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Strategy for Optimization of Higher Productivity and Quality in Field Crops through Micronutrients: A Review

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ABSTRACT

The importance of micronutrients has been realized widespread. Micronutrient deficiencies were observed in most of the Indian soils, where intensive agriculture is practiced. Micronutrients may be minor in terms of the amounts needed by the crop, but they can be major in terms of their impact on crop growth. Micronutrients often act as co-factors in enzyme systems and participate in vital functions in plants. Studies of the roles of nutrients in plants have involved several diagnostic criteria that address the accumulation of nutrients and their roles in plants. These criteria include visual diagnosis, plant analysis, biochemical tests, and soil tests. Factors such as soil pH, organic matter, temperature, moisture & texture are important in determining the availability of micronutrient. Scientific methods involving for correcting micronutrient deficiencies and toxicity in soils and in field crops. Foliar application combined with nano-biotechnology are an efficient methods applying nutrients directly to the plants without farming any intermediate complexes and may result in rapid and significant progress in the areas of fertilizer micronutrient development for their efficient delivery and production of abundant nutritious food.

Keywords: Essential, foliar, micronutrients, optimization, soil, temperature, nanotechnology

The word 'micronutrients' represents some essential nutrients that are required in small quantities for the normal growth and development of plants. These include zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), boron (B), molybdenum (Mo) and chlorine (Cl). Real impetus on micronutrient research came with report of *khaira* disease in mid-sixties (*Nene*, 1965) and establishment of All India Coordinated Research Scheme on Micronutrients in Soils and Plants in India. The accumulation of these micronutrients by plants generally follows the order of Mn>Fe>Zn>B>Cu>Mo. This order may change among plant species and growth conditions (e.g.; flooded rice). Zinc deficiency is the most ubiquitous micronutrient problem throughout the world affecting many crops including the staples maize, rice and wheat which reduces not only grain yield but also quality. Copper deficiency is important in some parts of the world, such as Europe and Australia where cereals are most affected. Micronutrient constitutes in total less than 1% of dry weight of most plants. Micronutrient availability is greatly influenced by soil pH. The increase of soil pH from 4-7; Zn, Fe, Mn & B decreases in solubility & availability while Mo increases in solubility & availability[3]. Incidence of micronutrient deficiencies in crops has increased markedly in recent years due to intensive cropping, loss of top soil by erosion, losses of micronutrients through leaching, liming of acid soils, decreased proportions of farmyard manure compared with chemical fertilizers, increased purity of chemical fertilizers, and use of marginal lands for crop production. Micronutrient deficiency problems are also aggravated by high demand of modern crop cultivars[2]. Several researchers have indicated that the availability of micronutrients in soils depends on soil pH, organic matter content, adsorptive surfaces and other physical, chemical and biological conditions in the rhizosphere. In India multi-micronutrient fertilizers are gaining momentum among the farmers[10] has investigated the multi-micronutrient-deficient areas in the country based on the analysis of 63,575. The deficiency in one, two, three or four micronutrients have been categorized (Fig.1–3). It is evident that the deficiency of a single micronutrient prevails compared to two, three and four micronutrient deficiencies. Thus, application of single micronutrient fertilizers is sufficient instead of multi micronutrient mixtures with higher cost of production.

Seventy-five Years of Micronutrient Research in India

At the first light of the Green Revolution, for the first time in India, the field scale occurrence of *khaira* disease of rice in *tarai s*oils of Pantnagar[6]. Almost around same time, reports of zinc deficiency in Mexican wheat varieties came from Punjab[7]. Reports of Fe[12] and Mn deficiencies[11] from coarse textured low organic matter alluvial soils in late seventies have been followed by reports of the micronutrient deficiencies from different parts of the country. Green revolution has greatly increased the crop production in India, accomplished through growing of high yielding varieties; use of high analysis NPK fertilizers, increase in irrigated areas and increase in cropping intensity catalyzed the depletion of the finite reserves of micronutrients in soil[8]. As a consequence, deficiencies of micronutrients have been on the rise one by one in the country over last four decades (Fig. 4).

FACTORS RESPONSIBLE FOR NUTRIENT DEFICIENCY OR TOXICITY

Soil Factors

Soil is major source of supply of most of essential plant nutrients. The soils vary greatly in the total contents of nutrients because of the wide variations in the nature of the parent material and the influence of soil forming processes under different climatic conditions. Quantity *I* intensity (Q/I) relationship decides the supply of nutrients. Soil texture, pH, and organic matter content, type of clay minerals and interaction among nutrients markedly regulate the availability of nutrients in soils.

Environmental Factors

The availability of nutrients to plants is also greatly influenced by soil moisture, temperature, light and climatic conditions. Nutrient deficiencies are generally noticed on a wider scale during cold as compared to warm weather.

Plant Factors

The differential absorption behavior of various genotypes in the same soil arises from difference in plant root characteristics. The reducing capacity of the roots and the amount and composition of the root exudates also influence the availability of nutrients to plants.

Lack of Adequate Knowledge

Lack of adequate knowledge about the required amount, kind of fertilizer and method of application for a particular crop also results in deficiency or excessive fertilizer application causing imbalance among nutrients[14] has identified the factors *viz.*, effect of particle size on the level of extractable micronutrients, oxidation of divalent ions in soil, interaction between micronutrients and with N and P or with divalent cations like Ca, Mg and anions, soil microbial oxidation or reduction, variation in the availability of Mn oxide to plants, interference due to Mg salts in soils and level of organic carbon, interference in enzymatic activity in plants, Cu-organic matter interaction, effect of free lime on micronutrient equilibrium, variation in micronutrient requirement of crop species, and influence of climate factors on the availability of micronutrients in the soil from time to time which causes imbalance among nutrients.

Diagnostic Techniques for Micronutrients in Solis and Plants

Different chemical extracting reagents were tried, established and recommended to measure the plant available micronutrients from soils by several workers. In majority of studies, IN·NH_4^+0Ac at various pH with or without combination of other reagents and DTPA + TEA buffer + $CaCI_2$ extracting solutions were used for soil available micronutrients. By and large, DTPA extractable micronutrient method is relatively better than other methods in predicting deficiency of micronutrient cations in various soil groups. An amount of nutrient present in the plant is an indicator of supply of that particular nutrient which is directly related to the quantity present in soil. These relationships between micronutrient soil test *viz.*, plant concentration and yield led to establish critical concentration either in soil or in plant. Summarization of Common micronutrient soil tests and critical levels in soils and plant advocated in India[15] presented in Table 1.

Diagnosis of Micronutrient Deficiencies

There are different types of micronutrient deficiencies noticed in crop plants. The visible deficiency is an aggravated situation of micronutrients deficiency expressed by the plants/ plant parts in terms of characteristic visual symptoms. When the plant system is unable to cope up with hidden deficiency internally, then it loses its nutrient balance and exhibit specific disorder (s). Some indicator plants are identified in respect of specific micronutrient deficiency as mentioned in Table 2.

Importance of micronutrients in crop production

Increases quality & yield because most micronutrients act as cofactors in various enzymes in the various metabolic activities of the plant like protein metabolism, carbohydrate metabolism, photosynthetic etc. therefore there will be increase in protein content, TSS and other quality parameters which results in improving the quality and availability of other micronutrients like iron, it is important for chlorophyll formation, photosynthesis and thus increase the yield.

In legumes, it influences N_2-fixation because Fe and Mo are important constituent of Nitrogenous enzymes which helps in leghaemoglobin formation (O_2 scavenger). Major economic impact of micronutrient concentrations in a farming operation is through the increased efficiency of macronutrient fertilizer use.

Causes of micronutrient deficiencies

Intensive cropping, High demand of modern crop cultivars, Losses of top soil by erosion, Losses of micronutrients through leaching, Use of marginal lands for crop production and the factors affecting availability of micronutrients are Soil pH, organic matter, Temperature, Moisture and soil texture.

Micronutrients and metabolic processes

Micronutrients play a significant role in plant growth and metabolic processes associated with photosynthesis, chlorophyll formation, cell wall development and respiration, water absorption, xylem permeability, resistance to plant diseases, enzyme activities involved in the synthesis of primary and secondary metabolites, and nitrogen fixation and reduction[1] and[13]. Accordingly, Zn, Fe, Mn and Cu are involved in many processes controlling plant growth, and their content in grains and leaves determine the quality of food consumed by humans and animals. Micronutrient deficiencies in plants lead to reduced yields and, in severe cases, to plant death. Among the micronutrients, Zn deficiency is the most detrimental to crop yield, especially in calcareous soils.

Nanotechnology-based delivery platform for micronutrients

The recent R&D efforts to develop intelligent nano-fertilizers (INF) for wheat and other crops will be essential and useful for the development of a nanotechnology based delivery platform for micronutrients. The fundamental and practical research work conducted by the Canadian Nano-fertilizer research group on INF has opened up new research avenues in nano-biotechnology for fertilizers in agriculture. Specifically, research conducted and experience gained by this group of scientists has focused on understanding the interactions between root exudates and root-microbial signals associated with soil N mineralization and its uptake by wheat and canola; the preparation of aptamer based biosensors to detect specific metabolites of communication signalling networks of plants with soil microorganisms; and the development of novel polymer films together with a nanocoating tool and process[4]&[5] provide evidence that the communication between roots and microorganisms

Table 1: Common soil tests and critical levels of micronutrients in soils and plants usually advocated in India

Micronutrient	Soil test method	Critical level in soil (ppm)	Critical level in plant dry matter (ppm)
Zinc	DTPA	0.4-1.2	<15-20
Manganese	DTPA	2	<20
Copper	DTPA	0.2	<4
Iron	DTPA	2.5-4.5	<50
Boron	Hot water	0.5	<20
Molybdenum	Ammonium Oxalate	0.2	<0.1

Table 2: Indicator plants are identified in respect of micronutrient deficiency

Nutrient	Indicator plant(s)
Iron	Sorghum, barley, citrus, and peach.
Zinc	Maize, onion, citrus, oats, pea, radish and wheat
Manganese	Apple, citrus, barley, maize, lettuce, oats, pea, radish and wheat
Copper	Apple, citrus, barley, maize, lettuce, oats, onion and tabacco
Boron	Lucem, turnip, cauliflower, apple and peach.
Molybdenum	Lettuce.
Chlorine	Cauliflower, other Brassical sp, lagumes, oat and spinach.

Table 3: Residual effect of Zinc and Boron on yield of French bean (*Hamsa et al.*, 2012)

Treatment	No. of pods/plant	Pod length (cm)	Pod yield (q/ha)
(Control)RDF	10.33	7.33	62.5997
Zn_6kg/ha	14.66	8.66	69.368
Zn_{12}kg/ha	15.33	9.00	77.1685
Zn_{18}kg/ha	19.33	11.13	90.7881
Zn_6kg/ha+B4kg/ha	17.66	10.33	78.8178
Zn_{12}kg/ha+B4kg/ha	23.33	11.83	95.3658
Zn_{18}kg/ha+B4kg/ha	25.66	12.8	98.7155
SEm±	**0.33**	**0.32**	**2.9**
CD at 5%	**0.76**	**0.721**	6.32

Table 4: Effect of graded levels of copper on the yield, Yield attributes and harvest index of wheat (*Kumar et al.*, 2009).

Cu applied (mg/kg)	Grain yield (g/pot)	Straw yield (g/pot)	1000-grain weight(g)	Harvest index (%)
0	3.88	6.92	32.58	35.92
0.5	4.48	6.64	35.02	40.29
1.0	4.64	6.68	38.62	40.99
1.5	6.32	6.92	41.35	47.73
2.0	4.44	6.44	35.85	40.81
2.5	3.80	5.84	33.93	39.42
SE(d)±	**0.98**	**—**	**1.54**	2.39
CD(0.05)	2.06	NS	3.24	5.03

Table 5: Number of tillers, number of grains, 1000-grain weight and grain yield of wheat as affected by different micronutrients (Nadim *et al.*, 2011).

Treatments	Tillers (m^{-2})	Grains ($spike^{-1}$)	1000- grain weight(g)	Grain yield ($t\ ha^{-1}$)
Zn @ 5 kg ha^{-1}	206.0	44.25	40.54	3.15
Zn @ 10 kg ha^{-1}	220.8	37.75	43.22	3.15
Zn @ 15 kg ha^{-1}	195.5	45.75	41.56	3.20
Cu @ 6 kg ha^{-1}	226.5	41.00	41.68	3.38
Cu @ 8 kg ha^{-1}	249.0	39.75	41.56	3.62
Cu @ 10 kg ha^{-1}	190.0	43.00	44.02	3.05
Fe @ 8 kg ha^{-1}	190.0	42.00	42.24	2.86
Fe @ 12 kg ha^{-1}	210.8	40.25	44.02	3.24
Fe@ 16 kg ha^{-1}	201.8	44.25	42.66	3.26
Mn @ 8 kg ha^{-1}	229.8	43.00	41.31	3.60
Mn @ 12 kg ha^{-1}	190.3	44.25	43.00	3.06
Mn @16 kg ha^{-1}	218.5	39.25	42.80	3.14
B @ 1 kg ha^{-1}	195.5	45.25	41.39	3.15
B @ 2 kg ha^{-1}	212.0	46.50	42.58	3.67
B @ 3 kg ha^{-1}	201.0	43.25	43.06	3.19
Zn+Cu+Fe+Mn+B @ 5+6+8+8+1 kg ha^{-1}	194.0	46.00	43.65	3.30
Zn+Cu+Fe+Mn+B @ 10+8+12+12+2 kg ha^{-1}	216.3	43.50	39.67	3.29
Zn+Cu+Fe+Mn+B @ 15+10+16+16+3 kg ha^{-1}	190.0	41.00	44.64	2.96
$LSD_{0.05}$	14.36	3.13	1.19	0.18

is an integral part of chemical signalling networks in wheat or other crops rhizosphere. As a result of this communication, microbial or plant metabolites are released into the soil solution. Fig. 7 shows that the chemical communication concepts represent a promising approach for developing model intelligent nano-fertilizer delivery platforms for MNs, such as Zn and Fe. The main mechanism of nutrient release is based on the recognition and binding of a specific plant signal by a nano-biosensor housed in a polymer film which coats Zn-fertilizer NPs or salts. Upon binding, the fertilizer-ZnO-NPs (or other MN-NPs) released in a synchronized fashion in response to root signal release, polymer permeability and MN crop needs. The binding of specific root chemical signals (yellow) with a nano-biosensor (red) housed in a thin polymer film (blue) coating ZnO-fertilizer nanoparticles (dark grey). The selective signal-biosensor binding process results in the release, dissolution, plant uptake and aggregation of ZnO NPs (white spheres) in the soil solution of crop rhizospheres.

Nano biotechnology for micronutrient delivery

Biotechnology and nanobiotechnology combined may result in rapid and significant progress in the areas of fertilizer-MN development for their efficient delivery and production of abundant nutritious food. In this section we attempt to identify and prioritize research directions for development of nanofertilizers for MNs. Increasing the MUE by crops requires urgent and significant support from governments and industry for increasing research activities in basic areas of nutrient cycling in soil-plant systems. Such research requires a multidisciplinary team effort including soil and plant scientists, chemists and engineers to understand basic processes affecting the cycling of MNs in soils, crop rhizospheres and plants, and the development of novel nanofertilizer products and technologies.

In particular, future research focus will be to gain additional experimental evidence about how metal oxide NPs applied alone or in combination with macronutrients to leaves and/or deficient soils

Table 6: Micronutrients function, deficiency, toxicity along with remedial measures of soil and foliar application

Nutrient	Function	Deficiency	Toxicity	Soil application	Foliar application
Zn	Enzyme activation, N metabolism, involved in photosynthesis and reproduction of DNA during cell division.	Interveinal Chlorosis in leaf, yellowing on leaves, stunted plant growth.	Necrotic lesions in interveinal tissue, mild Chlorosis and roots turn brown and necrotic.	0.5-35kg $ZnSO_4$ or Zn EDTA/ha	0.1-0.5% $ZnSO_4 7H_2O$
Fe	Chlorophyll production, photosynthesis, energy transfer within plants, protein metabolism.	Interveinal Chlorosis yellow between veins and pale white leaves.	Blackish-straw coloured leaves extending from margins to midrib.	30-100kg FeSO4	2% $FeSO_4.7H_2O$
Mn	For energy transfer, photosynthesis, Hill reaction, synthesis of organic molecules. N-fixation, enzyme cofactor.	Interveinal Chlorosis of young leaves, gradation of pale green and dark colour near to veins.	Dark green with extensive reddish purple specks, bronze yellow and uneven distribution of chlorophyll.	5-50kg $MnSO_4$/ha	0.1% $MnSO_4$ H_2O
B	Sugar transport, cell wall composition, protein synthesis, pollen germination, membrane stability.	Affects growing points of shoot, root and leaves.	Interveinal necrosis, brown on leaf margins, young leaves develop Chlorosis between veins.	0.75-7 kg Borax/ha	0.1-0.25%
Cu	Important for energy transfer, photosynthesis and disease resistance.	Chlorosis, gum may exude from fissures in the bark, young shoots die.	Chlorosis and light coloured leaves with red streaks along margin identified as reddish brown necrotic roots.	1-20kg $CuSO_4$/ha	0.1-0.2% solution $CuSO_4.5H_2O$
Mo	Important in activations of enzymes involved in N fixation and nitrate reduction and pollen formation.	Interveinal Chlorosis, leaves become narrow, grey green and cupping of leaves.	Red bands along leaf margins brilliant tints of golden yellow or blue in tomato.	0.01-1kg ammonium molybdate	0.07-0.1%ammonium molybdate

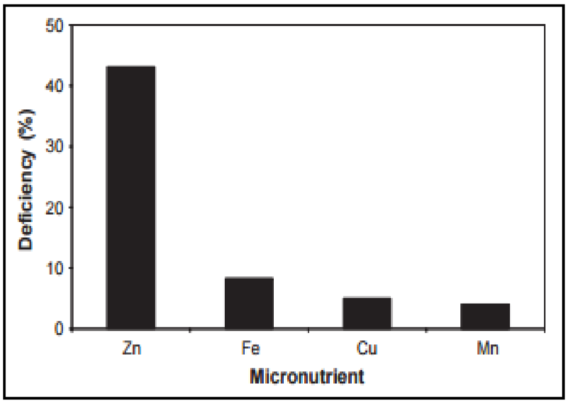

Fig. 1: Single micronutrient deficiency in Indian soils

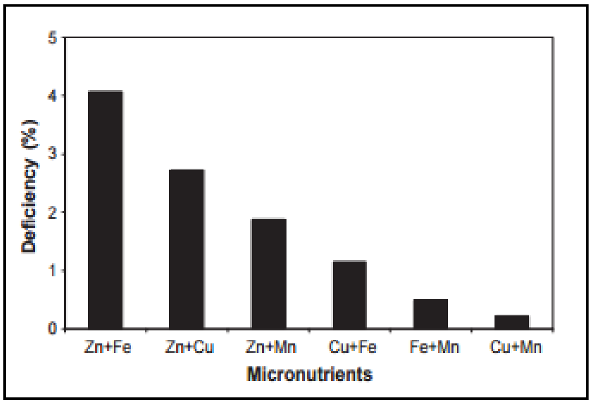

Fig. 2: Extent of deficiency in two micronutrients in Indian soils

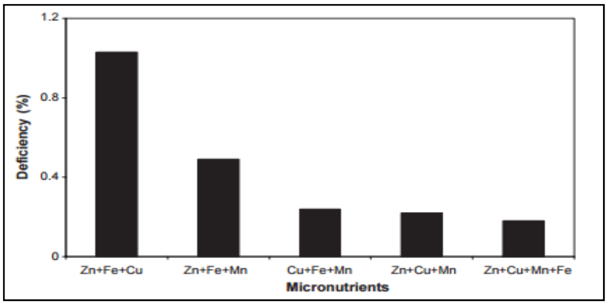

Fig. 3: Extent of deficiency in multi-micronutrients in Indian soils

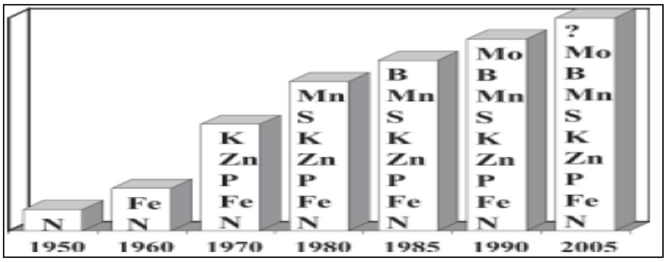

Fig. 4: Progressive expansion in the occurrence of nutrient deficiencies in India (Katyal and Rattan 1995).

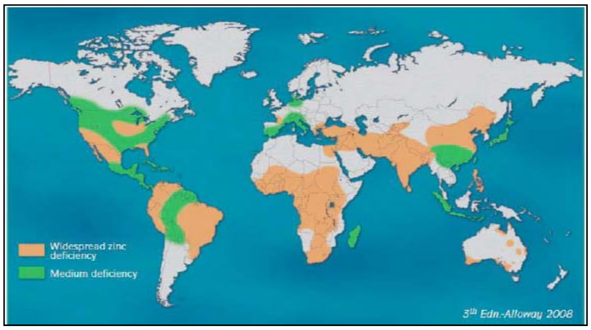

Fig. 5: Areas with Zn deficiency in the world (from Alloway, 2008b)

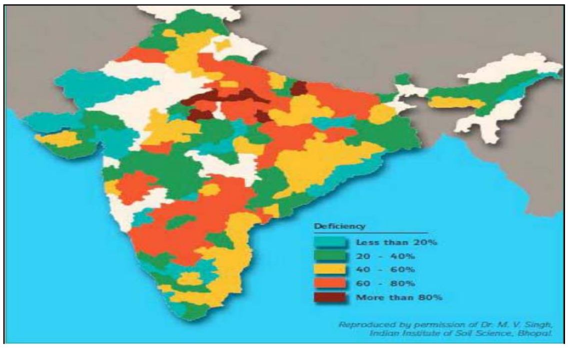

Fig. 6: Soil zinc deficiency in soils of India (from Alloway, 2008b)

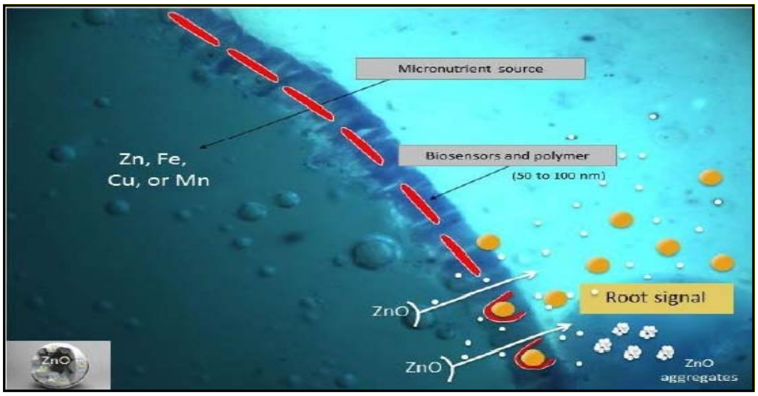

Fig. 7: A conceptual model for the synchronized release of ZnO nano-particles according to crop demand

under different environments increase crop MUE, grain yield and food nutrition. Advanced research prospects for integrating nanobiotechnologies into fertilizers should be explored, cognizant of any potential risks to the environment or to human health. New knowledge in soil-crop ecology and advances in nanobiotechnology can serve as the basis for significantly increasing MUE by crops in agriculture. Advances in nanotechnology, such as novel polymer film materials for nutrient encapsulation, NMs and NPs for MNs, identification of metabolites resulting from chemical communication between plant roots and soil microorganisms will permit better manipulation and synchronization of the release of fertilizer-MNs with their demand by crops during the growing season[13]. Research with a focus on the latter will contribute to the development of novel efficient MN-nanofertilizer platform delivery systems designed for specific soils, crops and agro-climates around the world.

Method of Application of micronutrient fertilizers

Micronutrient fertilizer use is highly cost-effective in deficient situations, especially with foliar feeding. The best method of micronutrient application depends on the element and when the deficiency is being addressed. The methods of correcting deficiencies by soil and foliar application presented in Table 6.

Future Strategies of Research

Screening and/or breeding of micronutrient efficient crops and their cultivars should be done on a priority basis, and more importantly, nutrient efficient crop rotations should be recommended, particularly those on deficient soils. Systematic studies to monitor micronutrient deficiencies in different crop rotations and soils should be carried out using GIS. The entire world may be covered once in 2 to 3 years and repeat survey should be done after 4 to 5 years to monitor the trends. In addition, critical limits for main crops should be refined for different soils.

Limited information is available on emerging deficiencies of B and Cu and on the response of different crops to application of Cu and B in deficient soils. More field experiments should be initiated to generate information, critical limits and their efficient management under field conditions[9].

CONCLUSION

Although the problems of micronutrient deficiency in crop production have been well attended in last seven decades or so in India, very limited efforts have been made to link these problems with animal and human health. While in Green Revolution era of the crop productivity by need-based inclusion of the micronutrient fertilizers, India has to witness a paradigm shift in terms of producing the micronutrient-rich food capable of alleviating micronutrient-deficiency syndrome in animal and human-beings. The 21st century, the stress was on maximizing since they are involved in various enzymatic activities, their deficiencies causes malfunctioning of the plant activities. To manage these micronutrient deficiencies spraying of suitable chemicals at recommended levels by foliar application will alleviate the deficiency. Foliar application combined with nano-biotechnology are an efficient methods applying nutrients directly to the plants without farming any intermediate complexes and may result in rapid and significant progress in the areas of fertilizer micronutrient development for their efficient delivery and production of abundant nutritious food.

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