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Micronutrient Fertilizers in Indian Agriculture – Product Profile, Availability, Forecast and Agronomic Effectiveness

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Abstract

Micronutrient fertilizers have assumed a significant role in Indian agriculture because of their widespread deficiencies under different soil-crop situations. On an average, 36.5%, 12.8%, 4.2%, 7.1%, and 23.2% soils of the country are deficient in zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), and boron (B), respectively. Along with single micronutrients deficiencies, multi-micronutrient deficiencies such as Zn+B, Zn+Fe, Zn+Mn, Zn+Cu, Fe+B, Zn+Fe+B, Zn+Fe+Cu+Mn, and Zn+Fe+Cu+Mn+B prevail in different states. Every fertilizer granule carrying the right amount of micronutrient delivered at the right time to the plant will help in quickly alleviating its deficiency. It is important to go in for innovative solutions which will allow proactive management of micronutrient nutrition in terms of ensuring higher and quality economic produce. The need-based micronutrient applications help in enhancing crop yields, producing quality agricultural produce, and sustaining animal and human health. Various types of micronutrient fertilizers namely, straight micronutrients fertilizers (19), fortified/coated micronutrient fertilizers (22), customized micronutrients fertilizers (30), and micronutrient mixtures (106) have been notified in Fertiliser (Inorganic, Organic, and Mixed) (Control) Order (FCO), 1985 of India and are presently available in the Indian markets for use by the farmers. Micronutrient deficiencies in the country can be managed by encouraging application of urea, DAP, and NPK complexes fortified, customized and/or coated with suitable micronutrient products. Price-affordability is a critical issue involved needing current policy review. From preliminary studies, nano-micronutrient formulations have also shown potential to act as alternative sources of micronutrients from better plant nutrition and increased use efficiency point of view. Responses of different crops to micronutrient applications vary with soil types and soil-crop management practices. Micronutrients also play a significant role in enhancing use efficiency of the major (macro) nutrients. Consumption of micronutrient fertilizers has shown significant increase over the years. As the spatial and temporal distribution of single micronutrient deficiencies and multi-micronutrients deficiencies in different parts of India are different, site-specific micronutrient management is needed. This warrants production and availability of different kinds of micronutrient fertilizers in different parts of the country.

Key words: Micronutrient deficiencies, soil micronutrients, micronutrient fertilizers, The Fertilizer (Inorganic, Organic or Mixed) (Control) Order 1985

Introduction

Agriculture and its allied sectors are indisputably the largest livelihood providers in India, more so in the vast rural areas, and contribute significantly towards the gross domestic product (GDP) of the country. Agriculture is the main source of food and nutrients for animals and humans alike. Fertilizers have played a key role in the success of India's Green Revolution and subsequent attainment of self-reliance and sustainability in food-grain production. Demand of fertilizers witnessed double digit growth rates over the past several years in the country on the strength of their 50% contribution to the increase in food production. However, partial factor productivity declined over the years due to accelerated emergence of micronutrient deficiencies in soils. Micronutrients are the essential nutrient elements, albeit required in very small quantities for overall growth of plants. Essential micronutrients involved in plant nutrition are: zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), chlorine (Cl), and nickel (Ni); for animals Zn, Fe, Mn, Cu, selenium (Se), iodine (I) and cobalt (Co) have been identified as being essential; and list for humans includes Zn, Cu, Fe, Mn, Mo, Co, I, Se, fluorine (F), and chromium (Cr). Boron is considered as beneficial trace element for animals and humans both because it prevents losses of Ca and Mg from their bodies. As enshrined in the essentiality criteria, every micronutrient performs specific role in plant, animal and human metabolism and its deficiency/role cannot be mitigated/substituted by any other element. Minerals applied to crops for their nourishment improve their concentration/content in the plant tissues. Inadequate supply of these nutrients in micronutrient deficient soils can lead to loss of yield as well as quality of produce, and consequentially health of animals and humans feeding thereon per se and also their productivity (Shukla et al., 2018). The intensification of agriculture-induced whooping nutrient mining of micronutrients from their finite

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soil resources led to what we experienced in terms of widespread micronutrient deficiencies. Continuous shipping away/export of micronutrients by crops has depleted soil micronutrient reserves and rendered the large tracts of the country deficient in these nutrients. On an average, 188,000 tonnes (t) of micronutrients are removed annually by agricultural crops. Research evidences suggest that the need-based inclusion of micronutrients in the fertilizer schedules would not only eliminate their deficiencies in soils but also enhance the efficiency of macronutrient fertilizers (Shukla and Behera, 2019). Stagnation in crop productivity can also be eliminated by following balanced fertilization schedule with micronutrients as its essential component. This will ensure reduction in cost of cultivation. Hence, innovative fertilizer products (specialty fertilizers, which include high solubility fertilizer, slow-release, controlled release, coated, fortified, chelated, organo-mineral, liquid fertilizers, bio-stimulants, bio-based and nano-fertilizers) need to be introduced with farmers on pilot scale initially with the support of suppliers and buyers. This pilot study should be conducted for a minimum period of one year or two crop cycles. Simultaneously, multi-locational field trials need to be set up in the designated ICAR Institutes / State Agricultural Universities (SAUs) for a minimum period of two-years. Farmer's feedback needs to be captured after one-year pilot study. More number of innovative micronutrient fertilizer products may be submitted by the fertilizer industry for their inclusion in The Fertilizer (Inorganic, Organic or Mixed) (Control) Order 1985 (FCO) based on the findings from the research institutes/agricultural universities.

Micronutrient Deficiencies in Crops and Soils

Single-Micronutrient Deficiencies

In spite of the relatively high total contents of micronutrients reported in soils of India, micronutrient deficiencies have been frequently reported on many crops grown from different parts of the country due to low available levels of these nutrients. The nature and extent of deficiencies vary with soil type, crop genotype, management and agro-ecological situations. With the intensive cropping of high yielding varieties of rice and wheat, deficiency of Zn initially, and subsequently deficiencies of Fe in rice, and Mn in wheat, emerged as the threats to sustenance of high levels of crop production. Micronutrient deficiencies are now frequently observed in intensively grown cereal, oilseed, pulse and vegetable crops.

Availability can be defined as the quantity of a soil nutrient that is accessible to plant roots during the period of growing season. Since plant roots accumulate micronutrients directly from the soil solution, the total pool of soil micronutrients is not directly available. Based on the critical limits followed in different states, deficiency status of micronutrients has been assessed in different soils. Analysis of more than 2.30 lakh soil samples revealed the occurrence of widespread deficiencies of micronutrients in the soils. On an average, 36.5%, 12.8%, 4.2%, 7.1%, and 23.2% soils are deficient in available Zn, Fe, Cu, Mn, and B, respectively (Shukla and Behera, 2019). Based on the newly devised critical limits, 7.9%, 28.6%, and 14.7% soil samples are acute deficient, deficient and latent deficient in Zn, respectively (**Figure 1**). Nearly 4.0%,

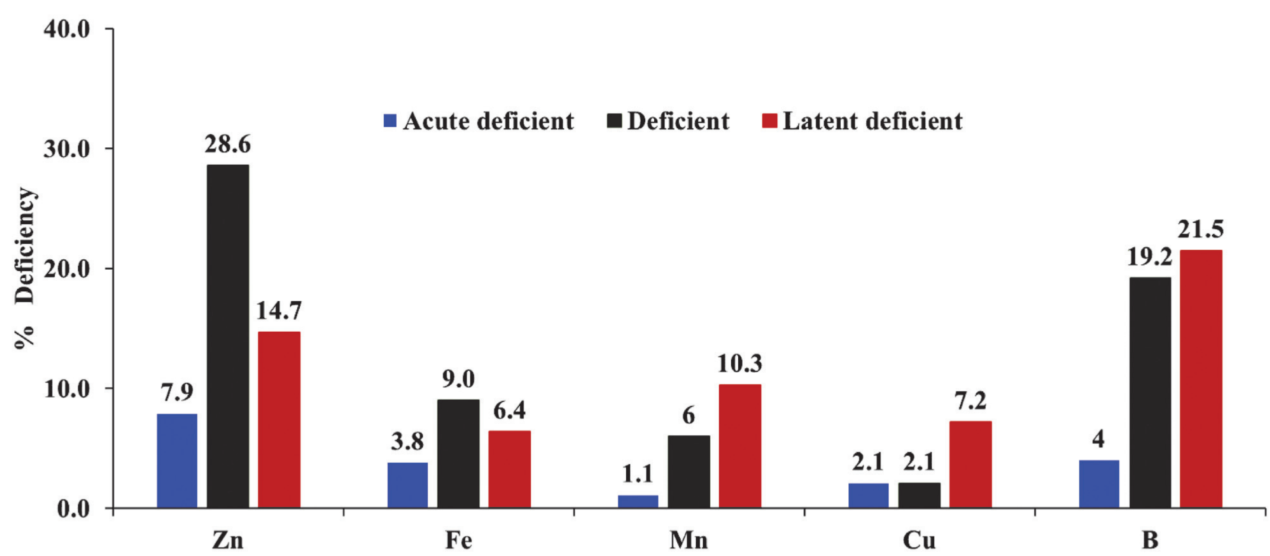


Figure 1. Extent of micronutrient deficiencies in Indian soils

19.2%, and 21.5% soil samples are acute deficient, deficient and latent deficient in B, respectively. Deficiencies of Mn, Cu and Fe in different categories are witnessing rising trends in different parts of the country.

By and large, the higher levels of Zn deficiencies prevail in the States of Madhya Pradesh, Tamil Nadu, Maharashtra, Bihar, and Uttar Pradesh. The western parts of the country, particularly Rajasthan, Gujarat and Maharashtra are reeling under acute Fe deficiency problem. Iron deficiency is also coming up in Telangana, Karnataka, Uttar Pradesh and Bihar. Incidences of Mn deficiency are increasing very fast under certain soil-crop conditions, particularly in rice–wheat cropping systems practiced on sandy or loamy sand soils of Punjab and Haryana. Copper deficiency mainly occurs in sandy, calcareous, eluviated and organic-rich soils. Addition of organic matter releases $CaCO_3$-bound Cu fraction in the soil and rebinds it with organic fraction, thus accentuating the Cu deficiencies/decreasing the Cu availability in calcareous and sandy loam soils. Presence of excess organic matter reduces the Cu availability in organic peat soils of Kerala and hill and submontane soils of the Himalayan *tarai* zone of Uttarakhand and Himachal Pradesh. Boron deficiency is more common in highly calcareous soils of Bihar and Gujarat and acid soils of West Bengal, Odisha and Jharkhand. In general, B deficiency is higher in eastern region of the country, which has resulted due to its excess leaching from sandy loam soils, alluvial and loess deposits. Most of the country's agricultural soils are adequate in Mo but its deficiency is noticed in some acidic, sandy and leached soils. Molybdenum deficiency is localized in some parts of Maharashtra and acidic soils of Odisha, West Bengal, Kerala and Himachal Pradesh.

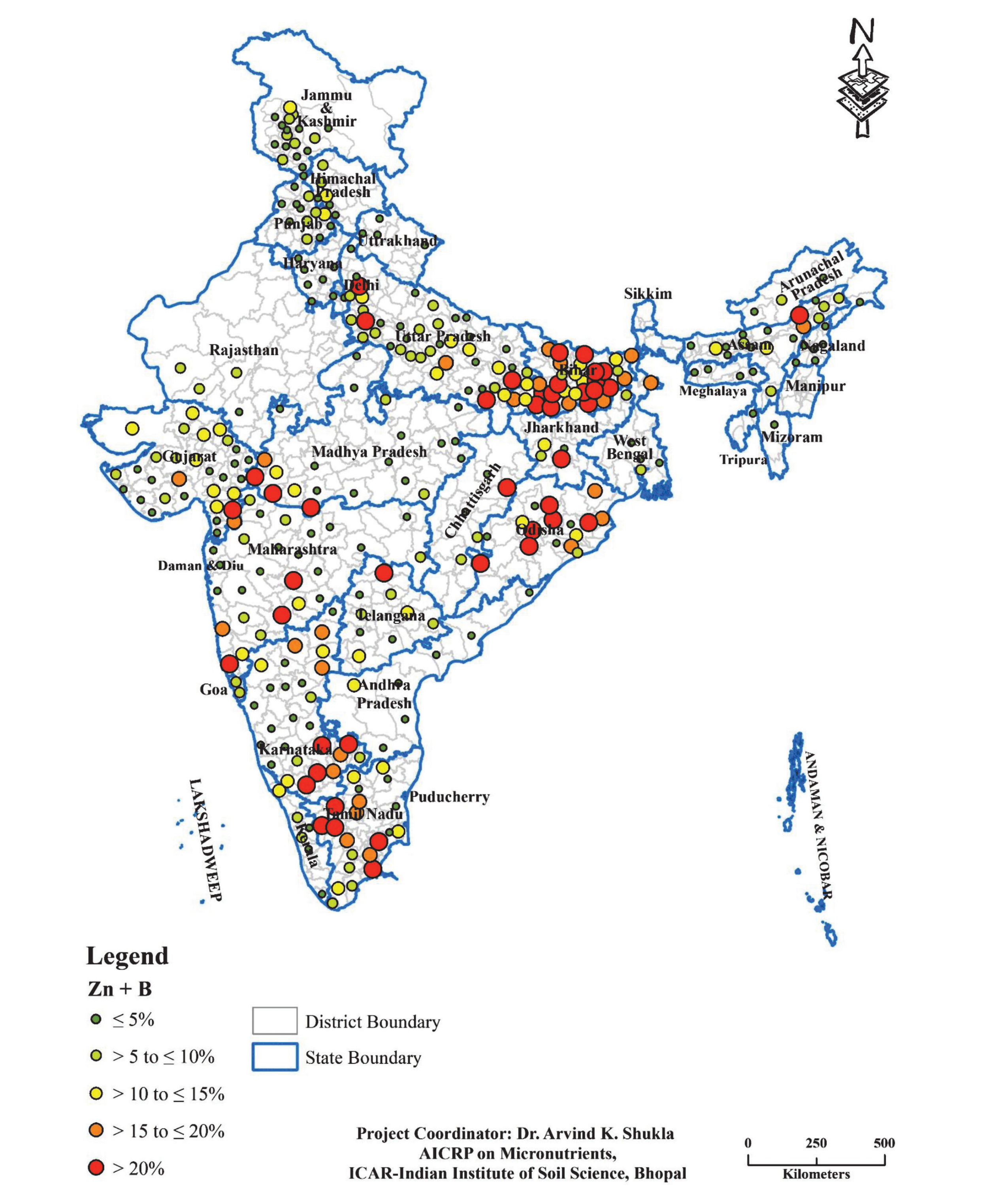
Multi-Micronutrient Deficiencies

In addition to single micronutrient deficiencies, multi-micronutrient deficiencies have emerged in different areas of the country over the years, posing a threat to sustainability of agriculture (**Table 1**). The average

Table 1. Multi-micronutrient deficiencies (% soil samples deficient) in different states of India

State	Zn+B	Zn+Fe	Zn+Mn	Zn+Cu	Fe+B	Zn+Fe+B	Zn+Fe+Cu+Mn	Zn+Fe+Cu+Mn+B
Andhra Pradesh	2.06	6.90	0.60	0.60	1.78	0.62	0.01	0.00
Arunachal Pradesh	2.41	0.00	0.50	0.30	0.00	0.00	0.00	0.00
Assam	7.88	0.00	0.00	0.90	0.14	0.00	0.00	0.00
Bihar	19.6	5.26	4.80	2.20	7.90	3.67	0.23	0.19
Chhattisgarh	8.87	3.04	0.90	0.90	0.87	0.63	0.02	0.00
Goa	6.32	2.21	10.30	2.10	0.59	0.29	0.00	0.00
Gujarat	7.29	11.7	0.30	0.30	4.35	1.94	0.01	0.00
Haryana	0.75	6.59	2.50	3.40	1.10	0.44	0.34	0.09
Himachal Pradesh	3.08	0.22	0.80	0.30	0.50	0.09	0.00	0.00
Jammu & Kashmir (undivided)	0.57	0.54	7.00	0.20	0.00	0.00	0.07	0.00
Jharkhand	8.40	0.00	0.20	0.10	0.00	0.00	0.00	0.00
Karnataka	15.3	9.24	1.20	1.10	6.84	3.31	0.02	0.01
Kerala	3.93	0.97	0.70	0.50	2.10	0.71	0.14	0.14
Madhya Pradesh	2.27	5.83	1.50	0.40	0.60	0.39	0.00	0.00
Maharashtra	5.19	9.82	1.80	0.10	5.23	1.48	0.01	0.00
Manipur	9.41	0.87	2.40	0.60	0.93	0.43	0.00	0.00
Meghalaya	1.31	0.07	0.30	0.10	0.62	0.07	0.00	0.00
Mizoram	1.11	0.00	0.00	0.20	0.22	0.00	0.00	0.00
Nagaland	2.19	0.40	0.30	0.10	0.60	0.30	0.00	0.00
Odisha	20.3	2.53	1.30	2.50	2.25	1.04	0.01	0.00
Punjab	2.83	4.64	7.00	2.70	1.82	0.68	0.48	0.15
Rajasthan	0.57	23.3	22.5	7.80	0.06	0.02	2.03	0.00
Tamil Nadu	13.1	7.71	5.30	9.10	2.00	1.38	0.66	0.10
Telangana	8.92	4.68	0.80	0.60	4.10	1.30	0.00	0.00
Tripura	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Uttar Pradesh	5.52	5.25	4.80	1.20	2.75	0.97	0.32	0.19
Uttarakhand	1.26	0.44	1.10	0.70	0.49	0.09	0.09	0.00
West Bengal	4.17	0.00	0.40	0.50	0.02	0.00	0.00	0.00
India	**8.70**	**5.80**	**3.40**	**2.80**	**2.70**	**1.20**	**0.30**	**0.10**

per cent soil samples showing multi-micronutrients deficiencies followed the order Zn+B > Zn+Fe > Zn+Mn > Zn+Cu > Fe+B > Zn+Fe+B > Zn+Fe+Cu+Mn > Zn+Fe+Cu+Mn+B. Zn+B deficiency varied from 0.6 to 20.3% spread over different states, with mean value of 8.7%. The prevalence of Zn+B deficiency was higher in states like Bihar, Karnataka, Odisha, and Tamil Nadu (**Map 1**). On an average, 5.8% of soils were deficient in Zn+Fe. Relatively higher per cent of soils of Gujarat, Karnataka, Maharashtra and Rajasthan



Map 1. Zn + B deficiency (% soil samples deficient in both the nutrients) in different parts of India

were deficient in Zn+Fe. More than 20% of soils in 9 districts of Gujarat, 5 districts each of Madhya Pradesh and Maharashtra, and 7 districts of Rajasthan suffered from the twin deficiencies of Zn and Fe. Relatively more soils of Goa, Jammu and Kashmir (erstwhile), and Rajasthan were deficient in Zn+Mn, with a national average of 3.4%. The higher per cent of soils in Bihar and Karnataka were deficient in Zn+Fe+B. More than 3-micronutrient deficiencies like Zn+Fe+Cu+Mn and Zn+Fe+Cu+Mn+B were very less, recorded on only 0.30% and 0.10% of soils, respectively. Less than 5% of soils in 13 districts of Bihar, 7 districts each of Punjab and Uttar Pradesh, and 16 districts of Tamil Nadu were deficient in Zn+Fe+Cu+Mn; whereas, less than 5% of soils in 13 districts of Bihar, 4 districts of Punjab and 10 districts of Tamil Nadu were deficient in Zn+Fe+Cu+Mn+B. This warrants/calls for the application of appropriate micronutrient fertilizers according to the prevailing micronutrient deficiencies in soils and requirement of crops for sustenance of crop production and improvement of crop quality.

Micronutrient Fertilizers in India

The term 'fertilizer' has legal connotation under the Fertiliser (Inorganic, Organix or Mixed) (Control) Order (FCO), 1985 in India. Fertilizer means any essential substance, either in straight or mixed form and derived from either inorganic, organic or mixed sources, that is used or intended to be used to provide essential plant nutrients or beneficial elements or both for the soils or makes essential nutrients available to the plants either directly or by biological processes or by both in the soil or plant as notified from time to time by the Central Government. Prefixes such as synthetic, mineral, inorganic, artificial, fortified, specialty, organic, bio- or chemical are often used to describe nature or purpose of use. Fertilizers containing micronutrients with specifications are included under schedule 1g (Micronutrients) and 1h (Fortified fertilizers) of the FCO. Straight micronutrient fertilizers cover Zn, Fe, B, Mn, Mo, Cu and Co. Government of India included a new category of fertilizers called "Customized Fertilizers" (CFs) under clause 20B of FCO basically to address the problems of increasing multi-nutrient deficiencies. In addition, a number of multi-micronutrient mixture formulations have been notified by different State Governments. While single-micronutrient fertilizers are common for all states based on FCO declaration, micronutrients mixtures *viz*., mixture of two or more micronutrients are notified by different states based on respective crops and soils.

Straight Micronutrient Fertilizers

This is the first and the most important category of micronutrient fertilizers mostly containing sulphates of metal cations. Several straight micronutrient fertilizers, included in the FCO are available in the country for soil and foliar application (FCO, 2021). Zinc sulphate heptahydrate ($ZnSO_4.7H_2O$) (21% Zn) was the first product used in India to correct zinc deficiencies. It is the most popular and widely used and is available in both crystalline and granular forms. Now, zinc sulphate monohydrate ($ZnSO_4.H_2O$) with 33% Zn is becoming increasingly popular because of its better storage and handling properties. It is also a preferred source for fortification/coating of zinc. Zinc sulphate is readily soluble in water and is used both as soil application and for foliar spray. Other straight zinc fertilizers are zinc oxide suspension (ZnO, 39.5% Zn) and chelated zinc (Zn-EDTA, 12% Zn and Zn-HEDP, 17% Zn). EDTA is most commonly used in producing chelated micronutrient fertilizers in India because as a chelate, it protects the nutrient till the time it is delivered to plant and does not release it prematurely for refixation in the soil. Chelated fertilizer is a more efficient source and is used in lower doses. The efficacy of Zn-EDTA and zinc suphate is comparable. Similarly, a number of boron products are available. Borax [$Na_2B_4O_7.10H_2O$] (10.5% B) is the most common fertilizer to apply B either through the soil or through foliar spray. Boric acid (H_3BO_3) (17% B) is largely used as foliar spray. Highly water-soluble B fertilizer, solubor ($Na_2B_8O_{13}.4H_2O$) containing 20% B suitable for both soil and foliar spray and, a low release B source colemanite ($Ca_2B_6O_{11}\cdot5H_2O$) or [$CaB_3O_4(OH)_3\cdot H_2O$] containing 11% B, a borate mineral found in evaporite deposits of alkaline lacustrine environments, have been included in FCO recently. It is a good source for acidic soils. Anhydrous borax ($Na_2B_4O_7$, 20.5% B), a 100% water soluble B product, also finds place in FCO; however, it is hardly used by farmers to correct B deficiencies in the field. This product is mainly used for development of B-based customized fertilizers. To correct iron deficiency, both inorganic salt of iron sulphate ($FeSO_4.7H_2O$, 19% Fe) and chelated iron [(Fe-EDTA (12% Fe) and Fe-HEDP (17% Fe)] are available in the market. Ammonium molybdate [$(NH_4)_6Mo_7O_{24}.4H_2O$] with 52% Mo is an efficient Mo source. Manganese sulphate ($MnSO_4.H_2O$, 30.5% Mn) and copper sulphate ($CuSO_4.5H_2O$, 24% Cu) are commonly used fertilizers for correcting Mn and Cu deficiencies in plants, respectively. Amino acid based chelated products such as metalosate zinc (6.8% Zn) and metalosate boron (5.0% B) liquid fertilizers are designed for foliar application on plants to prevent or correct deficiencies of these nutrients which may limit the crop growth and yields. Both these products are water soluble and nontoxic to plants. The recommendations for applying metalosate zinc and metalosate boron liquid foliar have been generated by AICRP-MSPE for various horticultural crops.

Fortified/Coated Fertilizers

Fortified fertilizers are multi-nutrient carriers which satisfy the crops' nutritional demand based on area, soil and growth stage of plant. A fortified fertilizer strengthens the nutrient supply to the plant and provides site-specific nutrient management option for achieving maximum fertilizer use efficiency for the applied nutrient in a cost-effective manner. The use of conventional fertilizers fortified/coated with micronutrients is considered as an ideal strategy to correct location-specific deficiency of micronutrients. Primary focus is to get higher yields with lesser fertilizer usage (as nutrients do not have to be applied independently), thereby enhancing efficiency of applied nutrients and increasing profitability of the farmers. In order to address the widespread deficiencies of micronutrients, mainly Zn and B, fortification of urea/DAP with these nutrients is being strongly suggested to ensure their application in areas where farmers are not applying straight micronutrient fertilizers. The fortified fertilizer facilitates uniform application of the small amounts of micronutrient fertilizers. A number of fortified fertilizers (mostly fortified with Zn and B with a concentration of 0.5 to 2.0% and 0.2 to 0.3%, respectively) have been included in FCO, particularly during last 10 years to expand the product basket for farmers (FCO, 2021). However, the production of fortified/coated fertilizers has not picked up much even after these policy initiatives. For example, the zincated urea (2% Zn) was the first fortified fertilizer notified in FCO in 1992 but its commercial production could not start because the cost of fortification/coating urea with Zn far-exceeded the notified maximum retail price (MRP). Government of India introduced a policy for encouraging the production and availability of fortified and coated fertilizers in 2008. Under the policy, manufacturers of subsidized fertilizers are allowed to fortify/coat 20% of their production and can charge up to 10% higher of MRP for fertilizers coated with zinc and boron. Consequently, some SSP manufacturers have started fortification of SSP with Zn and B. The production of zincated-SSP, boronated-SSP and SSP fortified with Zn and B were 655,224, 96,073 and 104,018 t during 2019-20, respectively (FAI, 2020). In order to promote fortified fertilizer, Government of India has also made a provision of additional subsidy of Rs. 500 t^{-1} and Rs. 300 t^{-1} for fortification with Zn and B of subsidized fertilizers under the nutrient based subsidy (NBS) scheme.

Multi-Micronutrient Mixture (MMM) Fertilizers

Multi-micronutrient deficiencies have been reported in different parts of India, with figures showing large inter-district variations. Requirements of micro-nutrients for horticultural crops are different from cereals and pulses and these require different sets of micronutrient recommendations to address the deficiencies of two or more micronutrients together. In order to find a solution to this serious problem, crop/soil specific micronutrient mixtures have been developed for foliar application, particularly for vegetable and fruit crops. A large number of multi-micronutrient mixture formulations containing two or more micronutrients, both solid and liquid, have been notified by different state governments. A list of state-approved multi-micronutrient mixtures is given in **Table 2**. Concentration of the micronutrients in mixtures varies widely, ranging from 0.5 to 7.6% for Fe, 0.2 to 15.0% for Mn, 2.0 to 10.0% for Zn, 0.05 to 2.5% for Cu, 0.01 to 3.0% for Mo, and 0.1 to 5.0% for B. Maharashtra and Tamil Nadu states have more numbers of notified micronutrient mixture grades as these have been in great demand in southern and western states of India for many decades. However, authentic information on consumption of these micronutrient mixtures is lacking. Moreover, most of these micronutrient mixture formulations, notified long ago, have not been updated with changing soil fertility status in the states. It is high time to review the composition of existing micronutrient mixture formulations in the light of recent soil micronutrient fertility data generated under All India Coordinated Research Project on Micro- and Secondary Nutrients and Pollutant Elements in Soils and Plants of Indian Council of Agricultural Research. The new grades of micronutrient mixtures should be developed considering the widespread multi-micronutrient deficiencies, including the latent deficiencies and marginal needs of crops, particularly horticultural crops. The provision should also be made for inclusion of novel crop- and site-specific grades in FCO for the different regions of the country.

Micronutrient-Containing Customized Fertilizers

According to FCO, customized fertilizers are multi-nutrient carriers designed to contain macro, secondary and/or micro nutrients both from inorganic sources and/or organic sources, manufactured through a systematic process of granulation, satisfying the crop's nutritional needs, specific to its site, soil and stage validated by a scientific crop model, capability developed by an accredited fertilizer manufacturing agency. To address the problem of site-specific multi-nutrient deficiencies, the Central Government included customized fertilizers (CFs) as a new category of fertilizers under clause 20B of FCO, 1985. It is mandated to include all the deficient nutrients including micronutrients in CFs mainly for important crops like rice, wheat, maize, sugarcane, potato, cotton, tobacco and chilli etc. The manufacturers are allowed

Table 2. Approved micronutrient mixtures in different states of India (Source: FAI, 2020)

State	No. of grades	Micronutrient-wise number of grades (range in concentration in %)					
		Fe	Mn	Zn	Cu	Mo	B
Andhra Pradesh	7	6 (0.5-6.0)	5 (1.0-3.0)	5 (5.0-6.0)	2 (0.5-1.0)	1 (0.1)	2 (2.0-5.0)
Telangana	6	6 (0.5-6.0)	5 (1.0-3.0)	5 (5.0-6.0)	2 (0.5-1.0)	1 (0.1)	2 (2.0-5.0)
Assam	2	0	0	2 (5.0-7.0)	2 (0.5-0.5)	2 (0.02-0.03)	2 (2.5-5.0)
Bihar	6	4 (0.5-4.0)	4 (0.2-0.5)	4 (2.0-10.0)	4 (0.2-1.0)	6 (0.01-0.05)	6 (0.5-2.0)
Chhattisgarh	6	4 (3.0-5.0)	5 (0.5-4.0)	5 (3.0-6.0)	3 (0.8-1.5)	3 (0.02-3.0)	6 (0.1-2.0)
Delhi	7	3 (0.5-0.5)	4 (0.5-2.0)	4 (3.0-10.0)	5 (0.1-1.0)	5 (0.01-0.05)	7 (0.2-0.6)
Goa	4	2 (1.0-2.0)	2 (1.0-3.0)	2 (3.0-5.0)	2 (0.5-1.0)	1 (0.1-0.2)	2 (0.8-1.0)
Gujarat	5	5 (2.0-6.0)	5 (0.5-1.0)	5 (4.0-8.0)	5 (0.2-0.5)	0	5 (0.5-0.5)
Himachal Pradesh	3	2 (2.0-2.0)	3 (0.5-2.0)	3 (2.0-5.0)	3 (0.5-0.5)	3 (0.1-0.2)	3 (1.0-1.5)
Karnataka	5	3 (0.5-2.0)	3 (0.2-2.0)	3 (3.0-10.0)	0	0	5 (0.3-0.5)
Madhya Pradesh	2	0	2 (0.5-1.0)	2 (3.0-5.0)	1 (0.5)	0	2 (0.5-0.1)
Maharashtra	11	9 (2.0-5.0)	6 (1.0-3.0)	6 (3.0-10.0)	6 (0.05-1.0)	4 (0.1)	10 (0.5-1.2)
Odisha	7	3 (0.5)	4 (0.2-2.0)	4 (3.0-10.0)	4 (0.1-1.0)	5 (0.01-0.1)	7 (0.2-0.6)
Punjab	3	2 (3.5-7.5)	2 (3.0-15.0)	2 (4.0-6.5)	0	0	3 (0.5-1.0)
Rajasthan	4	4 (2.0-2.0)	4 (2.0-2.0)	4 (5.0-5.0)	4 (0.5-0.5)	4(0.01-0.05)	4(0.5-0.5)
Tamil Nadu	14	14 (1.0-7.6)	14 (0.3-9.1)	14 (1.7-7.4)	12 (0.1-2.5)	7 (0.1-0.4)	14 (0.1-3.2)
Uttar Pradesh	5	5 (1.5-5.0)	4 (0.5-2.0)	5 (3.0-10.0)	5 (0.5-1.0)	0	0
Uttarakhand	3	3 (1.5-3.0)	2 (0.5-1.5)	3 (3.0-6.0)	3 (0.5)	0	1 (0.5)
West Bengal	7	1 (6.6)	2 (4.3-5.0)	7 (3.6-8.0)	3 (0.8-2.4)	3 (0.1-0.5)	5 (0.5-1.0)
Total	106	76 (0.5-7.6)	76 (0.2-15.0)	85 (2.0-10.0)	66 (0.05-2.5)	45 (0.01-3.0)	86 (0.1-5.0)

to use the subsidized fertilizers as raw material for production of these customized fertilizers. The permission to manufacture and sell a particular grade of CF is given by Central Government (DAC&FW) after following a systematic process. A number of grades of CFs have been approved and renewed in last 10 years but not much growth has taken place during this period. At present, a total of 50 grades (32 grades for basal and 18 grades for top-dress) of CFs notified under clause 20B of FCO are valid for different areas and crops of the country (FAI, 2020). Out of 50 grades, 30 grades contain one or more micronutrients (**Table 3**). The production and sale of CFs in India did not follow any specific trend during 2008-09 to 2019-20. This indicates the need for development and production of appropriate and efficient formulations of CFs for various soil-crop situations and creating awareness among the farmers about the benefits accruing from the use of CFs.

Nano-based Micronutrient Formulations

Nanotechnology is an emerging field of science being exploited in energy, environment, health sciences and medicine but rarely made use of in agricultural sciences. Recent studies have shown that nanotechnology might be a potential strategy for enhancing nutrient use efficiencies which have remained stagnant at abysmally low level for the past several decades. Particularly, use efficiencies of the applied micronutrients seldom exceed 2-5% with bulk of the applied micronutrients getting fixed in the soil. In order to overcome the fixation of added micronutrients, several nano-technological options such as encapsulation of micronutrients, nano-zeolite fortified micronutrients, and nano-emulsions of micronutrients have been attempted and these have proved to be effective in enhancing nutrient use efficiencies besides biofortication of Fe and Zn in cereals (Subramaniam et al., 2018). It has been reported that the nano-sized zeolite is capable of retaining Zn and slowly release it into the soil solution, which may make it serve as a slow-release Zn fertilizer and improve its use efficiency. Nano-sized manganese hollow core shell loaded with Zn was found to release Zn for longer period of time compared to $ZnSO_4$-fortified soil. The effectiveness of nano ZnO particles applied through seed coating in improving plant growth and development has also been reported for maize, soybean, pigeon pea and okra crops (Adikari et al., 2016). However, results from field studies carried out on some nano-micronutrient fertilizers by AICRP-MSPE at its centres at PDKV, Akola; GBPUAT, Pantnagar; OUAT, Bhubaneswar; and PJTSAU, Telangana have not been very encouraging. Recently, IFFCO has innovated and introduced Nano Zn and Nano Cu developed in-house at IFFCO Nano Biotechnology Research Centre (NBRC) Kalol, Ahmedabad, Gujarat. These products tested in 730

Table 3. Approved formulations of micronutrients containing customized fertilizers notified under FCO, 1985 (Source: FAI, 2020)

S. No.	Name of Fertilizer	Composition	Crop	Districts/ State
1.	N:P_2O_5:K_2O:S:Zn:B	16:16:10:4:1:0.2	Chilli (Basal)	Karimnagar, Warangal and Khamam of the state of Telangana and Krishna, Guntur and Prakasam of the state of Andhra Pradesh.
2.	N :P_2O_5:K_2O:S:Zn:B	12:24:0:0:0.5:0.2	Cotton (Basal)	Kurnool, Guntur. Krishna, Anantapur, Cuddapah, Prakasam, Vizianagaram, East Godavari, Sri Potti, Sriramulu Nellore, Srikakulam, West Godavari and Visakhapatnam districts of the state of Andhra Pradesh; Adilabad, Bhadradri Kothagudem, Jagtial, Jangaon, Jayashankar Bhupalpally, Jogulamba Gadwal, Kamareddy, Karimnagar, Khamman, Kumurambheem, Asifabad, Mahabubabad, Mahabunagar, Mancherial, Medak, Medchal-Malkagiri, Nagarkurnool, Nalgonda, Nirmal, Nizamabad, Peddapalli, Ranjanna Sircilla, Rangareddy, Sangareddy, Siddipet, Suryapet, Vikarabad, Wanaparthy, Warangal Rural, Warangal Urban and Yadadri Bhuvanagiri districts of the stete of Telangana.
3.	N :P_2O_5:K_2O:S:Zn:B	14:22:12:5:0.5: 0.05	Maize (Basal)	Purnia, Kathiar, Araia, Kisanganj, Muzzafarpur, Vaishalli, Madehpura, Saharsa, Supaul, Siwan, Saran, Bhagalpur, Begusarai, Khagaria, Darbhanga and Samastipur districts of Bihar.
4.	N :P_2O_5:K_2O:Zn:B	12:22:18:5:0.5	Paddy (Basal)	Bardhwan, Murshidabad, Malda, Nadia and Howrah districts of West Bengal.
5.	N :P_2O_5:K_2O:S:Zn	12:26:18:5:0.5	Wheat (Basal)	Pratapgarh, Barabanki, Jaunpur, Raebarelli, Ambedkar Nagar, Lucknow, Kanpur Nagar, Kanpur Dehat, Kannauj, Etawah, Auriya, Sitapur, Varanasi, Chandauli, Gazipur, Azamgarh, Ballia, Mau, Gonda, Balrampur, Bahraich, Shiravasti, Gorakhpur, Maharajganj, Deoria, Khushinagar, Basti, Sant Kabir Nagar, Siddharth Nagar and Amethi districts of Uttar Pradesh.
6.	N :P_2O_5:K_2O:S:Zn	12:26:18:5:0.5	Paddy (Basal)	Pratapgarh, Barabanki, Jaunpur, Raebarelli, Sultanpur, Faizhabad, Ambedkar Nagar, Lucknow, Kanpur Nagar, Kanpur Dehat, Kannauj, Etawah, Auriya, Sitapur, Varanasi, Chandauli, Gazipur, Azamgarh,Ballia, Mau, Gonda, Balrampur, Bahraich, Shiravasti, Gorakhpur, Maharajganj, Deoria, Khushinagar, Basti, Sant Kabir Nagar, Siddharth Nagar and Amethi districts of Uttar Pradesh.
7.	N :P_2O_5:K_2O:S:Zn:B	12:16:18:6:0.6:0.1	Potato (Basal)	Murshidabad, Malda, Nadia, Bankura, Birbhum, West Midnapur, Howrah, North 24 Paraganas and Birbhum districts of West Bengal.
8.	N :P_2O_5:K_2O:S:B	12:6:23:3.5:0.9 (Mg):0.16(B)	Oil palm (Basal)	East Godawari, West Godawari, Srikakulam, Vizianagaram, Krishna and Vishakapatnam districts of Andhra Pradesh. Khammam, Kothgudem, Bhadradiri, Nalgonda, Suryapet and Yadadri districts of Telangana.
9.	N :P_2O_5:K_2O:S:Zn:B:Fe	14:12:10:4:0.8: 0.2:1.4	Chilli (Basal)	Dharwad, Bellary, Gadag, Haveri, Raichur and Belgum Belgaum districts of Karnataka.
10.	N :P_2O_5:K_2O:S:Zn	16:18:11:4:1	Maize (Basal)	Davangare, Belgaum, Hassan, Shimoga, Haveri, Bagalkot, Chitradurga, Chamrajnagar, Bellary and Koppal districts of Karnataka
11.	N :P_2O_5:K_2O:S:Zn:B:Fe	14:14:13:4:1: 0.1:1	Sugarcane (Basal)	Belgaum, Bagalkot, Bijapur, Gulbarga, Bidar, Gadag, Mandya, Mysore, Chamrajnagar, Bellary, Koppal, and Yadgir districts of Karnataka.
12.	N :P_2O_5:K_2O:S:Zn	14:19:16:4:1	Rice (Basal)	Raichur, Davangare and Gulbarga districts of Karnataka.
13.	N :P_2O_5:K_2O:S:Zn	21:16:9:4:1	Rice (Basal)	Shimoga, Bellary, Mysore, Gadgir, Koppal, Hassan and Mandya districts of Karnataka.
14.	N :P_2O_5:K_2O:S:Mg: Zn:B:Fe	15:15:09:5:1: 0.3:1	Cotton (Basal)	Dharwad, Gulbarga, Gadag, Raichur, Belgaum, Davangare, Yadgir, Haveri, Bellary, Mysore, Gadgir, Koppal, Chitradurga, Chamrajnagar and Tumkur districts of Karnataka.
15.	N :P_2O_5:K_2O:S:Zn	15:21:13:4:0.5	Rice (Basal)	Thiravarur, Thanjavur, Villupuram, Nagapattiunam, Cuddalore, Thiruvallur, Tiruvannamalai, Tirunelveli, Kanchipuram, Ariyalur, Virudhunagar, Kanyakumari, Pudukottai, Tiruchirapalli, Madurai, Erode, Vellore, Salem, Krishnagiri, Dharmapuri, Theni and Dindigul districts of Tamil Nadu.

Table 3. Approved formulations of micronutrients containing customized fertilizers notified under FCO, 1985 (Source: FAI, 2020)				
S. No.	**Name of Fertilizer**	**Composition**	**Crop**	**Districts/ State**
16.	N :P_2O_5:K_2O:S:Mg: Zn:B	11:23:10:4:1.9: 0.4:0.2	Cotton (Basal)	Jalgaon, Aurangabad, Yavatmal, Beed, Nanded, Jalna, Parbhani, Dhule, Wardha, Amravati, Buldhana, Akola, Chandrapur, Nandurbar, Nagpur, Ahmednagar, Hingoli, Nasik Osmanabad, Washim and Latur districts of Maharashtra.
17.	N:P_2O_5:K_2O:S:Mg:Zn: B:Fe:Si	8:10:16:8:1.8-0.5: 0.2:0.9:1.9	Flue Cured Virgina Tobacco (Basal)	Mysore and Hassan districts of Karnataka.
18.	N:P_2O_5:K_2O:S:Zn	16:23:10:0:0.5	Rice (Basal)	East Godavari, West Godavari, Krishna, Guntur, Srikakulam, Vizianagaram, Kurnool, Prakasam, Kadapa, Chittoor, Nellore and Vishakapatnam districts of Andhra Pradesh.
19.	N:P_2O_5:K_2O:Zn:B	16:23:10:0:0.5	Maize (Basal)	East Godavari, West Godavari, Krishna, Guntur, Srikakulam, Vizianagaram, Kurnool, Prakasam, Kadapa, Chittoor and Vishakapatnam districts of Andhra Pradesh.
20.	N:P_2O_5:K_2O:S:Zn:B	9:23:12:5:1:0.2:1	Sugarcane (Basal)	Solapur, Kohlapur, Pune, Ahmednagar, Sangli, Satara, Latur, Osmanabad, Beed, Parbhani, Jalna, Nanded, Nasik, Hingoli, Aurangabad, Yavatmal, Nandurbar, Jalgaon, Dhule, Bhandara and Wardha districts of Maharashtra.
21.	N:P_2O_5:K_2O:S:Zn:B	14:22:10:4:0.5	Rice (Basal)	Nalgonda, Warangal, Karimnagar, Khammam, Nizamabad, Mahbubnagar, Medak, Adilabad and Ranga Reddy districts of Telangana.
22.	N:P_2O_5:K_2O:S:Zn:B	14:22:10:4:0.05	Maize (Basal)	Nalgonda, Warangal, Karimnagar, Khammam, Nizamabad, Mahbubnagar, Medak, Adilabad and Ranga Reddy districts of Telanagana
23.	N:P_2O_5:K_2O:S:Zn:B	12:14:15:4:1.0:0.1	Sugarcane (Basal)	Thiravarur, Coimbatore, Dindigul, Tiruchirapalli, Madurai, Theni, Pudukottai, Tiruvallur, Dharmapuri, Thanjavur, Vellore, Salem, Namakkal, Erode, Cuddalore, Tiruvannamalai and Villupuram districts of Tamil Nadu.
24.	N:P_2O_5:K_2O:S:Zn:B	7:20:18:6:0.5:0.2	Sugarcane (Basal)	Sharanpur, Muzaffarnagar, Bulandshar, Gaziabad, Bareilly, Baduan, Shahjhanpur, Bijnor, Moradabad, Amroha, Rampur, Sitapur, Hardoi, Lakhimpur Kheri, Bahariach, Meerut, Pillibhit and Bagpat districts of Uttar Pradesh; U.S. Nagar district of Uttarakhand.
25.	N:P_2O_5:K_2O:S:Zn:B	8:16:24:6:0.5:0.2	Potato (Basal)	Aligarh, Saharanpur, Muzaffarnagar, Shahjahanpur, Mainpuri, Bulandshar, Ghaziabad, Bareilly, Baduan, Amroha, Rampur, Gautam Buddha Nagar, Etah, Kasganj, Agra, Firozabad, Farrukhabad, Hathras, Sambal, Shamli, Hapur, Mathura and Meerut districts of Uttar Pradesh.
26.	N :P_2O_5:K_2O:S:Zn:B	8:18:26:6:1:0.1	Potato (Basal)	Sultanpur, Jaunpur, Raebareli, Faizabad, Ambedkar Nagar, Lucknow, Barabanki and Pratapgarh districts of Uttar Pradesh.
27.	N :P_2O_5:K_2O:S:Zn:B	8:22:18:6:0.5	Sugarcane (Basal)	Sultanpur, Jaunpur, Amethi, Raebareli, Faizabad, Ambedkar Nagar, Lucknow, Barabanki, Pratapgarh, Kanpur Nagar, Kanpur Dehat, Kannauj, Etawah, Auraiya, Sitapur, Varanasi, Chandauli, Azamgarh, Ballia, Mau, Gonda, Balrampur, Bahraich, Shravasti, Gorakhpur, Maharajganj, Deoria, Khushinagar, Basti, Sant Kabir Nagar and Siddarth Nagar districts of Uttar Pradesh.
28.	N :P_2O_5:K_2O:S:Zn:B	8:18:26:6:0.5	Potato (Basal)	Kanpur Nagar, Kanpur Dehat, Kannauj, Etawah, Auraiya, Sitapur, Varanasi, Chandauli, Azamgarh, Ballia, Mau, Gonda, Balrampur, Bahraich, Ghazipur, Shravasti, Gorakhpur, Maharajganj, Deoria, Khushinagar, Basti, Sant Kabir Nagar and Siddarth Nagar districts of Uttar Pradesh.
29.	N :P_2O_5:K_2O:S:Zn:B	8:18:10:6:0.5	Potato (Basal)	Bhadohi, Fatehpur, Hardoi, Kaushambi, Mirzapur, Allahabad, Unnao and Sonbhadra districts of Uttar Pradesh.
30.	N :P_2O_5:K_2O:S:Zn	9:16:12:05:01	Sugarcane	Medak, Sangareddy, Siddipet, Nizamabad, Kamareddy, Khammam, Kothagudem, Bhadaradiri, Mahbubnagar, Jogulamba, Nagarkurnool, Wanaparthy, Karimnagar, Jagitaial, Rangareddy, Medchal, Vikarabad, Peddapalli, Rajanna, Nalgonda, Suryapet and Yadadri districts of Telangana.

farmers' fields in the state of Uttar Pradesh have been found to be effective depending on the magnitude of the deficiencies of Zn and Cu in soils and the nature of the crops (Kumar et al., 2020). Experiments with application of seaweed extract-based products / bio-stimulants along with chemical fertilizers have demonstrated higher nutrient assimilation by crops at the reduced rates of applied nutrients. These products along with soil amendments / conditioners can help in reducing chemical fertilizer application by 20-25% without any yield decrement. Further pot and field studies are needed for assessing the efficacy of nano-based micronutrient formulations as alternative sources of micronutrients and subsequently their use as micronutrients fertilizers.

Agronomic Effectiveness of Micronutrients Fertilizers

Responses of Crops to Application of Micronutrient Fertilizers

Micronutrient fertilizers are applied to ameliorate their deficiencies in the soil-crop systems and harness the higher crop yield potentials. Crop responses to micronutrient application vary widely depending upon soil and crop types (Takkar and Shukla, 2015). Crop responses to Zn application in large number of crops have been reported across the country based on >19,000 trials conducted at cultivator's fields from 1967 to 2019. Depending upon the level of increase in relative economic yield (REY) of different crops, a soil was classified as marginal or non-responsive, responsive, very responsive, and highly responsive to Zn when incremental REY was <200, 200-500, 500-1000, > 1000 kg ha^{-1}, respectively. Out of 4,144 trials conducted on farmers' fields during 1967-84, 58 and 42% experiments exhibited response and no response to Zn application, respectively (Takkar et al., 1989; Shukla et al., 2016). The number of responsive trials increased over the years from 58% during 1967-1984 to 63% during 1985-2000, 72% during 2000-2010, and 85% during 2011-2019 (**Figure 2**) (Singh, 2009; Shukla and Behera, 2012). This indicates that either new cultivars are more responsive to Zn application or its deficiency has magnified due to greater mining of Zn from soil without proper replenishment. Soil application of 0.5 to 2.5 kg B ha^{-1} gave a response of 108 to 684 kg grain kg^{-1} of B or 10 to 44% over NPK and helped in sustaining the high productivity of cereals, pulses, oilseeds and cash crops in B-deficient soils of Bihar, Orissa, West Bengal, Assam and Punjab. Response of crops to Mo application ranged from 0.24 to 1.01 t ha^{-1} for rice, 0 to 0.47 t ha^{-1} for wheat, 0.08 to 0.19 t ha^{-1} for soybean, and 0.10 to 0.40 t ha^{-1} for green gram. On an average, crop responses to soil and foliar application of Fe ranged from 0.45 to 0.89 t ha^{-1} for cereals, 0.3 to 0.68 t ha^{-1} for millets, 0.34 to 0.58 t ha^{-1} for pulses, 0.16 to 0.55 t ha^{-1} for oil seeds, 0.20 to 1.53 t ha^{-1} for vegetables, and 0.39 to 9.68 t ha^{-1} for cash and other crops. Crop responses to the soil and/ or foliage application of Mn were significant on Mn-deficient soils; these ranged from traces to 3.78 t ha^{-1} for wheat, traces to 1.78 t ha^{-1} for rice, 0.03 to 1.02 t ha^{-1} for soybean, 0.40 to 0.70 t ha^{-1} for sunflower, 3.63 to 4.30 t ha^{-1} for onion, and 0.30 to 0.80 t ha^{-1} for tomato. Crop responses to Cu application ranged from traces to 1.78 t ha^{-1} in cereals, 0.20 to 0.30 t ha^{-1} in millets, traces to 0.80 t ha^{-1} in oilseed crops, 4.43 to 6.18 t ha^{-1} in onion, and 0.30 to 0.50 t ha^{-1} in sugarcane.

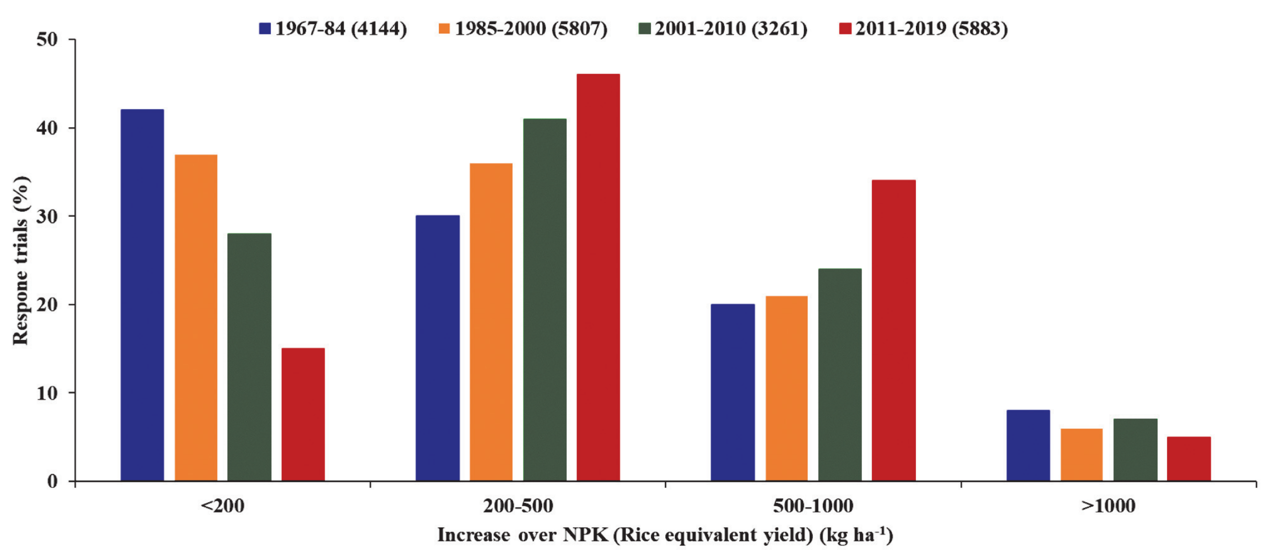


Figure 2. Variations in crop responses to Zn application with time in farmers' field trials

Micronutrients in Enhancing Use Efficiency of Macronutrients

Although micronutrients are required in lesser quantities but these nutrients play important roles in enhancing the use efficiency of macronutrients (NPK). Striking decrease in partial factor productivity of NPK due to omission of micronutrients in fertilization schedule has been reported in rice-wheat systems at different parts of India (**Table 4)**. Cumulative increase of 16.7% in the productivity of rice-wheat system was obtained after 15 years with application of Zn over NPK. Productivity loss due to omission of Zn from balanced fertilization schedule ranged between 3.5% and 17.5% at 9 sites across the country. Another study conducted on rice-rice system revealed that the highest increase in P use efficiency occurred with addition of Zn (35.4%) followed by B (28.7%) and Mn (15.6%). On an average, agronomic efficiency of fertilizer K was enhanced by 35.1%, 32.4%, 33.7%, and 10.3% with addition of S, Zn, B, and Mn, respectively in the balanced fertilization schedule. Addition of micronutrients in balanced fertilization schedule increased the internal utilization efficiency of NPK (Shukla et al., 2009).

Consumption and Requirement of Micronutrient Fertilizers in Relation to Food Grain Production

An increasing trend in consumption of micronutrient fertilizers and food grain plus oil seed production of the country over the years **(Figure 3)** shows the importance of micronutrients in sustainable food production. According to an estimate, the contribution of Zn and B fertilizers to present food crop production comes around 29 Mt rice equivalent yields (Shukla and Behera, 2012). The contribution from other micronutrients should not be underestimated as their use has been increasing consistently and are proving critical in enhancing the crop productivity. As per recent estimate of micronutrients consumption, the use of zinc sulphate fertilizer was the highest (2,11,275 tonnes) followed by ferrous sulphate (35,745 tonnes), boric acid/borax (25,559 tonnes), manganese sulphate (17,396 tonnes) and copper sulphate (3,815 tonnes) during 2019-20 (FAI, 2020). Analysis of state-wise and country-wise zinc consumption data revealed that five states, *viz*; Punjab, Haryana, Uttar Pradesh, Karnataka and Maharashtra together accounted for nearly 70% of country's total zinc sulphate consumption consumption (FAI, 2020). The whole array of product range (including Zn EDTA, Zn coated fertilizers, Zn fortified fertilizers, Zn containing liquid fertilizers, etc.) is available for addressing the issue of Zn nutrition. Since, Zn-EDTA is cost-prohibitive, it is expected that zinc sulphate will continue to be the principal Zn containing fertilizer, if cost of efficient fertilizer (like Zn-EDTA) does not come down. Of the total Zn used, 70% goes to the field crops and remaining 30% to vegetable and fruit crops, while the reverse is true for Mn, Fe and Cu. Of the total B application, about 60% is applied to vegetable and fruit crops and 40% goes to food grain and oilseed crops. The present requirement of different micronutrients is 285,000 t of Zn, 177,000 t of Fe, 118,000 t of Mn, 29,000 t of Cu and 129,000 t of B, as estimated based on current level of deficiency, nutrient mining from the soil and micronutrient recommendations for different crops **(Table 5)**. However, this requirement may increase to 347,000 t for Zn, 193,000 t for Fe, 127,000 t for Mn, 31,000 t for Cu and 147, 000 t for B by 2035; and to 402,000 t for Zn, 216,000 t for Fe, 138,000 t for Mn, 34,000 t for Cu and 167,000 t for B by 2050 as estimated based on area likely to be deficient and enhanced crop requirement due to projected intensification of agriculture.

Table 4. Loss in system productivity (kg ha^{-1}) due to omission of micronutrients from balanced fertilization schedule in rice-wheat cropping system at different locations of India (03-years average) (Source: Shukla and Behera, 2019)

Location	System productivity with balanced fertilization as *REY (t ha^{-1})	Loss in system productivity (t ha^{-1}) due to omission of from balanced fertilization schedule of			
		Zn	B	Mn	Cu
Modipuram	17.57	2.06 (11.7)	1.74 (9.9)	1.44 (8.2)	-
Kanpur	15.37	1.62 (10.5)	-	-	-
Faizabad	12.99	2.28 (17.5)	1.50(11.5)	1.06 (8.2)	-
Varanasi	12.82	1.10 (8.5)	0.49 (3.8)	0.49 (3.9)	0.67 (5.2)
Pantnagar	13.31	1.23 (9.2)	0.57 (4.6)	-	-
Sabour	14.30	-	-	-	-
Ranchi	11.66	0.49 (4.2)	0.53 (4.5)		
Palampur	10.04	0.35 (3.5)	0.80 (7.9)	-	-
R.S Pura	13.49	0.80 (6.0)	-	0.25 (1.8)	0.34 (2.5)

Values in parenthesis depict percentage loss, *REY = Rice equivalent yield

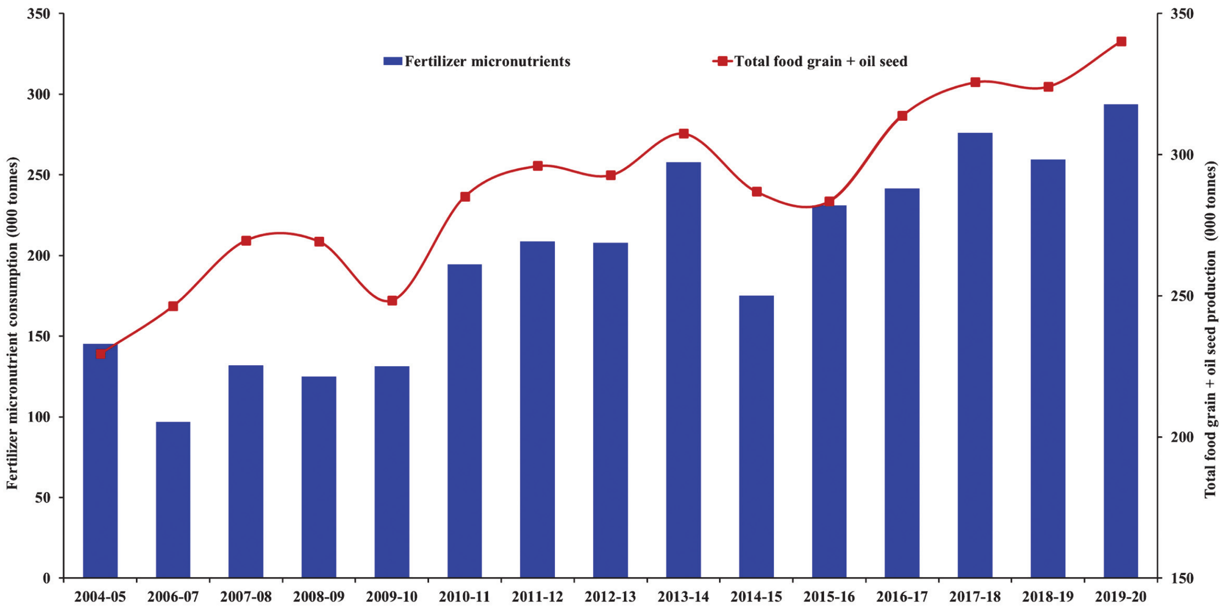


Figure 3. Food grain + oil seed production *vis-a-vis* consumption of micronutrient fertilizers in the country over the years

Table 5. Micronutrients requirement for agricultural and horticultural crops

Nutrients	Micronutrient requirements ('000' tonnes) in		
	2020	2035	2050
Zn	285	347	402
Fe	177	193	216
Mn	118	127	138
Cu	29	31	34
B	129	147	167

The current requirement (2020) of different micronutrients has been calculated based on current level of deficiency, nutrient mining from the soil and micronutrients recommendation for different crops. The future requirement has been estimated based on area likely to be deficient and enhanced crop requirement due to intensification of agriculture by 2035 and 2050.

Policy Issues

- Encouraging the production and use fertilizers fortified with micronutrients is the ideal strategy to overcome the problem of micronutrient deficiencies in Indian soils. However, fortified fertilizers have not come to the market because of price anomalies. For example, the zincated urea (2% Zn) was notified in Fertilizer Control Order (FCO) in 1992 but its commercial production has not been started so far because the actual cost of coating urea with 2% Zn (supplying 20 kg Zn) is about Rs 2,500 t^{-1} but the government notified MRP of zincated urea allows recovery of just Rs 540 t^{-1}. Prohibitive higher costs have hindered the micronutrient use despite their proven agronomic and nutrition advantages. It is, therefore, suggested that, the Zn content in the zincated urea may be reduced from 2% to 0.5%, thereby reducing the production cost as it will pave the way for its economic feasibility.
- The scale of operation and farmers' price are very important in ensuring sustainable growth in production and sale of CFs. Inordinate delays in getting approval of specific grades of CFs may be avoided, if product is good and can fulfil the need of large acreage. After the implementation of direct benefit transfer (DBT) scheme in fertilizer sector *w.e.f.* 1st March, 2018 in all the states, the CF manufacturers are facing a serious problem in getting raw material for producing CFs. Adequate availability of raw material for CF may be ensured by the Govt.
- In general, customization of Zn and B together should be discouraged as the simultaneous deficiency of both these nutrients is confined to 8.7% across the Indian soils. However, fertilizer products of urea and DAP fortified separately with Zn and B may be brought out.
- *Inclusion of New Products in the Central Government Schemes*: On nutrient need basis, new products need to be introduced in the Central Government food security schemes like NFSM etc. Financial assistance should be provided on per hectare per year basis for initial three years. Fertilizer industry should come forward to support such a

noble cause for initial three years. This will ensure on ground timely usage of the new products.

- ❖ Impact of beneficial fertilizers containing silicon, cobalt, selenium nutrients etc, (which are co-factors of many useful plant enzymes) should be evaluated in relation to crop productivity and quality of produce in soil-plant animal/human continuum mode.
- ❖ Regulatory guidelines for innovative/novel fertilizer products like nano-fertilizers, bio-stimulants, liquid fertilizers, beneficial nutrients products (nickel, selenium, cobalt etc.) have to be fast-tracked for wider availability/ acceptability of these products.

Conclusions

Indian soils are generally poor in fertility, especially in micronutrients as these have consistently been mined from the finite soil resources for a very long time without external addition of these nutrients through respective fertilizer sources. Identification of specific micronutrient-deficient and/or toxic areas under major soil types for different cropping systems and preparation of the detailed geo-referenced digitized maps is helpful in precise micronutrient fertilizer applications to achieve higher sustainable agricultural productivity, nutritional quality, and better soil and human health. Recognizing the importance of micronutrients in balanced crop nutrition, Government has started incentivizing the farmers with partial subsidies on micronutrient fertilizers through different schemes. However, availability of varieties of efficient micronutrient fertilizers at opportune times for the farmers of the country is a matter of concern. Product basket of micronutrient fertilizers needs to be expanded with better availability for all situations. For those not having access to the micronutrient fertilizers, growing micronutrient-efficient crop varieties having better utilization of these nutrients from the non-labile pool of soils will continue to be a sustainable practice.

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