha^{-1} and Zn uptake increased from 142 to 256 g ha^{-1} with long-term application of crop residues along with Zn by using appropriate rates, methods (soil) and sources (such as $ZnSO_4$) (Prasad et al. 2010). Although there are many sources of Zn, the most popular source of Zn remains $ZnSO_4$. In general, soil application of 5–10 kg Zn ha^{-1} is recommended for 3–4 crop seasons to sustain crop production. Chelated Zn sources are more expensive and are usually applied at 1–2 kg ha^{-1} so that little residual Zn is available for the next crop.

Conclusion

The use of increased amounts of nitrogenous and phosphatic fertilizers with high-yielding hybrid varieties of wheat, maize and other crops causes Zn deficiency where the plant soil available Zn levels are marginal. Thus the prevention and/or correction of Zn deficiency in crops have a considerable effect on yield and quality of production. Whenever there are clear Zn deficiency symptoms in crops, farmers need to take up preventive measures such as foliar Zn application. Soil and foliar application along with organic manure (FYM, incorporation of green leaf manuring, composts, tank silt, etc.) are effective in ameliorating Zn deficiency disorders. Screening of cultivars of major crop species for Zn efficient strains reduces the requirement for Zn fertilizers.

Table 6. Critical concentration of zinc (Zn) from leaf analysis of cereal crops.

Crop	Severity of deficiency	Critical concentration (mg Zn kg^{-1} dry matter) (whole plant)
Wheat	Acute	<8 ppm
	Moderate	8–12 ppm
	Latent	12–20 ppm
	No response to zinc	>20 ppm
Maize	Deficiency	<20–22 ppm
Sorghum	Deficiency	8 ppm

Table 7. Effect of secondary and micronutrients on yield of cotton in Gujarat[1].

	Yield (kg ha^{-1})	
Treatment	Amargadh	Orwada
Control	3650	2598
50 kg ha^{-1} $FeSO_4$	3900	3137
25 kg ha^{-1} Zn SO_4	3825	3505
50 kg ha^{-1} $FeSO_4$ + 25 kg ha^{-1} Zn SO_4	3925	–
S at 20 kg ha^{-1} through gypsum	4125	2843
S at 20 kg ha^{-1} through bentonite	–	3113
2 kg ammonium molybdate ha^{-1}	3725	–
0.25% boron spray (two)	3850	–
$MgSO_4$ at 30 kg ha^{-1}	–	2745
25 kg ha^{-1} Zn SO_4 + 50 kg ha^{-1} $FeSO_4$ + 30 kg ha^{-1} $MgSO_4$ + 10 kg ha^{-1} borax	–	2966

1. Source: Annual Report of AICRP on micronutrients (2005–06), AAU, Anand, Gujarat.

Future line of work

- As intensive high nutrient demand crops/systems are involved in rainfed agriculture, frequent monitoring of soil Zn status and plant Zn content is essential.
- As state departments provide $ZnSO_4$ on subsidy, frequency and amount of its application should be guided properly, particularly under rainfed conditions.
- Impacts of foliar Zn application need to be studied.
- Studies on new forms of Zn fertilizers need to be carried out for their effectiveness and recommendations.

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