Micronutrient: Status and Management

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ARTICLE ID: 071

Introduction:

Micronutrients are the elements required by plants in very small quantities but it is essential for proper growth and development of the plants. Micronutrients also called as 'trace elements', are: iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), nickel (Ni) and chlorine (Cl) are essential for plant growth. Iron, manganese, copper and zinc are called micronutrient cation as they carry positive charges while boron, molybdenum and chlorine occur as anions and they carry negative charges. Through their involvement in various enzymes and other physiologically active molecules, these micronutrients are important for gene expression, biosynthesis of proteins, nucleic acids, growth substances, chlorophyll and secondary metabolites, metabolism of carbohydrates and lipids, stress tolerance, etc. (Singh, 2004; Rengel, 2007; Gao *et al.*, 2008).

The micronutrient content of soil is determined by the chemical composition of its parent material and its availability to plants is influenced by the distribution within the soil profile (Singh and Dhankar, 1989). Land-use pattern, besides soil characterisation, plays a vital role in governing the nutrient dynamics and fertility of soils (Venkatesh *et al.*, 2003). Knowledge of the pedogenic distribution of micronutrients is crucial because the roots of many plants penetrate subsurface layers of the soil to draw required nutrients. Both deficiency and toxicity of micronutrient is soil is related to the low or toxic content of the nutrient in the parent rock and minerals from which it has developed (Deb *et al*. 2009). It is quite impossible to get the maximum benefit from crop production without the availability of adequate micronutrients.

Table 1: Micronutrient elements discovered so far

Micronutrient elements	Essentiality established by	Year of discovery	Plant uptake form

Iron	E. Gris	1843	Fe^{2+}
Manganese	J. S. McHargue	1922	Mn^{2+}
Zinc	A L. Sommer and C. B. Lipman	1926	Zn^{2+}
Copper	A L. Sommer, C. P. Lipman, and C. McKinny	1931	Cu^{2+}
Molybdenum	D. L. Arnon and P. R. Stout	1939	MoO_4^{2-}
Boron	K. Warington	1923	H_3BO_3, $H_2BO_3^-$, HBO_3^{2-}, BO_3^{3-}
Chlorine	Broyer, Carlton, and others	1954	Cl^-
Nickel	P. H. Brown, R. M. Welch, and E. E. Cary	1982	Ni^{2+}

Importance:

The importance of micronutrients has been realized during the past four decades when widespread micronutrient deficiencies were observed in most of the soils of our country, where intensive agriculture is practiced. The deficiencies have been attributed to the following changes in Indian agriculture:

1. Continuous removal of micronutrient from the soil by the recently introduced fertilizer responsive improved varieties of crop.
2. Use of micronutrient free high analysis fertilizers in modern agriculture.
3. Improved instrumentation techniques and increased knowledge about mineral nutrition of plants which has helped in the diagnosis of micronutrient deficiencies in soil and plants.

The demand for increasing crop production will require a thorough knowledge of the soil factors that regulate the supply and availability of micronutrients in soils. They are not only important for better crop productivity, but also essential for sustaining animal and human health. Inadequate consumption of any essential micronutrient results in adverse metabolic disturbances, leading to sickness, poor health, impaired development in children and large economic costs to society. (Deb *et al*. 2009)

The most of the micronutrients like Zn, Cu, Fe, Mn, B, Mo and Cl are also essential to human. However, some elements, like I (Iodine), Se (Selenium), F (Fluoride) and Cr

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(Chromium) absorbed by plant from soil and water and moved to animal and human gut through food chain, are essential for human but not for plants. Further, micronutrient deficient soils result in production of food/feed/fodder low in micronutrient content/ density and that in the long-run have been inflicting their deficiency in humans and animals. Hence, the rampant micronutrient deficiency in soils has resulted in increased incidence of micronutrients deficiencies in animals and humans in recent years and taking a toll on the food and economic security of the country in terms of the yield and economic losses due to unmatched yield goals (Shukla *et al.*, 2014)

Micronutrient concentration in plants:

In plants, the optimum concentrations of micronutrients are 100, 50, 100, 20, 20, 0.1, 0.1 and 6 mg kg^{-1} of dry matter for Cl, Mn, Fe, B, Zn, Mo, Ni and Cu, respectively. Visual diagnosis of micronutrient disorders is an influential tool for the quick identification of plant health associated with fertility, micronutrient availability, uptake and confirmation of soil or foliar test results. Careful remarks of the growth of plants can deliver a direct indication of their nutritional conditions.

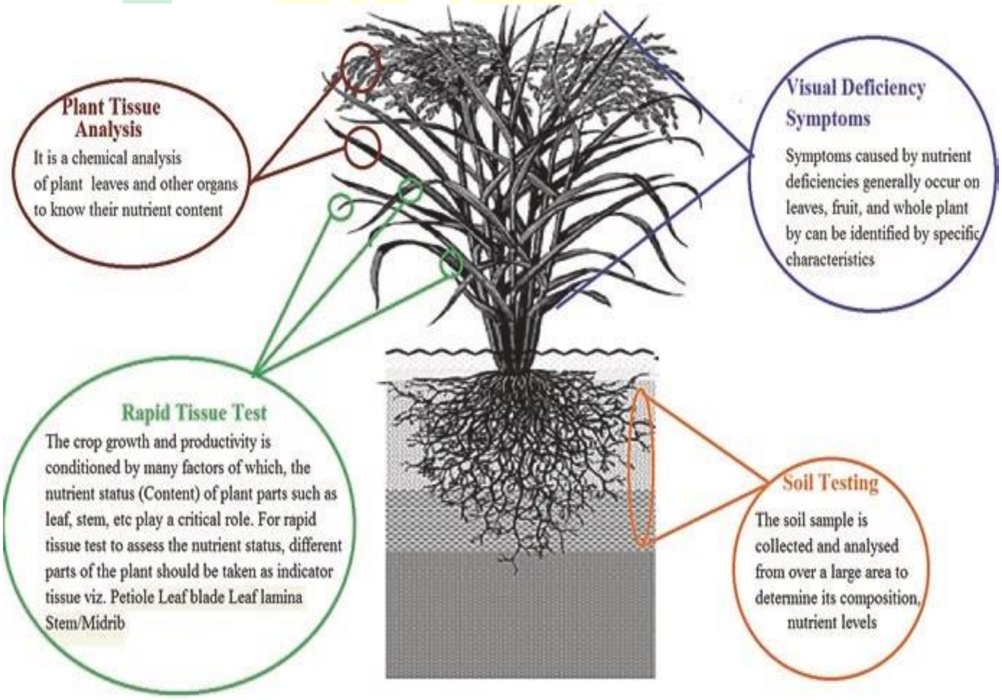

Fig. 1: Possible steps to identify the nutrient deficiency

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Metabolic disturbances subsequent from micronutrient deficiencies offer relations between the function of an element and the appearance of specific development of micronutrient deficiency in the plant:

Step 1: Reduction of micronutrients stored in the body—lessening the degree of saturation of the carriers and enzymes.

Step 2: Damage of micronutrients is reliant on biochemical functions.

Step 3: Determinate changes in cellular and physiological functions.

Step 4: Presence of structural and functional lesions. When a plant lacks a particular nutrient, it reveals the injury of biological and physiological functions (up to step 3) before showing deficiency as lesions or clinical symptoms (step 4). The first three stages mark a hidden hunger, which may cause a critical loss in growth and development of plant and eventually decrease in yield, if not identified through plant tissue analysis in time (Table 4).

Table 4: Micronutrient concentration in plants

Micronutrients	**Crops**	**Critical concentration (mg kg^{-1})**
Zn	Cereals	15
	Millets	15–20
	Legumes	7–20
	Vegetables (French bean)	36
	Oilseeds	12–25
B	Cereals	4–10
	Millets	7–15
	Legumes	3–15
	Vegetables	3–5
	Oilseeds	5–10
Cu	Cereals	2–4
	Millets	2–3.5
	Legumes	4–8
	Vegetables	2–6
	Oilseeds	2–10

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Mn	Cereals	25
	Millets	10
	Legumes	10–35
	Vegetables	30–40
	Oilseeds	5–18

Source: Shukla *et al.* (2018)

Micronutrient Deficiency Scenario in India:

Variability in the total micronutrient content of the soils is a mirror of the diversity in parent materials from which these have originated (Rattan *et al.* 2008). Parent material and pedogenic processes govern total soil micronutrient content. Leaching loss of micronutrients, liming of soils, limited use of manures and use of excessive micronutrient fertilizers deprived of micronutrient additions aggravate depletion of available micronutrients in soils. Indian soils are reasonably acceptable concerning total micronutrient content. But despite the comparatively high entire contents, micronutrient deficiencies have often been reported in many crops due to low availability of available micronutrients (Singh 2008; Behera and Shukla 2014; Shukla and Tiwari 2016).

In acidic soils of India, Boron (B), Molybdenum (Mo) and Zinc (Zn) are three most deficient micronutrients with their deficiency reported in 45, 46 and 31 % of the agricultural soils, respectively (Singh, 2007). The deficiencies are even more severe (60 %) in acidic soils of Northeastern India (Annual Report of ICAR-NEH, 2012-13), which may be attributed to a number of soil and climatic factors including high rainfall, light texture, abundance of Fe and Al oxides, low rate of organic matter decomposition, and high critical levels of nutrient availability (Singh, 2007; Goldberg *et al.* 1996). Soil acidity and micronutrient deficiency are major factors constraining productivity of a wide range of crops in northeast India (Singh, 2007; Kumar, 2001; Srivasta *et al.*2011).

Table 5: Distribution of micronutrient deficiencies in India (in %)

State	Zinc	Copper	Manganese	Iron	Boron
Andhra Pradesh	22.92	1.33	1.63	17.24	4.08
Arunachal Pradesh	4.63	1.40	3.01	1.44	39.15
Assam	28.11	2.80	0.01	0.00	32.75

Bihar	45.25	3.19	8.77	12.00	39.39
Chhattisgarh	25.29	3.22	14.77	7.06	20.59
Goa	55.29	3.09	16.91	12.21	12.94
Gujarat	36.56	0.38	0.46	25.87	18.72
Haryana	15.42	5.13	6.16	21.72	3.27
Himachal Pradesh	8.62	1.43	6.68	0.51	27.02
Jammu and Kashmir	10.91	0.34	4.60	0.41	43.03
Jharkhand	17.47	0.78	0.26	0.06	60.00
Karnataka	30.70	2.28	0.13	7.68	36.79
Kerala	18.34	0.45	3.58	1.23	31.21
Madhya Pradesh	57.05	0.47	2.25	8.34	4.30
Maharashtra	38.60	0.14	3.02	23.12	20.69
Manipur	11.50	2.46	2.06	2.13	37.17
Meghalaya	3.84	1.03	2.95	1.33	47.93
Mizoram	1.96	0.98	1.22	0.49	32.76
Nagaland	4.62	0.53	3.05	2.00	54.31
Odisha	32.12	7.11	2.12	6.42	51.88
Punjab	19.24	4.67	26.20	13.04	18.99
Rajasthan	56.51	9.15	28.28	34.38	2.99
Tamil Nadu	63.30	12.01	7.37	12.62	20.65
Telangana	26.77	1.36	3.54	16.65	16.49
Tripura	5.51	2.36	0.00	1.57	23.62
Uttar Pradesh	27.27	2.84	15.82	15.56	20.61
Uttarakhand	9.59	1.51	4.82	1.36	13.44
West Bengal	14.42	1.76	0.98	0.03	37.05
All India average	36.50	4.20	7.10	12.8	23.4

Source: Shukla et al. (2018)

Shukla and Behera (2017) analysed 2.0 lakhs soil samples collected from across the country using global positioning system exhibited large-scale deficiencies of micronutrients, viz; Zn-36.5%, Fe-12.8%, Cu-4.2%, Mn-7.1% and B-23.2%.Available contents of Zn, Fe, Mn, Cu and B in different soils of the country varied widely (Table 6).

Table 6. Percentage wise distribution of micronutrient deficiencies in different soil:

Soil type	Per cent soil samples deficient (PSD) in				
	Zinc	Iron	Manganese	Copper	Boron
Alluvial soils – Recent	29.0	13.4	3.70	2.20	11.3
Brown hills soils	13.3	5.3	4.10	2.20	11.4
Calcareous alluvial soils	29.3	12.4	3.00	1.30	24.4
Calcareoussierozemic soils	13.4	22.8	9.90	5.00	5.80
Deep black soils	32.4	12.5	18.8	0.50	20.7
Deltaic alluvium	28.8	5.2	1.90	0.70	20.1
Desert soils-lithosolic	86.3	51.7	37.8	18.5	2.40
Desert soils-rhegoslic	54.0	39.4	16.3	7.50	24.7
Glaciers and eternal snow	8.6	1.3	1.10	0.50	12.3
Gley brown soils	32.7	25.1	0.30	0.60	46.3
Laterite soils	24.8	6.5	2.20	4.80	19.5
Medium black soils	39.4	22.3	1.10	0.30	16.9
Mixed red and black soils	36.2	17.9	3.50	2.20	12.7
Old alluvial soils	30.8	25.0	7.70	7.40	5.00
Red and yellow soils	31.7	11.9	1.50	0.80	17.2
Red loamy soils	27.3	11.4	9.50	1.60	11.5
Red sandy soils	20.9	15.0	4.80	0.40	22.8
Skeletal soils	63.2	22.4	2.10	0.30	0.60
Sub- montane soils (podzolic)	9.9	1.0	0.00	0.20	33.7
Tarai soils	21.1	10.8	1.70	2.10	6.60

Mapping Soil Micronutrient Status (2011-17)

In order to formulate the remediation strategies for the correcting micronutrient deficiencies in crops, GPS-based district-wise micronutrient delineation programme has been performed during 2011-17 and PSD maps have been prepared by ICAR-AICRP-MSPE for various states of India. Further, agro-ecological region-wise maps were also developed to

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understand the nature and extent of distribution of micronutrient deficiencies for quantitative support and policy decision making for development of balanced and prudent micronutrient management package and precision fertilizer distribution at regional level (Figure 2).

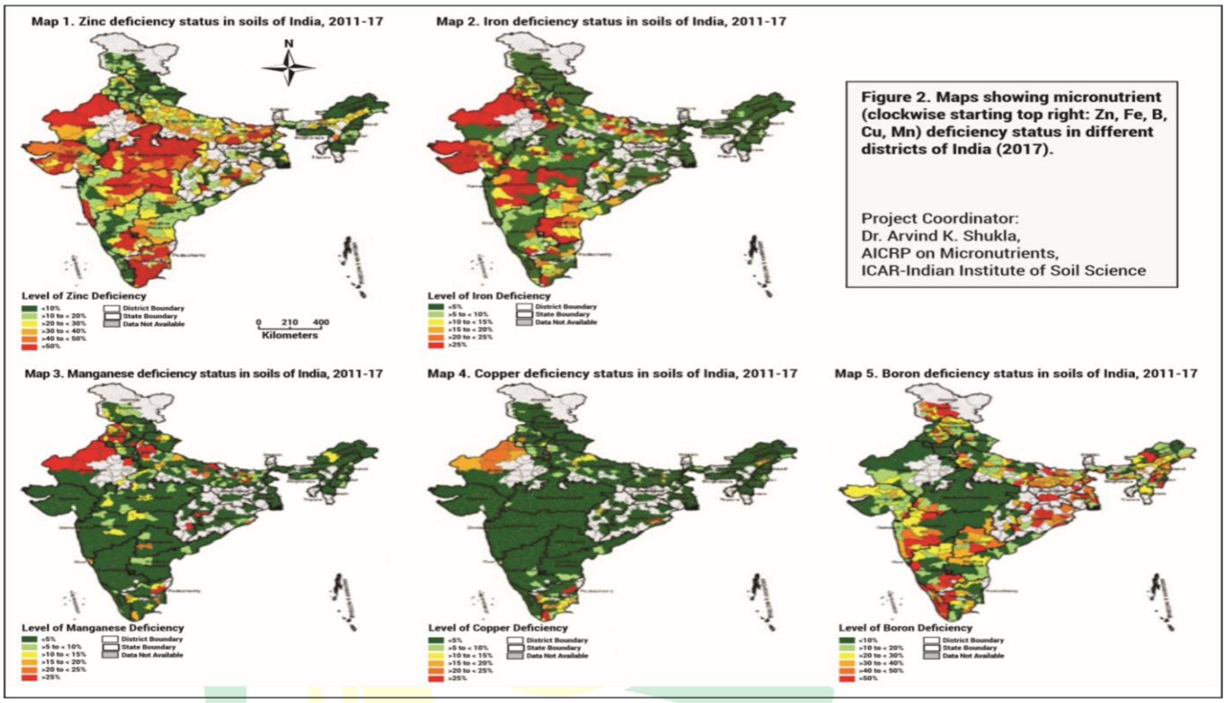

Figure 2. Maps showing micronutrient (clockwise starting top right: Zn, Fe, B, Cu, Mn) deficiency status in different districts of India (2017).

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Periodic Changes in Micronutrient Status of the Indian Soils:

Zinc deficiency declined from 46% in 1967-1987 to 36.5% in 2011-2017 in soils of the country (Figure 2) due to regular and more use of Zn fertilizer in some parts of the country. This has resulted into build-up of Zn level in soil, consequently Zn deficiency has decreased to 36.5% in 2017. However, the deficiencies of Fe and Mn increased slightly from 11.0 to 12.8 and 3.0 to 7.1%, respectively over the years from 1967-1987 to 2011- 2017. The increase in Mn deficiency is on account of more areas coming under rice-wheat system in Punjab, Haryana and western Uttar Pradesh. The deficiency of Cu fluctuates between 3 to 5% over the years.

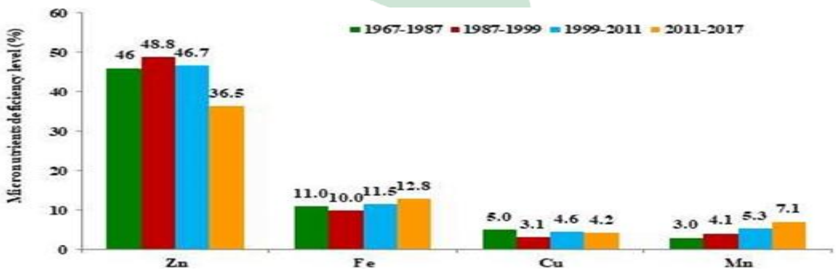

Fig.3: Periodic Changes in Micronutrient Status of the Indian Soils

Bandyopadhyay *et al.* (2018) identified priority zones of available micronutrients in the soils of agro-ecological subregions (AESR) of north-eastern states of India (Assam, Nagaland, Sikkim and Tripura) using geo-spatial techniques.

Surface soil samples (0–25 cm) were collected from Assam (AESRs 15.2, 15.3, 15.4 and 17.1), Nagaland (AESR 17.1), Sikkim (AESR 16.2) and Tripura (AESR 17.2) and analyzed for pH, organic carbon and DTPA-extractable micronutrients (Fe, Mn, Zn and Cu) by standard procedures. A total of 36,500 soil samples were collected comprising 20,031 samples in Assam, 8484 in Nagaland, 5560 in Sikkim and 2425 in and inaccessibility and remoteness of locations, AESR 16.1 (minor Tripura. Because of the insufficient number of sampling parts of Assam bordering to Bhutan) and AESR 16.3 (Arunachal Pradesh) were not considered for the present investigation. The AESR map was overlaid on spatial distribution layers to obtain spatial variability of micronutrients in the AESRs of north-eastern regions of India.

Zinc deficiency was common in all the AESR. Maximum deficient area of Zn, Mn and Cu was observed in AESR 15.4, and it was regarded as the high-priority zone, whereas AESR 16.2 and AESR 17.2 were considered as low-priority zone. Rainfall, pH and organic carbon appeared to be the key factors in controlling micronutrient availability in soils of north-eastern regions of India.

Management:

Micronutrient deficiencies in the soil affect the proper growth and development of plants. Hence, nutrient stress is to be managed effectively to assure food and nutritional security. Since the micronutrient need of a crop is specific and the micro nutrients are interrelated in their functional relationship, it is very difficult to generalise the soil management practices for maintaining adequate levels of micronutrients in soils. Location-specific expertise and management is essential as there is not much difference in the toxicity and deficiency levels of micronutrients in soil.

The knowledge about factors affecting the availability of micronutrients in soil provides a general guidance to the management practices to be followed for keeping them in available form. Due consideration is to be given to soil texture, pH, soil water regimes and $CaCO_3^-$ content before any management step is decided and the next consideration for the intensity of cropping and the fertilizer consumption pattern. The different management practices for micronutrients in soil-plant system are:

i. Application of micronutrient fertilizer: The simplest management of micronutrient deficiency in soils is to add micronutrient fertilizers along with NPK in the alternate years, if soil test shows deficiency. Soil application of micronutrient fertilizer is more effective in field crops and in fruit trees, both soil and spray application are effective methods of application.

ii. Addition of soil amendments: Most of the micronutrients occur in acid soils in very high amounts which may become toxic to sensitive crops. It is very difficult to remove the micronutrients from the soil system once these have entered there but their availability or solubility can be changed by addition of appropriate soil amendments. Lime is added to acidic soil to considerably decrease the micronutrient availability. While in calcareous, alkaline and sodic soils, deficiencies of Fe, Zn, Cu and Mn are frequently observed and gypsum is used in bringing the high pH. Thus increasing the availability of micronutrients in soils.

iii. Soil moisture regimes: The micronutrient availability is regulated by the soil moisture regimes. The availability of micronutrients is comparatively less in the oxidised state even under acid soil conditions than in their reduced forms. Under submerged soil conditions, the reduced forms of Fe and Mn dominate the soil solution and Zn and Cu may become deficient to crop, if the native content of these two micronutrients is low.

iv. Improved varieties of plants: the most modern concept of micronutrient management in soil is to grow varieties of crop which have the ability to extract required micronutrients from insoluble sources. Such crop varieties are to be developed by genetic manipulation and genetic engineering.

Both soluble and insoluble micronutrient carriers are utilised in routine agricultural practices to supply adequate level of micronutrients in soil. A list of common micronutrient fertilizers is given in table 10 along with their rates of application.

Table 10: Major micronutrient containing fertilizer sources.

Nutrient	Name of salt	Formula	Nutrient content (%)	Rate of soil application as nutrient

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				(kg/ha)
Fe	Ferrous sulphate	$FeSO_4.7H_2O$	21	5-20
	Ferric sulphate	$Fe_2(SO_4)_3$	17	
	Ferric chloride	$FeCl_3$	5-18	
	Iron-EDTA	Fe-EDTA	12	
Mn	Manganese sulphate trihydrate	$MnSO_4.3H_2O$	26-28	10-25
	Manganese sulphate monohydrate	$MnSO_4.H_2O$	30-32	
	Manganese dioxide	MnO_2	55-65	
	Manganese-EDTA	Mn-EDTA	5-12	
Zn	Zinc sulphate heptahydtare	$ZnSO_4.7H_2O$	21	2.5-10
	Zinc sulphate monohydrate	$ZnSO_4.H_2O$	33	
	Zinc oxide	ZnO	55-70	
	Zinc-EDTA	Zn-EDTA	12	
Cu	Copper sulphate pentahydrate	$CuSO_4.5H_2O$	24	1.0-5
	Copper sulphate monohydrate	$CuSO_4.H_2O$	35	
	Copper-EDTA	Cu-EDTA	9-13	
B	Borax	$Na_2B_4O_7.10H_2O$	10.5	2-5
	Boric acid	H_3BO_3	17.5	
	Solubor	$Na_2B_4O_7.5H_2O$+ $Na_2B_4O_7.10H_2O$	19	
Mo	Sodium molybdate	$Na_2MoO_4.2H_2O$	37-39	0.05-0.10
	Ammonium molybdate	$(NH_4)_6Mo_7O_{24}.4H_2O$	54	
Cl	Potassium chloride	KCl	48	**

Source: As per FCO (1985), FAI (1998)

**usually not applied as fertilizer supplier of chloride, except in coconut crops

In India, the most common fertilizer for Zn is $ZnSO_4.7H_2O$. Zinc oxide is also another fertilizer source of Zn, but its Zn-content is variable due to impurities. For other micronutrient cations, their sulphate salts are used as fertilizers because these are water soluble. Manganese dioxide is also used as fertilizer but its efficiency is muxh less as compared to $MnSO_4$. Micronutrient chelates are water soluble and these are now becoming popular for use in field and orchard crops.

It may be mentioned that the micronutrient management in soil requires expert knowledge. In micronutrient deficient soils commercial preparations, available in market for use as foliar spray, are not very useful. Proper soil management and soil application of adequate level of micronutrient is beneficial to the crops. Unlike N, P, K and S excess application of micronutrients in soil adversely affects the plant growth and may lead to deterioration of soil fertility and reduction in crop production. Scientific soil management needs a thorough understanding of the behaviour of micronutrients under different soil conditions.

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