September 2019

All for a good harvest: Addressing micronutrient deficiencies

pwc

International Zinc Association

Zinc...essential for modern life

Message from the Minister of Agriculture, Government of India

नरेन्द्र सिंह तोमर
NARENDRA SINGH TOMAR

सत्यमेव जयते

कृषि एवं किसान कल्याण,
ग्रामीण विकास तथा पंचायती राज मंत्री
भारत सरकार
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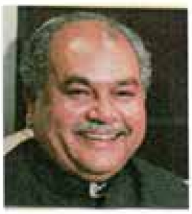
**MINISTER OF AGRICULTURE & FARMER WELFARE,
RURAL DEVELOPMENT AND PANCHAYATI RAJ
GOVERNMENT OF INDIA
KRISHI BHAWAN, NEW DELHI**



MESSAGE

Agriculture globally faces multi-pronged challenges due to burgeoning population, degradation/deterioration of soil health and impending climate change. Ironically to feed around 10 billion mouths in 2050, food grain production shall have to achieve proportional hike. There is a need of increasing both the quantity and quality of crop produce through optimal and efficient use of agri-inputs.

Green Revolution in mid-sixties centered on producing more food grains essentially rice and wheat in irrigated ecosystems with application of nitrogen, phosphorus and potassium (NPK) fertilizers to high yielding varieties. Over-exploitation of the soil led to the appearances of deficiencies of the secondary and micronutrients. Food grains poor in micronutrients like zinc and iron led to the deficiencies of these nutrients in human feeding on these diets. Micronutrients are required in small quantities but are as essential as are the major nutrients. They enhance plant growth and confer benefits to humans in the form of enhanced immunity, mental development etc.

This knowledge paper attempts to identify major micronutrient deficiencies around the world and in India, identify existing key opportunities and options and offers solutions to overcome challenges and constraints faced by the micronutrient sector and maximize the sector potential.

I congratulate the organizers for bringing out this wealth of information on micronutrients.

3/9/19

(Narendra Singh Tomar)

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Message from the State Minister of Agriculture, Government of India

कैलाश चौधरी
KAILASH CHOUDHARY

कृषि एवं किसान कल्याण
राज्य मंत्री
भारत सरकार
MINISTER OF STATE FOR AGRICULTURE
& FARMERS WELFARE
GOVERNMENT OF INDIA

MESSAGE

Micronutrients are essential plant nutrients that are required in small quantities for the normal growth and development of plants. These include zinc, copper, iron, manganese, nickel, boron, molybdenum and chlorine. In India, micronutrient research became major priority with reports of *khaira* disease of rice in mid-sixties by Dr. Y.L. Nene in 1966 and establishment of All India Coordinated Research Scheme on Micronutrients in Soils and Plants in 1967. Widespread deficiencies of zinc, boron and iron have emerged under intensive agriculture with 36, 23 and 12% of more than two lakh soil samples, respectively being deficient.

It is established that zinc and iron are not only important for sustenance of crop productivity, but have also become increasingly limiting in human nutrition. Dietary micronutrient deficiencies affect a large part of the global population. The World Health Organization estimates that globally some two billion people are affected by iron deficiency Also zinc deficiency is increasingly recognized as an important public health problem.

Application of severely deficient micronutrients gave spectacular increases in yields, but their contents in edible produce, in particular grains, witnessed reduction. Consumption of these low micronutrient grains led to the emergence of number of diseases. Alarmed at this the CGIAR institutes have launched a project HarvestPlus with participation of many national and international agricultural organisations to produce zinc and iron dense seeds following a biofortification route. India is playing a major role and it has not only strengthened its information on agronomic fortification, but also released zinc-dense rice varieties developed through genetic biofortification.

It is true that to make country food and nutrition secure, holistic approach is needed for developing sustainable micronutrient supply systems developed through interactions/ discussions among the researchers, planners and finally farmers.

I am happy that this knowledge paper contains a base information on all the aspects of micronutrient management which will get further enriched with two-day intensive deliberations.

I congratulate the authors for collating voluminous information in the form of this compilation and hope that readers will find it as useful reference material.

Jai Hind.

(Kailash Choudhary)

Dated 02.09.2019
New Delhi

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Message from the Government of India and Indian Council of Agricultural Research

त्रिलोचन महापात्र, पीएच.डी.
एफ एन ए, एफ एन ए एस सी, एफ एन ए ए एस
सचिव एवं महानिदेशक

TRILOCHAN MOHAPATRA, Ph.D.
FNA, FNASc, FNAAS
SECRETARY & DIRECTOR GENERAL

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अनुसंधान परिषद
कृषि एवं किसान कल्याण मंत्रालय, कृषि भवन, नई दिल्ली 110 001

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FOREWORD

Public interest in soil health is increasing throughout the world as decline in soil factor productivity, biological degradation, and ever-widening multi-nutrient deficiencies impacting crop quality in addition to crop productivity. The sustenance and wellbeing of humankind are inevitably linked to the stocks, cycling and manipulation of essential nutrients in the bio-geosphere. The capacity to produce adequate and quality plant biomass depends greatly upon the adequacy of mineral nutrients in the soil.

Widespread micronutrient deficiencies (Zn 36.5, B 24.2, Fe 12.8, Mn 7.1 and Cu 4.2%) recorded across the country have led to severe losses in yield and nutritional quality of produce. Research evidences suggested that need-based inclusion of micronutrients in the fertilizer schedules would not only eliminate their deficiencies in soil but also enhance the efficiency of macronutrient fertilizer. Stagnation in crop productivity could also be eliminated by proper micronutrient management with balanced fertilization schedule, leading to reduction in cost of cultivation.

Lack of awareness of the soil health status, particularly micronutrients and imbalanced use of plant nutrients are some of the important causes of soil health deterioration. Regular monitoring of soil health and effective remediation of the ailments, if any with the adoption of scientific recommendations, therefore, assume great significance. Realizing the importance of soil micronutrients towards sustainable agriculture, ICAR -All India Coordinated Research Project on Micronutrients has been working on assessing soil micronutrients status, generating soil-crop specific recommendations based on extensive field experimentation and disseminating to the stakeholders. However, further impetus is needed in collaboration with fertilizer industries and other stake holders to strengthen micronutrient management for improved soil crop productivity and crop quality.

It is a matter of great pleasure that on the initiative of the International Zinc Association (IZA) in collaboration with the Fertiliser Association of India (FAI) and ICAR-AICRP-Micronutrients is organizing the 'Global Micronutrient Summit' during 5-6 September 2019 at New Delhi to increase the awareness among the stakeholders and sensitise them on the importance of micronutrients in balanced fertilizer use for sustaining soil-crop productivity and better animal/human health.

I believe the Global Summit will come out to the recommendation for effective implementation to alleviate micronutrient deficiencies. I wish grand success of the Global Summit on micronutrients.

(T. MOHAPATRA)

Dated the 2nd September, 2019
New Delhi

Message from the Fertiliser Association of India

SATISH CHANDER
Director General

THE FERTILISER ASSOCIATION OF INDIA

FAI
ENSURING FOOD SECURITY

30th August, 2019

Message

To meet the challenge of providing food to all, agricultural intensification evolved in the early 20th century centered around growing the high yielding varieties of economically important crops with assured inputs including water, fertilizer, plant protection chemicals. India successfully adopted this model on wheat and rice in mid-sixties in the Indo-Gangetic plains, named Green Revolution. Fertilizer application under assured supply of other inputs led to dramatic increase in food production and proportionately mined the nutrients from soil. In some situations, N fertilizer became synonymous with fertilizer. Exhaustion of nutrient reserves in the soil, which were either not added or applied in suboptimal amounts through fertilizer led to emergence of their deficiencies.

In the Indian scenario, balanced application of NPK and in some cases NPKS have led to the emergence of Zn and B deficiencies. Deficiencies of Fe, Mn and Cu have also started appearing but at a slower rate. Besides directly increasing the crop yields, supplementation of deficient micronutrients also increases the use efficiency of major nutrients. Recognition of Fe and Zn deficiencies in humans and their linkage to the low Zn/Fe food produced on soils poor in them calls for a holistic approach for combating their deficiencies in soil-plant-animal-human continuum.

Against this background, this knowledge paper attempts to identify major micronutrient deficiencies around the world and in India. It enlists various products available for correcting micronutrient deficiencies and carries out an overall industry analysis to explore this niche market. Paper delves on the socio-economic impact of the micronutrient sector. It also attempts to identify key opportunities and options that exist and highlights approaches and strategies to overcome challenges and constraints faced by the micronutrient sector.

It is appropriate that this knowledge paper is being released on the occasion where experts and resource persons from across the globe have gathered to discuss developments in micronutrients. I sincerely hope that this paper will contribute to achieve the sectoral priorities and objectives.

(Satish Chander)

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Message from PwC

Ajay Kakra

Executive Director, Government Reforms and Infrastructure Development (GRID) - Agriculture and Natural Resources

India faces the twin challenges of a rising population and the need to increase food production without harming its food systems. These challenges will need to be dealt with using our limited resources. Agricultural production requires land, water and energy resources; hence, sustainable use of resources with evolving technologies is the need of the hour.

Crops grown in a majority of the soils suffer from deficiencies. The nature and extent of deficiencies may vary with soil type, crop type and other agro-ecological situations. Intensive cropping of high-yielding varieties of food crops has resulted in micronutrient deficiencies. Encouraging the production and use of fertilisers fortified with micronutrients can be one of the primary strategies to overcome the problem of micronutrient deficiencies in Indian soils.

The importance of micronutrients needs to be viewed in the context of food systems, as their inclusion in a balanced fertilisation schedule would optimise micronutrient supply and availability in our food systems. A large number of innovative products are available that enable farmers to restore micronutrient deficiency.

This knowledge paper titled 'All for a good harvest: Addressing micronutrient deficiencies' aims to provide an overview of the various deficiencies and their impact on food security and human health. It provides insights into the micronutrient deficiency status in India and products that are popular around the globe to deal with such deficiencies. The paper also provides an overall analysis of this niche market and delves into the socioeconomic impact of the micronutrient sector. Understanding these issues and implementing remedial measures will ultimately contribute towards achieving the twin goals of economic growth and food security.

Key message from IZA

Dr. Andrew Green
Executive Director, International Zinc Association

"

It is not merely a question of healing the animal or man stricken by disease, it is necessary to heal the soil so as to have to heal the animal or man.

- Andrew Harley, Principal Geochemist, Duraroot Environmental Consulting

"

Micronutrients are essential for plant growth and for ensuring balanced crop nutrition. They are as important for plant nutrition as primary (nitrogen, phosphorus, potassium) and secondary macronutrients (calcium, magnesium, sulphur), though plants do not require micronutrients in very large quantities.

However, deficiency of any one of the micronutrients in the soil can limit growth, even though all other nutrients maybe present in adequate amounts.

Today, with increased use of soil testing and plant analyses, micronutrient deficiencies have been verified in many soils. Some of the reasons for these deficiencies include:

- High-yield crop demands which remove micronutrients from the soil
- Increased use of NPK fertilisers which are not fortified with micronutrients
- Advances in fertiliser technology reduce the residual addition of micronutrients.

These factors contribute to a significant increase in the need for micronutrients in order to achieve balanced nutrition.

Though the Green Revolution led to food security by increasing the yield of staples, the importance of the nutritional value of diets was undermined. However, in recent times, interest in micronutrient malnutrition has increased gradually. One of the main reasons is the realisation that micronutrient-deficient soil also contributes substantially to the global burden of diseases in humans and livestock.

Today, we stand committed to building a world where micronutrients are recognised as essential for plant, animal and human life. And I am confident that this report will be instrumental in identifying opportunities and options that can be explored to position micronutrients as a mainstream agricultural input.

Table of contents

1. Executive summary

Micronutrients are essential elements which are required in very small quantities for overall growth of plants. Inadequate supply of these nutrients can lead to deficiency symptoms in plants and hamper the quantity and quality of produce. Deficiencies in the soil are also closely associated with deficiencies in humans. Hence, understanding deficiencies in micronutrients and options to restore them becomes very important.

Micronutrients play an important role in agriculture for achieving sustainable crop production. The low fertility and micronutrient levels of Indian soils can be attributed to repeated cultivation cycles with little or no addition of micronutrient fertilisers. In addition, increased withdrawal of micronutrients by high-yielding crop cultivars during the Green Revolution (especially rice and wheat) as well as adoption of intensive cropping practices, low usage of organic manures and crop residues, growing of crops in soils with low micronutrient reserves, and other natural and human factors have affected the availability of micronutrients.

The nature and extent of deficiencies vary based on factors such as soil type and agro-ecological situations. Micronutrient deficiencies are commonly observed in intensively grown cereals, oilseeds, pulses and vegetable crops.

Globally, zinc is reported to deficient in 49% of soils, making it the most prominent micronutrient deficiency in the world. Boron (B) is the next most deficient micronutrient with 31% of soils deficient in it (B). Apart from these, 15% of soils are deficient in molybdenum (Mo); 14%, in copper (Cu); 10%, in manganese (Mn); and 3%, in iron (Fe). In India, analysis of over 2 lakh soil samples revealed that, on an average, 36.5% of soils are deficient in Zn; 12.8%, in Fe; 4.2%, in Cu; 7.1%, in Mn; and 23.4% in B.[1]

The deficiencies that are identified in soils can be corrected and the micronutrient balance be restored by using various products available in the market that help in restoring the soil balance and improving the micronutrient content of the soil. The major products that are used for correcting deficiencies are straight, chelated, multi-nutrient mixture and fortified micronutrients. Along with these, nanotechnology and bio-release fertilisers are some of the technological innovations that may help in correcting micronutrient deficiencies.

The government also provides policy support for correcting micronutrient deficiencies through the Soil Health Card Scheme, National Food Security Mission, Nutrient Based Subsidy, etc. Apart from these initiatives, various state governments also provide assistance in the form of subsidies at the state level. Private sector companies have also launched a wide array of products to help restore the micronutrient balance.

Going forward, the sector needs to increase its focus on replenishing the soil with essential micronutrients. This will help in increasing productivity.

Use of slow-release fertilisers and efficient cultivars will ensure that the uptake of micronutrients by plants is increased. Innovations and R&D will also help in addressing the problem.

However, the use of micronutrients is still viewed as a luxury among farmers, and steps to sensitise them and increase awareness will be required.

To sum up, a large gap still exists between desired and actual levels of micronutrient use in India. The government, industry and farmers need to come together to bridge this gap.

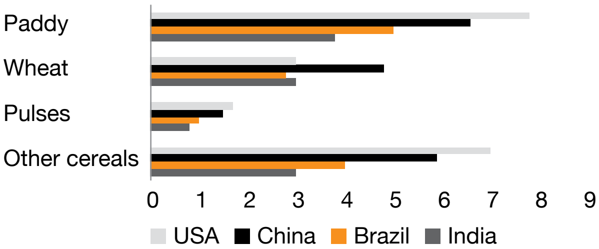
1. Shukla, A. & Behera, S. (2018). Micronutrient research in India: Retrospect and Prospects. DOI: 10.13140/RG.2.2.20370.76489

2. Setting the context

The global population is expected to rise to 8 billion people by 2020. To ensure food availability for all, foodgrain production needs to increase from the present volumes of about 2 billion tonnes per year to over 3 billion tonnes. For achieving this level of crop output, intensification of the output on existing land needs to account for most of the growth.

India is among the top producers of various crops such as wheat, rice, pulses, sugarcane and cotton. However, the yield (quantity of crop produced per unit of land) is found to be lower compared to other producing countries such as China, Brazil and the United States.

Figure 1: Yield in top crop production states (in tonnes/ha)



Source: FAO (2014-15) and PwC analysis

The key issues which affect agricultural productivity include the decreasing size of agricultural land holdings, dependence on the monsoon, inadequate access to irrigation, improper use of soil nutrients, low penetration of formal agricultural credit and absence of adequate market linkages.

Soil is one of the most important factors contributing to productivity of agriculture. It is important to ensure soil health for increased productivity. With time, the levels of food production have increased, with more nutrients being drawn from the soil. This has resulted in an imbalance of nutrients in the soil, leading to overall depletion of soil health. This imbalance in the use of fertilisers in the soil may also result in loss of fertility.

Besides water, agricultural sustainability hinges mainly on 17 nutrient elements, which are essential for plant growth.[2] These elements are indispensable for the maintenance and growth of crop plants. Carbon, hydrogen and oxygen are supplied from the air and water. The other nutrients are categorised into primary (N, P, K), secondary (Ca, Mg, S) and micronutrients (Zn, Cu, Fe, Mn, Ni, B, Mo and Cl).[3]

These elements are further classified into macronutrients (which include primary and secondary nutrients) and micronutrients.

Every micronutrient has a specific role to play in the plant and is hence classified as essential. Their presence in the optimum concentration is a must for the plant to complete its life cycle, which ends with maturity and harvesting of the produce. One essential nutrient cannot take the place of another and the deficiency of one micronutrient can be corrected only by applying a fertiliser containing that specific micronutrient only or by taking such steps which will improve the availability of that specific micronutrient to the crop. When a nutrient is deficient, all the essential plant processes which are dependent on that micronutrient get slowed down or are disrupted.

For example, boron (B) is essential for cell division and formation of organs (differentiation), which takes place at the growing tips. B deficiency damages these tips. Similarly, plants show subtle signs of deficiency when they do not get a particular micronutrient in adequate amounts. When the deficiency is marginal, the plant does not show any visible signs, and the deficiency is not easy to detect. This is known as the hidden hunger, which causes the plant to yield less than expected. By getting plants analysed in a reliable laboratory and following recommendations provided, hidden hunger can be reduced.

It is also interesting to note that all crops are not equally sensitive to the deficiency of a nutrient, even under similar growing conditions. The fact that some crops are more sensitive than others to deficiency of micronutrients implies that the critical concentration of a nutrient is not the same for all crops. It is also different under different soil and climatic conditions.

2. Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulphur (S), Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Nickel (Ni), Boron (B), Molybdenum (Mo) and Chlorine (Cl)

3. R.K. A et al., Boron in Indian agriculture: Retrospect and prospects, Indian Journal of Fertilisers, Vol 14 (11), pp. 12–21

The nutritional health of soil affects the health of humans. There have been reported epidemics of vitamin and mineral deficiencies in many countries, especially the developing ones. The number of people affected by micronutrient deficiency stands at approximately 2 billion people worldwide. This malnutrition is the result of insufficient intake of micronutrients through staple foods. Deficiency of Zn, Fe, Cu, Mn and B has been observed in 36.50%, 12.80%, 4.20%, 7.10 % and 23.40% of soils of India, respectively.

> "Agricultural development is one of the most powerful tools to end extreme poverty, boost shared prosperity and feed a projected **9.7 billion people by 2050**.
>
> **- World Bank Group**"

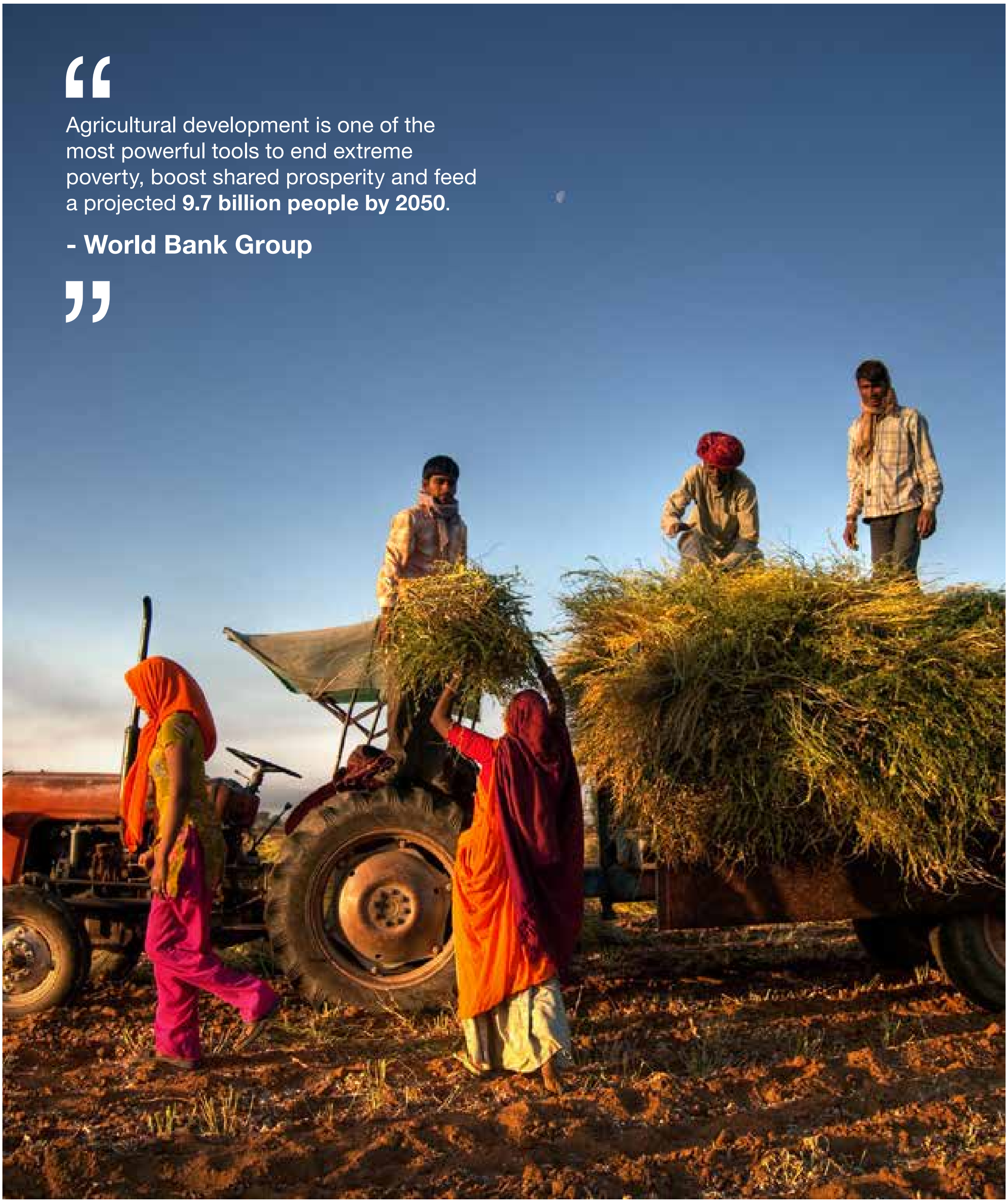


Table 1: Extent of deficiency in major Indian states (%)

State	Zinc	Iron	Copper	Manganese	Boron
Andhra Pradesh	22.92	17.24	1.33	1.63	4.08
Arunachal Pradesh	4.63	1.44	1.40	3.01	39.15
Assam	28.11	0.00	2.80	0.01	32.75
Bihar	45.25	12.00	3.19	8.77	39.39
Chhattisgarh	25.59	7.06	3.22	14.77	20.59
Goa	55.29	12.21	3.09	16.91	12.94
Gujarat	36.56	25.87	0.38	0.46	18.72
Haryana	15.42	21.72	5.13	6.16	3.27
Himachal Pradesh	8.62	0.51	1.43	6.68	27.02
Jammu & Kashmir	10.91	0.41	0.34	4.60	43.03
Jharkhand	17.47	0.06	0.78	0.26	60.00
Karnataka	30.70	7.68	2.28	0.13	36.79
Kerala	18.34	1.23	0.45	3.58	31.21
Madhya Pradesh	57.05	8.34	0.47	2.25	4.30
Maharashtra	38.60	23.12	0.14	3.02	20.69
Manipur	11.50	2.13	2.46	2.06	37.17
Meghalaya	3.84	1.33	1.03	2.95	47.93
Mizoram	1.96	0.49	0.98	1.22	32.76
Nagaland	4.62	2.00	0.53	3.05	54.31
Odisha	32.12	6.42	7.11	2.12	51.88
Punjab	19.24	13.04	4.67	26.20	18.99
Rajasthan	56.51	34.38	9.15	28.28	2.99
Tamil Nadu	63.30	12.62	12.01	7.37	20.65
Telangana	26.77	16.65	1.36	3.54	16.49
Tripura	5.51	1.57	2.36	0.00	23.62
Uttar Pradesh	27.27	15.56	2.84	15.82	20.61
Uttarakhand	9.59	1.36	1.51	4.82	13.44
West Bengal	14.42	0.03	1.76	0.98	37.05
All India average	36.50	12.80	4.20	7.10	23.4

Source: Shukla (2018), Micronutrients in soil, plants, animals and humans

Diversification of the cropping system and fertilisation for meeting nutritional requirements is essential for reducing malnutrition and achieving socioeconomic well-being.

3. Micronutrients and their need

Micronutrients are substances that are essential for plants but are required in small quantities. The eight elements which have been established as micronutrients are iron, zinc, manganese, copper, nickel, boron, molybdenum, chlorine. Based on the form of absorption by plants, these are further grouped as cationic (iron, zinc, manganese, copper and nickel) and anionic (boron, molybdenum and chlorine) micronutrients. These are essential for plant growth and take part in many complex processes in plant development.

Each micronutrient performs certain biochemical functions which affect the metabolism, growth and productivity of crops.

Table 2: Micronutrients and their functions in plants[4]

Micronutrient	Function
Iron	• Involved in biosynthesis of chlorophyll • Plays an essential role in enzymes and RNA metabolism • Responsible for oxidation – reduction in plants and regulates respiration and photosynthesis
Zinc	• Constituent of several enzyme systems • Helps regulate metabolic reactions in plants • Helps in utilisation of N and P in plants • Helps in reproduction and formation of growth hormones and protein
Boron	• Essential for proper pollination • Helps in seed and cell wall formation • Is an enabler for mobility of energy in the plants • Helps in calcium and protein synthesis
Copper	• Helps in formation of vitamin A in plants • Enables formation of ethylene in ripening fruit • Aids in carbohydrate and nitrogen metabolism
Manganese	• Activates and regulates enzymes • Translocates iron • Responsible for nitrogen metabolism and chlorophyll synthesis
Molybdenum	• Helps in nitrogen fixation in legumes • Involved in nitrogen metabolism of plants
Chlorine	• Plays an important role in opening and closing of stomata (which is important for photosynthesis) • Increases water-holding capacity of plant tissue
Nickel	• Required by seeds to germinate and grow • Responsible for absorption of iron

Source: Food and Agriculture Organization, 2001

4. Food and Agriculture Organization (FAO)

Deficiency symptoms

An essential element is said to be deficient in a plant when its absence makes it impossible for a plant to complete the normal vegetative or reproductive stages of its life cycle and it develops deficiency symptoms. These symptoms can only be corrected by the supply of that particular nutrient. Deficiency is assessed by knowing the critical limits. Below these limits, plants develop deficiency symptoms and can be treated through fertiliser application.

The visual method of recognising nutrient deficiency symptoms is a quick and easy method for determining nutrient status. General symptoms indicating micronutrient deficiency include:

- Poor seed germination
- High mortality rate
- Poorly developed crop stands and abnormal mortality
- Severe stunting of the crop
- Top leaves yellowing/top chlorosis
- Yields do not improve with high doses of NPK, or if yield improves quality is poor

Mobility of nutrients varies in soil and plants; thus, the appearance of deficiency symptoms on leaves differs from nutrient to nutrient.

When plant tissues require nutrients for growing newer parts/leaves, mobile elements from lower plant parts are transferred to the deficient plant parts. Hence, deficiency of mobile elements like **N, P, K, Mg, Mo and Zn** is found in **old leaves**, while deficiency of immobile nutrients like **Fe, Mn, Cu and S** is seen in **newer plant leaves**. Extremely immobile elements like **Ca and B** show deficiency symptoms on **bud leaves** and growing shoots.

Table 3: Micronutrients, deficiency symptoms and their critical limits in soil

Nutrient	Deficiency symptoms	Critical limits in soil (mg/kg)
Boron	Terminal leaves lose colour. Loss of colour starts at the base with eventual death of the terminal bud. Boron deficiency can develop deformed young leaves and deformed fruits, cause death of shoot tips and stunted root growth.	0.5
Manganese	Manganese deficiency causes interveinal chlorosis with necrotic spots and stunted root development.	2.0
Zinc	The leaf is narrow and small. Lamina is often chlorotic, veins remain green. Necrotic spots develop randomly all over the leaf.	0.6
Iron	Younger leaves are affected with interveinal chlorosis (also known as lime induced iron chlorosis), with main veins remaining green; in severe cases, the entire leaf may become bleached.	4.5
Copper	Interveinal chlorosis. Rosetting and permanent wilting of leaves. The leaf detaches easily from the stem. Copper deficiency causes pollen sterility, yellowing and curling of leaves and lower density of ear production in cereals.	0.2
Molybdenum	Leaf turns a light green. Dead necrotic spots appear over the leaf except on the veins. Affected areas may extrude a resinous substance from the under surface of the leaf. Molybdenum deficiency causes restricted flower formation and stunted plant growth.	0.1
Chlorine	Chlorine deficiency causes chlorosis and burning of leaf tips, leading to bronzing and drying; over-wilting and leaf fall reduces the yield.	8.0
Nickel	Nickel deficiency can lead to accumulation of toxic urea in plant tissues. It results in poor germination, reduced growth, vigour and flowering, dwarfed internodes and poor kernel filling. Nickel deficiency is linked to dwarf foliage production and development of reddish pigmentation in young leaves.	0.1

Source: Journal of the Indian Society of Remote Sensing, 2013

Micronutrients for disease resistance: Lack of nutrition of some elements can make the plant less vigorous and susceptible to diseases. For example:

- Zinc is necessary to prevent leakage of essential elements from plant surfaces as it maintains the integrity and stability of plant membranes. Shortage of zinc can cause leakage of sugar on plant surfaces and that can provide a site for pathogens to grow.
- Copper is useful for lignin synthesis, which acts as a partial barrier to the entry of pathogens.
- Manganese applications tend to reduce powdery mildew, downy mildew, tan spot in cereals, common scab of potatoes, etc.
- Boron has a key role in developing resistance against diseases caused by Plasmodiophora in crucifers, Fusarium solani in beans, Verticillium alboatrum in cotton, tobacco mosaic virus in beans, tomato yellow leaf curl virus and Blumeria gramini in wheat.
- Foliar application of Fe has proved useful in increasing resistance to Sphaeropsis maloram in apple and pear and Olpidium brassicae in cabbage.

Soil and plant analysis

Since micronutrients are required in lower quantities, the range between the deficiency and toxicity of nutrients is very narrow. This stresses the need for precise estimation.

Comparing the quantity of nutrients present in the soil with the critical limits for the respective micronutrient is necessary. The critical limit is the level of availability of a nutrient, below which the plants develop deficiency symptoms and produce a response to fertiliser application. The critical limit of soil availability of Zn (Zn++ DTPA) is 0.6 mg/kg of soil. Similarly, the critical limits for Cu, Mn, Fe, B and Mo are 0.2, 2.0, 4.5, 0.5 and 0.1 mg/kg respectively[5]. Soils with half the values mentioned above are categorised as 'very low' and those with double the above values are considered to be 'adequate' for that particular nutrient. For example, Zn content of the soil will be said to be 'very low' if the availability of Zn is 0.3 mg/kg or less, whereas it will be adequate if it is 1.2 mg/kg or more. It has been reported in certain studies that probability of response to micronutrient application is more than 90% for 'very low'; 60 to 90% for 'low' and 30 to 60% for 'optimum' levels of availability of the micronutrient[6]. Also, availability of the nutrient in soil does not ensure its uptake by plants; the availability is affected by other soil characteristics like soil pH, organic carbon content and calcareousness. Hence, these factors and their effect on availability of the nutrient should be considered while selecting the fertilisation method. Soil testing can help identify the quantity of micronutrients as present in the soil but not their availability for plants.

Hidden hunger

It is a stage in crop growth which is difficult to distinguish. A crop may not express its deficiency despite the requirement of one of more essential nutrients, or it may express its deficiency in the form of poor yields. Soil and plant analysis can help in identifying this stage and preventing damage by adopting balanced plant nutrition.

5. Katyal, J. C. (2018). Micronutrients in Indian Agriculture. Indian Journal of Fertilisers, Vol. 14(4), 12-26
6. Cooper and Abi-Ghanem,2015

Plant tissue analysis is a preferred diagnostic technique, as it gives us the idea about the nutrient status of the plant and the corrective measures if it is deficient. Success of the plant analysis depends of the time of sampling and the plant parts used for sampling. Generally, sampling is done at the early growth stage, where the whole plant is taken as the sample. Sampling may also be done at the initiation of reproduction stage, where the upper six inches of the plant are preferred. Proper timing of plant tissue analysis is important because, if delayed, deficiency might have already caused damage to the plant, which cannot be corrected through application of fertiliser. The critical limits for nutrient availability vary across crops.

Combination of annual soil testing with regular plant analysis can help in accurate diagnosis of deficiencies. Plant analysis in the later growth stages of deficient and unaffected crops help in comparing the performance of the fertilisation method and in preparing for the next season.

Misdiagnosis

- Poorly nourished crops exhibit deficiency symptoms like yellowing, necrosis and burning of leaf tip and edges.
- Sometimes these symptoms are misdiagnosed as disease or pest attack and treated accordingly.
- For example, heart rot or root rot of cabbage is considered as a bacterial/ fungal infestation.
- Soil and plant analysis can help prevent this and save the crop and cost for farmers.

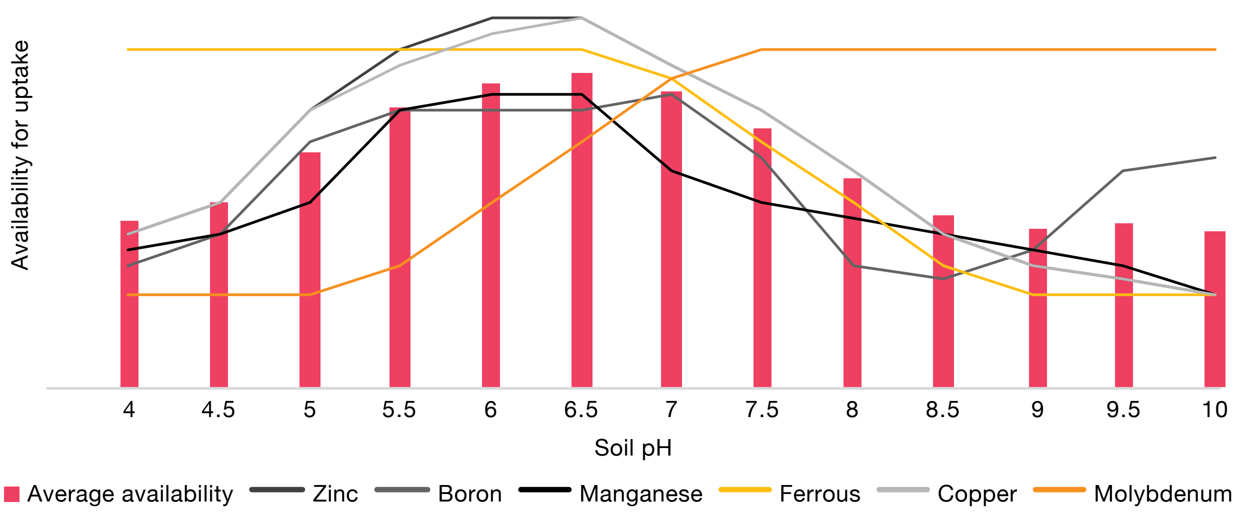
4. Micronutrient deficiency in India

4.1. Soil characteristics that affect nutrient availability and uptake

Various soil characteristics affect the availability and uptake of micronutrients – mainly soil pH, organic carbon content, temperature, calcium carbonate content and other nutrients.

Effect of soil pH on availability of micronutrients: The degree of acidity or alkalinity in the soil is expressed on the pH scale. Soil pH ranges from 0–14, where 0–7 is acidic and 7–14 is alkaline. Soil pH between 5.5 and 7.5 is considered optimal for growth of most plants and microorganisms. Soils with acidic pH have a high concentration of H+, Fe3+ and Al 3+ ions which usually combine with other ions like Mo, Ca, Mg, S and N and make them unavailable for plants. Availability of most micronutrients is higher in acidic soils as compared to alkaline soils. Alkaline soils contain free hydroxide (OH-) ions which react with free cationic[7] micronutrients like Zn2+ and Mn2+, and precipitate into minerals, making them unavailable for plant uptake. Except Mo, availability of all micronutrients decreases with an increase in pH (Fig 3). Soil pH between 6 and 7 shows the highest availability of micronutrients. Since 71% of Indian soils are moderately alkaline, soil micronutrients tend to be deficient in them. Soil alkalinity can be corrected by adding gypsum or magnesium salts.

Figure 3: Effect of pH on availability of nutrients



Source: Adapted from Truog, E. (1946). Soil reaction influence on availability of plant nutrients and PwC analysis

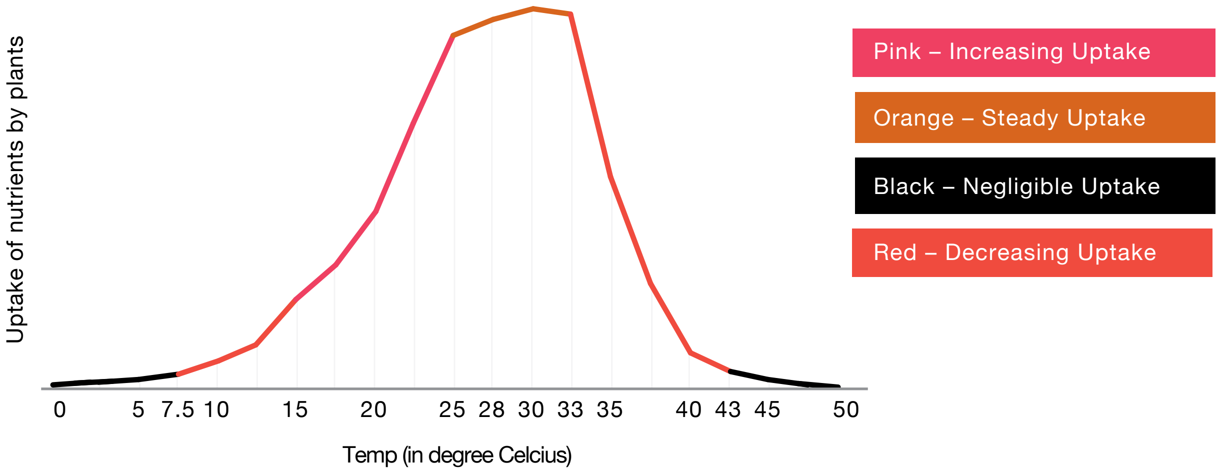
Soil organic matter is another important factor that affects availability of micronutrients. Cationic ions are held by clay particles or humus and are made available to plants when required. Clay soils with good organic matter content have high cation exchange capacity (CEC)[8] and are better at supplying nutrients to the crop. Due to intensive cultivation, soil erosion and depletion on land, soil organic matter levels have gone down, which has affected availability of micronutrients to plants. Dwindling organic carbon in Indian soils is another reason for widespread micronutrient deficiencies.

7. Cations are the positively charged atoms or molecules and anions are the negatively charged atoms or molecules of different elements present in the soil.

8. CEC is a measure of how many cations can be retained on the soil particle surface.

Soil temperature: Micronutrient uptake is also affected by the soil temperature. Micronutrient uptake increases with increasing rates between temperatures of 16 ˚C to 24 ˚C and becomes maximum at temperatures between 24˚C and 33 ˚C.[9]

Figure 4: Effect of temperature on uptake of nutrients by plants



Source: IMT Technologies Limited (2019) and PwC analysis

Factors affecting availability of individual micronutrients

Several factors affect the availability of zinc in soil. Zinc availability decreases with the rise in soil pH (Figure 4). Since 71% of Indian soils are moderately alkaline, zinc availability becomes a major concern. Availability of zinc goes down with increasing sand content, calcareousness and waterlogged conditions. Low temperatures (rabi season), vulnerability of leaching acid soils and removal of top soil also reduce availability of zinc. Increasing organic carbon content is better for zinc availability.

Boron availability is also affected by increased alkalinity of the soil. Calcareous soils tend to be deficient in boron. Sandy soils tend to leach out the elements; hence, the deficiency is higher in sandy soils. The eastern region of the country faces severe boron deficiency because of excess leaching in sandy loam soils due to high rainfall. Organic carbon content helps in easy availability of boron, and it is found more in the upper soil profile.

Like other cations, iron availability decreases with an increase in soil pH and sand (Sandy soils) content. Reduced content of organic matter and increased calcareousness can make the nutrient unavailable for plant uptake.

Copper availability increases with an increase in organic carbon content and clay content, but decreases with a rise in the soil pH and calcareousness. Sandy soils and leaching acid soils are deficient in copper.

Factors governing the availability of manganese are quite similar to those of ferrous. Increasing organic matter content and waterlogged conditions favour manganese availability.

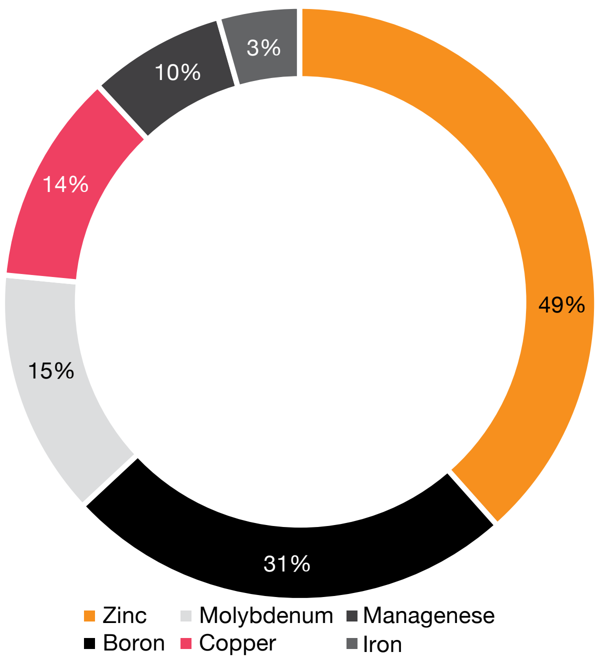
Unlike other elements, the availability of molybdenum increases with rising soil pH. Excess of **sulphur and copper** may induce molybdenum deficiency in soils.

9. IMT technologies Limited, 2019

4.2. Global micronutrient status

Soils with alkaline pH, high calcium carbonate content, low organic matter, extreme temperatures and soils under moisture stress and high antagonistic interactions[10] have been found to be susceptible to micronutrient deficiencies. These deficiencies are also associated with the parent rock/matter and its abundance.

Figure 5: Global micronutrient deficiency status



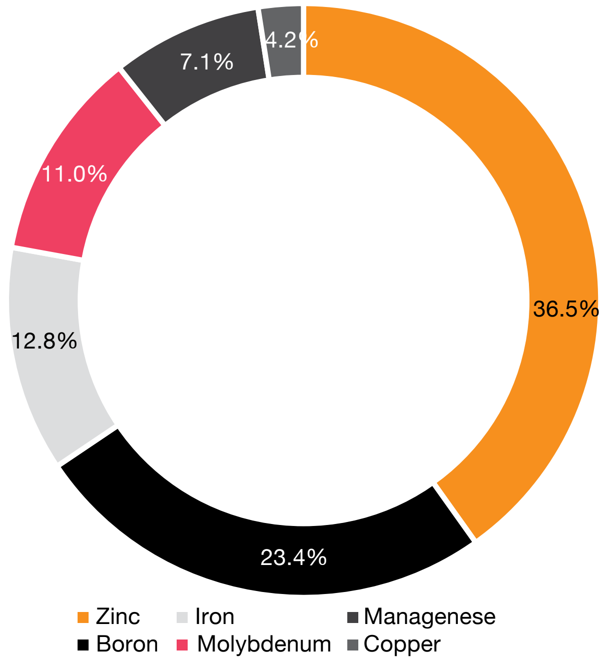
Source: Graham, R.D., 2008, Springer and PwC analysis

Global studies report zinc deficiency in about 49% of soils, making it the most prominent micronutrient deficiency in the world. Boron follows, with 31% of soils deficient in it. Moreover, 15% of soils are deficient in molybdenum; 14%, in copper; 10%, in manganese; and 3%, in iron.

4.3. Micronutrient status of Indian soil

In India, an analysis of over 2 lakh soil samples revealed[11] that, on an average, 36.5% of soils were deficient in zinc; 23.4%, in boron; 12.8%, in iron; 7.1%, in manganese and 4.2%, in copper. (Figure 6).

Figure 6: Micronutrient deficiency in Indian soil



Source: Indian Journal of Fertilisers, 2018 and PwC analysis

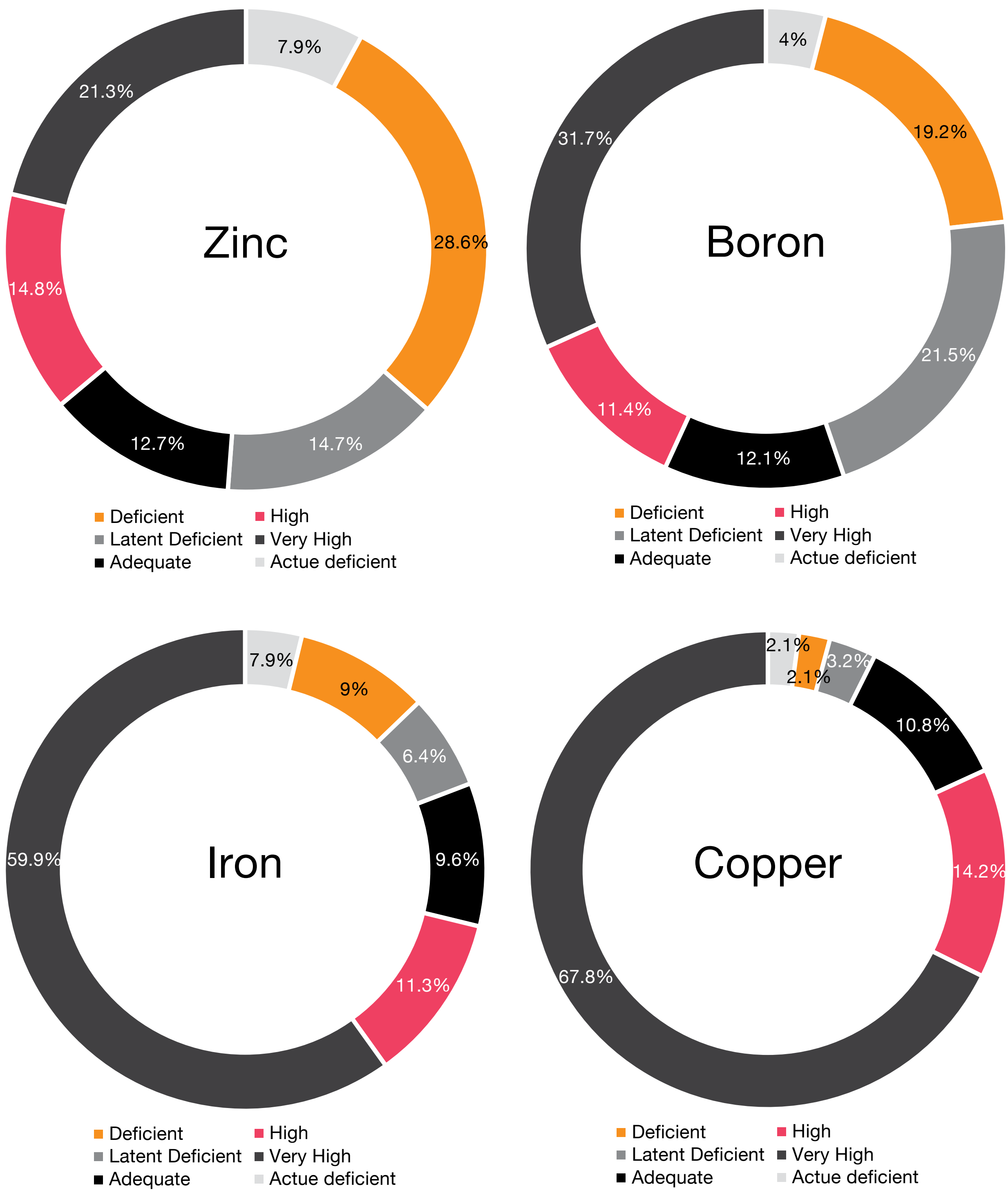
Zinc deficiency is the most predominant deficiency across all geographies in India, as 36.5% of Indian soils are deficient in zinc. **Medium black soils (39.4) and mixed red and black soils (36.2%)** have high zinc-deficient soils. The greatest zinc deficient soils are the ones that are coarser in texture (sandy/loamy sand), high in pH (> 8.5 or alkali/sodic soils) and/or low in organic carbon (<0.4%), or calcareous/high in $CaCO_3$ (>0.5%) and intensively cultivated.

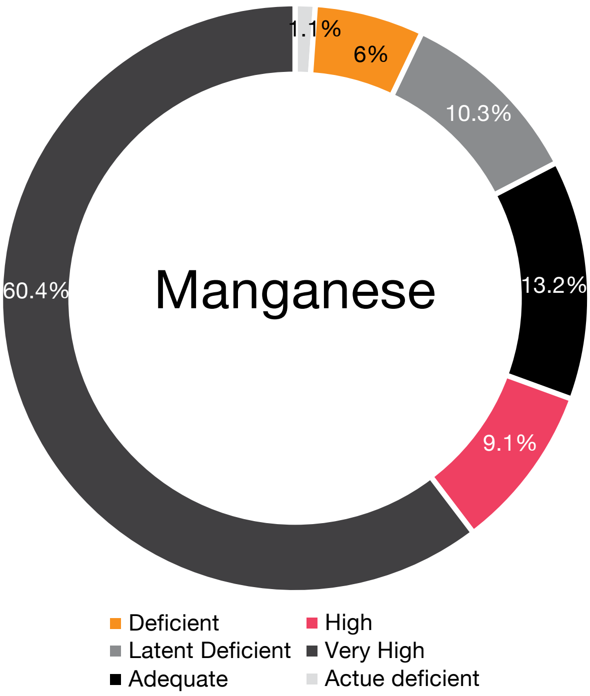
Boron deficiency is also prominent in India, as 23.2% of Indian soils are deficient (acute + deficient), while 21.5 % are marginally (latent) deficient in boron. Also, the very low use efficiency of boron (seldom exceeding 5%) is an area of concern. The deficiency of boron varies across agro-ecological zones, being higher in **grey brown soils (46.3%), sub montane soils (33.7%) and calcareous alluvial soils.** Boron deficiency is critical in highly calcareous soils, sandy leached soils, limed acid soils or reclaimed yellow or lateritic soils. In general, boron deficiency is higher in the eastern region of the country, largely due to its excess leaching in sandy loam soils, alluvial and loess deposits.

10. Antagonistic interactions are the negative interactions between nutrients, where presence of one nutrient may affect the availability and uptake of other nutrients.

11. This data is based on a study of specific samples and may vary under different agro-ecological conditions. The analysis in the Indian Journal of Fertilisers provides the data on average deficiency.

Figure 7: Deficiency status of micronutrients in Indian soils





Source: Shukla, et al., 2018. Micronutrients in soils, plants, animals and humans. Indian Journal of Fertilisers and PwC analysis

Iron deficiency in India increased from 11.0 % to 12.8% during 1967–1897 to 2011–17. It is associated with **grey brown soils (25.1%) and old alluvial soils (25%)**.
In India, the problem of iron deficiency is mainly in calcareous and other alkaline soils having pH > 7.5. The availability of iron is reduced under draught or moisture stress conditions due to conversion of the ferrous form of iron (Fe^{2+}) into a less-available ferric form (Fe^{3+}). Sometimes, high concentrations of phosphorous, nitrate nitrogen (NO_3-N) and high organic matter contents hinder iron availability.

The **deficiency level of manganese** has increased from 3.5% in 1987 to 7.1% in 2017. Though the deficiency level decreases with a rise in soil pH, sand content and leaching, manganese availability in soil reduces.

Copper deficiency is insignificant, with **only 4.2% of soils deficient**. Copper deficiency mainly occurs in sandy, calcareous, eluviated and organic rich soils. **Old alluvial soils (7.4%) and laterite soils (4.8%)** have a tendency to be deficient in copper.

Molybdenum: Most of the soils have adequate levels of molybdenum, but there is a moderate deficiency in some parts of **Maharashtra, Kerala and Odisha**.

4.3.1. Major crops affected by micronutrient deficiencies

Crops grown in a majority soils in India suffer from deficiencies of one or more micronutrients. The nature and extent of deficiencies vary based on factors such as soil type and agro-ecological situations. Micronutrient deficiencies are frequently observed in intensively grown cereals, oilseeds, pulses and vegetable crops. Different crops exhibit different sensitivity levels to micronutrient deficiencies (Table 4).

In the case of fruits, vegetables and ornamental crops, marketability depends on the health of the produce for which complete nutrition is very important. Deficiency symptoms of micronutrients affect the quality of the produce in terms of more than just the yield (e.g. boron deficiency causes brown heart in turnip and corking in apples). Hence, in order to obtain quality produce and better yields, farmers growing fruits and vegetables tend to adopt the use of micronutrients.

Table 4: Micronutrients and sensitive crops

Micronutrient	Sensitive crops	Micronutrient	Sensitive crops
Zn	Corn, onion, soybean, beans, paddy, peach, grapes	Cu	Wheat, corn, onion, citrus, lettuce, carrot
Fe	Sorghum, tree crops, blueberries, roses, grapes, nut trees	B	Alfalfa, cauliflower, celery, grapes, apples, peanut, beets, rapeseed
Mn	Peas, oats, apples, sugar beet, beetroot, citrus	Mo	Alfalfa, crucifers (broccoli, cabbage), citrus, most legumes activity

Source: Katyal, 2018 and Ganeshamurthy et al., 2018.

9. https://www.pwc.com/gx/en/issues/blockchain/blockchain-in-business.html
10. Nasscom Blockchain Report 2019

Table 5: Sensitivity of selected crops to micronutrient deficiencies (L = Low, M = Medium and H= High)

Crop		B	Cu	Fe	Mn	Mo	Zn
Cereals	Maize	L	M	M	M	L	H
	Wheat	L	M	L	M	L	L
	Sorghum	L	M	H	H	L	H
	Rice (lowland)	L	L	L	L	L	H
Pulses	Soybean	L	L	H	H	L	H
	Bean	M	L	M	M	M	L
	Cowpeas	H	L	L	L	H	M
	Peas	L	L	M	H	M	L
Vegetables	Potato	L	L	M	H	L	L
	Cauliflower	H	M	H	M	H	M
	Brinjal	M	L	L	L	L	M
	Carrot	M	M	M	M	L	L
	Cucumber	H	L	L	L	H	M
	Onion	M	L	M	L	L	M
	Tomato	H	M	H	M	M	M
	Spinach	M	H	H	H	H	H
	Okra	M	L	H	L	M	H
	Bottle gourd	H	L	L	L	H	M
Fruits	Apple	H	L	H	L	M	H
	Banana	M	L	H	L	L	H
	Grapes	H	L	H	L	L	H
	Mango	H	L	L	L	M	H
	Citrus	H	L	H	L	L	H
	Papaya	H	L	M	L	M	H
	Pineapple	H	L	L	L	M	H

Source: Katyal, 2018 and Ganeshamurthy et al., 2018.

11. https://www.idc.com/getdoc.jsp?containerId=US44755019&pageType=PRINTFRIENDLY

4.4. Products available to restore deficiency

The deficiencies identified in soils can be corrected and the micronutrient balance can be restored by using various products available in the market that help in restoring the soil balance and improving the micronutrient content of the soil.

The Fertilizer (Control) Order, 1985 (FCO Amendment, 2019) includes micronutrient fertilisers under Schedule 1f (micronutrients) and 1g (fortified fertilisers). The FCO provides specifications for each fertiliser product, and 23 such micronutrient fertilisers are notified (Fertiliser Association of India, 2018).

Six major product categories exist technically, i.e. straight, chelated, multi-nutrient mixture and fortified micronutrient fertilisers:

a) Straight micronutrients are most commonly available as sulphate salts of minerals like zinc sulphate and iron sulphate, and are easily soluble in water. They are available in crystalline or granular form. They can be applied to the soil by the broadcast method or band placement, foliar spray and also through irrigation (fertigation).

Straight fertilisers can be applied along with primary fertilisers or agrochemicals, and can save the cost of application. However, there is a possibility of nutrients getting segregated, leading to the uneven supply of nutrients to the plant. Sulphates are popular owing to relative effectiveness, low cost, wide availability and ease of handling.

Oxides of micronutrients are another source of micronutrients that have a lower per unit cost of the metal than sulphates, but are insoluble in water. Thus, the immediate effect of oxide may be low when applied in the granular form. Thus, finely ground oxide should be uniformly applied and mixed well into the soil to maximise soil contact for better uptake.

Oxysulpahtes are the oxides of copper, manganese and zinc, which are partially acidulated with sulphuric acid. The solubility of oxysulphates in water increases with increasing acidulation.

b) Chelated micronutrients are a group of products in which the micronutrient element is bound to an organic ligand in order to improve its availability to plants. A chelate is an organic compound in which two or more atoms are capable of bonding to the same metal atom, thus forming a ring. The organic molecule is termed as a ligand. These organic molecules may be synthesised by the roots and exuded into the soil, may be present in soil organic matter (SOM), or may be synthetically produced. In such a complex form, the cations are protected from reactions with inorganic soil components and thus are made available for plant uptake. Not all nutrients can be chelated. While iron, zinc, copper, manganese, calcium and magnesium can be chelated, others cannot.

Some frequently used chelating agents:

EDTA - Ethylenediamine tetraacetic acid

HEDTA - Hydroxyethylene diaminetriacetic acid

DTPA - Diethylene triamine pentaacetic acid

EDDHA - Ethylene Diamine di (O-Hydroxyphenyl Acetic Acid)

NTA - Nitrilotriacetic acid

Several organic substances (chelating agents) are used to produce chelates. EDTA is the most common synthetic chelating agent and is used for both soil and foliar-applied nutrients. DTPA is used mainly for chelates applied to alkaline soils. It is more effective than EDTA but is usually more expensive. Iron chelates made with HEDTA and EDDHA are the most effective iron fertilisers on high pH soils, but are also the most expensive.

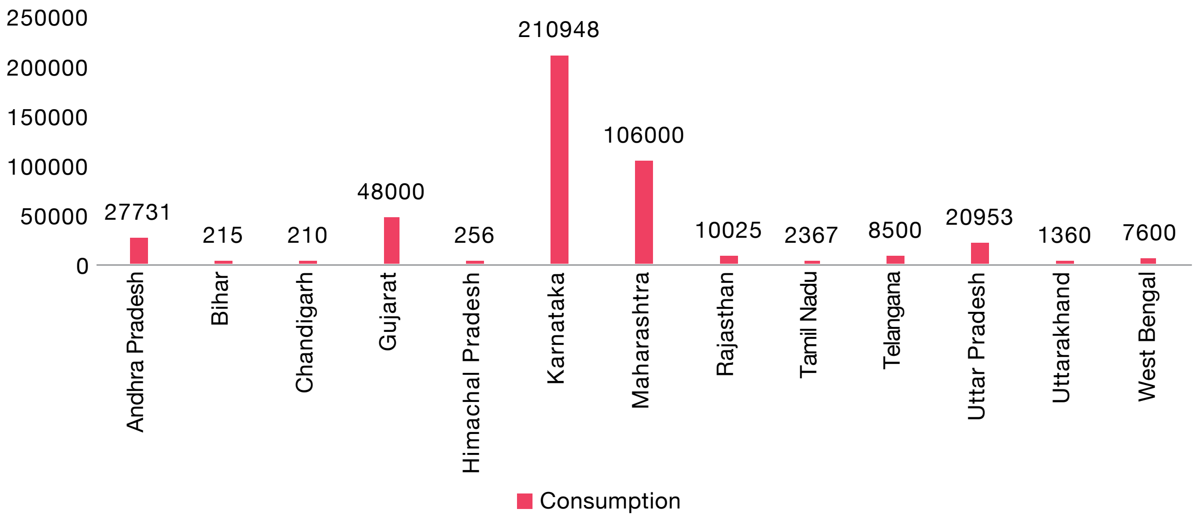
Other economical options for using chelates involve using compounds like gluconate and citrate, which are naturally exuded from roots. Chelated forms of micronutrient elements (e.g. Zn-EDTA) are known to be highly efficient as they protect the nutrient till the plant consumes it and avoids loss due to fixation in the soil. Though chelated forms of micronutrients are more effective per unit of the micronutrient, they are also expensive, limiting their use to only high-value crops like horticultural crops.

c) Multi-micronutrient mixture fertilisers are available in both solid and liquid forms to correct deficiencies of multiple micronutrients with a single application. These mixtures contain three or more micronutrients and are notified by state governments. Micronutrient mixtures are developed according to the needs of the region or the crops grown there. Micronutrient mixtures are popular in southern and western India. Karnataka, Maharashtra, Gujarat and Andhra Pradesh constitute 88% of the total micronutrient mixture consumption of India. The Government of Maharashtra has notified 11 grades of micronutrient mixtures which are specifically designed according to soil types (acid soil grade, cotton in alkaline soil grade, etc.). Similarly, the Government of Tamil Nadu has notified 14 different grades of micronutrient mixtures according to the needs of a crop (groundnut grade, banana grade, etc.).[12]

12. FAI, 2018

Multi-micronutrient applications are useful as every essential micronutrient that is required by the crop and soil can be provided in a single application. They provide all essential micronutrients and hence help avoid the 'hidden hunger' stage in crop growth.. However most of these micronutrient mixtures were notified three to four decades ago and with the changing fertility status of soil, these grades need to be updated.

Figure 8: Consumption of micronutrient mixture (2017-18) (in MT)



Source: Specialty Nutrients and Micronutrient Fertilizer Statistics, FAI 2017-18, data available for selected states and PwC analysis

d) Fortified/coated fertilisers are formed by coating conventional fertilisers with one or more micronutrients. Micronutrients can be combined with NPK fertilisers by coating a micronutrient layer on granular primary fertilisers, incorporating micronutrients during manufacture or by mixing with fluid fertilisers.[13] The use of fortified fertilisers helps in the uniform application of micronutrient fertilisers in small amounts, avoiding the cost of additional operation of soil placement, broadcasting or spraying. If straight micronutrient fertilisers are mixed physically with primary fertilisers and applied together, there are chances that they might segregate, and this may lead to uneven distribution of nutrients to plants. Hence, coating of the primary fertiliser with a micronutrient element can help ensure uniform application of nutrients to plants without a separate application operation. Micronutrients can be incorporated with fluid fertilisers, which provides a convenient and uniform method of application. However, it is important to select compatible micro- and macronutrient sources. Soil application of fortified fertilisers should be accompanied with foliar applications if deficiency symptoms persist.

There are 26 approved formulations of fortified fertilisers, zincated urea (2% Zn) and boronated SSP (1.2% B) being the most important ones. Under the Nutrient Based Subsidy (NBS) scheme, an additional subsidy of INR 500 per tonne and INR 300 per tonne is provided for the fortification of subsidised fertilisers with zinc and boron. Manufacturers of fortified fertilisers are permitted to coat/ fortify 20% of their production and are allowed to sell fertilisers coated with zinc and boron at a rate that is 10% above the notified MRP.[14] Despite this, the production of fortified fertilisers did not pick up much because the subsidy does not recover the cost of coating the fertiliser. An article published in the Fertilizer Association of India[15] states that "cost of coating of urea with 2% zinc over INR 2500 per tonne, but with government notified MRP the recovery is just INR 540 per tonne". The production of zincated urea and boronated SSP was 2,14,900 tonnes and 59,800 tonnes in year 2016–17.

13. Fluid fertilisers are not used in India, at present.

14. Fertilizer Report 2017, notification, p. 201

15. Satish Chander, Micronutrient: Macro Issues, Indian Journal of Fertilizers, July 2017

e) Customised fertilisers are multi-nutrient carriers designed for specific crops and specific geographies to contain macro, secondary and/or micronutrients both from inorganic and organic sources. Customised fertilisers are one step ahead of micronutrient mixture fertilisers as they include primary, secondary and micronutrients, manufactured using fusion-blend granulation. For basal application, customised fertilisers should be granular in size, with at least 90% of the material passing through sieves of size 1 to 4 mm and 10% passing through sieves whose size is ≤1 mm. Sieves should not exceed 5%.[16] The moisture content should not exceed 1.5%. For foliar applications, however, 100% water solubility is required.

Only three companies in India manufacture customised fertilisers. Recently, a few other players in the bulk fertiliser segment have also started production.

f) Fritted or slow release fertilisers help in the slow release of micronutrients because of the slow weathering of silicates, which can be regulated by the fineness of grinding and by addition of calcium, sodium or potassium into a silicate matrix. These products were developed to be used on coarse-textured soils in high rainfall areas where leaching is a problem. The slow release property of fritts helps ensure a continuous supply of the micronutrient source without any loss. However, that makes it preferable for maintenance applications rather than correcting deficiencies.

4.5. Role of technology and innovations in designing high-efficiency products

Over the years, a lot of research has been done on straight micronutrient fertilisers, customised fertilisers and fortified fertilisers. A key benefit in using sulphate-based fertilisers is said to be their solubility. Soluble fertilisers have a flexible mode of application, and can provide nutrients immediately, which are easily consumed by plants. But, being soluble in water, these fertilisers tend to leach out or convert into unavailable forms due to reactions with the soil. A large portion of added fertilisers either remain in the soil or enter water bodies, causing pollution. The fertiliser use efficiencies of micronutrient fertilisers seldom exceeds 3%, and about 97% of these fertilisers get fixed in the soil.

Nanotechnology and bio-release fertilisers are some innovations that may help in correcting micronutrient deficiencies.

Nanotechnology in micronutrient fertilisation:

Nanotechnology can be used to improve the efficiency of micronutrient fertilisers, with the use of Nano clay polymer composite (NCPC) to supply micronutrients slowly and steadily as per a plant's needs. Nanotechnology is aimed at enhancing the recovery of applied micronutrients and supplying micronutrients through NCPCs. The use of NCPCs have indicated more than 10% recovery of zinc in the wheat crop. Foliar application of nano-zinc emulsions and seed coating have been tested. The application of 160 mg nano-zinc per ha was found to increase the zinc use efficiency by four crops to 78.6%, which is very high as against 3.5% in mega- zinc particles.[17]

Bio-release smart fertilisers:

This is a type of slow release micronutrient fertiliser and is a compound of one micronutrient among Zn, Fe, Cu and Mn; a polyphosphate and one micronutrient from the group of B, Mo or Cl. The characteristic features of this compound are that it is a solid, free-flowing, non-hygroscopic powder fertiliser, insoluble in water but soluble in 2% citric acid supplying nutrients for absorption by plants. The release of nutrients is governed by organic acids secreted by plants and microbes and not soil moisture. Being insoluble in water prevents losses due to leaching and conversion to non-available forms. Moreover, bio-release micronutrients are available for plant uptake throughout the crop period, at a lower dose and higher nutrient content. The technology claims to bring down dosage to 10% to 25% as compared to conventional micronutrient fertilisers.

Another innovation that is used for restoring micronutrients in the soil is **the use of organic matrix**. This mechanism allows the slow release of nutrients. The product is homogenous and does not require any coating. The product includes an organic matrix), which has both positive and negative charges, and holds cations like ammonium, potassium, zinc and ferrous, and anions like sulphate and phosphorous. The binding of nutrients to the organic matrix slows down the reactions of nutrients with the soil. Then, soil microbes begin to break the matrices and nutrients are gradually released for plants' uptake. This technology provides an efficient system of providing essential micronutrients in a base nutrient package that can also improve soil tilth and water holding capacity.

16. Clause 20B of FCO, 1985

17. Tarafdar, J. C., Rathore, I. and Thomas, E. 2015. Enhancing nutrient use efficiency through Nano-technological interventions. Indian Journal of Fertilisers 11(12), 46-51

5. Micronutrient industry

Overview of the industry

The global micronutrients market is moderately consolidated with no major players accounting for a very high market share. Thus, companies are on a drive to penetrate new markets with high growth potential. Major players are involved in the R&D process to improve their product specifications, which is also a key factor for market development.

In terms of geography, Asia Pacific is a major regional market and is characterised by the growing agriculture industry, especially in India and China. The North American market is also growing, mainly owing to the depletion of arable land in the U.S. and Canada. The increasing vegan population in Europe, coupled with high awareness regarding nutrient-rich diets among consumers is expected to drive regional market growth in the coming years. The Middle East and Africa may witness stable demand in the coming years owing to increasing agricultural yield and evolving farming technology in Northern Africa.

Based on major end-use agricultural segments, the market can be segmented into cereals, fruits and vegetables, pulses and oilseeds and floriculture. Cereals accounted for the highest demand owing to increasing wheat, maize, rice, barley and oats consumption. Fruits and vegetables are projected to be the fastest growing end-use segment owing to increasing cultivation and requirements for high vegetable yield.

Sources and reserves

The main inorganic sources of micronutrients for the fertiliser industry include metallic salts (e.g. chlorides, nitrates, sulphates), borates, carbonates, molybdates and oxides. Other sources of micronutrient fertilisers involve synthetic chelates and natural organic complexes.

Apart from these, industrial byproducts are also used as sources of micronutrients. Various industries such as steel manufacturing, galvanising, brass foundaries, brass mills and tyre incineration produce waste material that can be used as a source of zinc for fertilisers. Industrial byproducts such as electric ace furnace dust, brass foundry dust, brass mill slag, galvanising waste are used in the manufacture of zinc sulphate as a source of zinc. Similarly, mining waste, pickle liquor, mill scale are byproducts containing iron that may be used in the manufacture of iron fertilisers.

The primary sources of micronutrient elements are minerals which contain the oxide, silicate or carbonate forms of the element. For example, Zinc is primarily obtained from Smithsonite (ZnCO3), Willemite (Zn2SiO4) and Franklenite (ZnFe2O4). The reserves of different micronutreints are provided in the paragraphs below:

Boron: The world reserves of boron (boric oxide/ B2O3) are about 1100 million tonnes (US Geological Survey, 2018). The four borate minerals, namely tincal, kernite, ulexite and colemanite make 90% of the borate minerals. Out of which tincal is water soluble, kernite and ulexite are partially water soluble and colemanite is water insoluble. Countries with considerable B resources are **Turkey, the United States, Russia, Chile and China**. Canada, China, India, Bangladesh, Japan, and Malaysia are the countries that imported the largest quantities of refined borates from the United States in 2018. The total boron (all products) consumption in the world is approximately 3.5 million Mt and India accounts for 4% (0.14 million Mt) of the total consumption; out of which Agriculture sector accounts 19% consumption.

India does not have any economically viable deposits of boron and is entirely dependent on imports to fulfil its demand. India imports refined borate and crude borate, which are further refined in the country to produce borax, DOT and boric acid.

Zinc: Identified zinc resources in the world are about 1.9 billion tonnes. Globally, the zinc metal market is in deficit, with consumption exceeding production. In 2018, global refined zinc production was 13.42 million tonnes, while the consumption was 13.74 million tonnes, leading to a deficit of 322,000 tonnes. India holds 9.9 million tonnes of zinc reserves as of 2015. The zinc deficit is expected to increase in the future with increased demand from China and India and other developing nations, and with no considerable addition in production. Hindustan Zinc Limited is the only known source of primary zinc at present in India.

Iron: Global iron ore production stands at 1500 million tonnes. **Australia, Brazil, China, India and Russia** are the leading producers of iron ore. India produced 130 million tonnes of iron ore in 2018, the majority of which was used for steel manufacturing.

The remaining micronutrients are abundantly available and required in lesser quantities.

Micro-nutrients trade

Globally, China is a major exporter of micronutrients, mainly sulphate salts of metals such as zinc and copper. China alone contributes to 40% of the exports of the top 10 sulphate exporters. India is the fourth-largest exporter of sulphates with export value of USD 189 million in 2017. India also imports $12743438 worth of sulphate, and is the thirty-sixth largest importer globally. The US is the largest exporter of Boron, followed by Turkey. They both constitute 88% of the total exports of the top ten countries. China and Belgium are the major importers of borax. India ranks thirteenth in the import of borax and other boron sources, and is the eighth-largest exporter of the same.

Figure 9: Top importers of micronutrients, 2017–18 (in USD million)

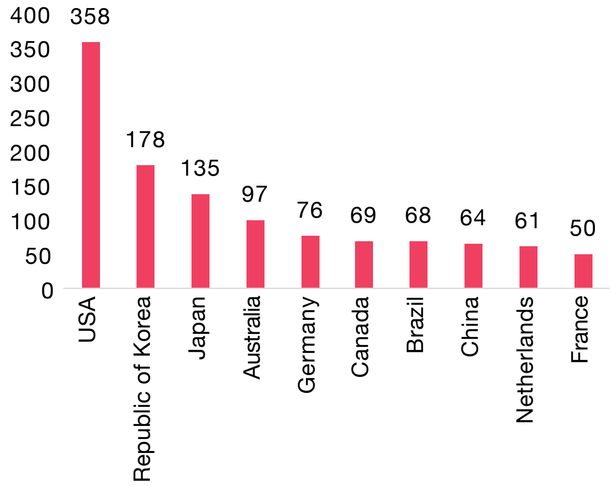
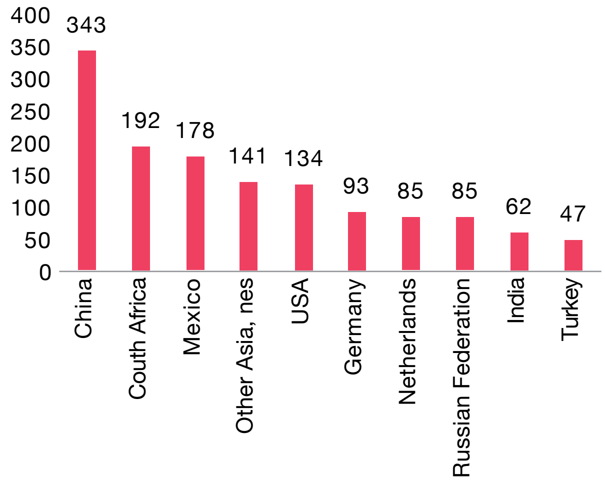


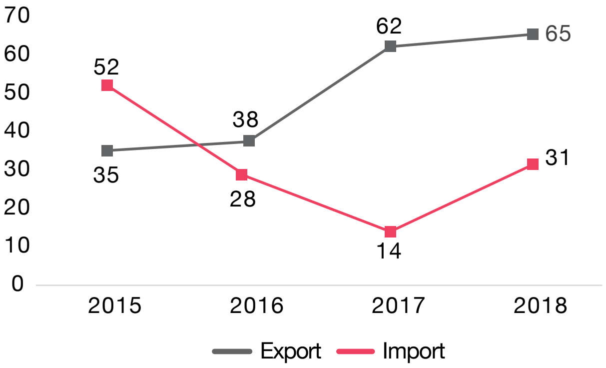
Figure 10: Top exporters of micronutrients, 2017–18 (in USD million)



Source: UN Comtrade

From 2015, the imports of micronutrients have seen a decline. On the other hand, the export of micronutrients has witnessed an increase in the last three years. One interesting point to note here is that until January 2019, the export of micronutrient fertilisers was restricted. However, with the latest amendment in the Fertilizer Control Order, 1985, the export of micronutrient fertilisers with either nitrogen, phosphorous or potassium is permitted subject to approval from the Department of Fertilizers. With this, there can be an increase in the value of micronutrient fertiliser exports from India. Given the difficulty of the classification of micronutrient fertilisers, it is difficult to regulate the imports and exports of micronutrient fertilisers. The following figure (Fig 11) presents India's imports and exports of micronutrients.

Figure 11: India's imports and exports of micronutrients (in Billion USD)



Source: UNCOMTRADE

The following table provides the value and volume of the micronutrient compounds exported from India in the year 2017 - 18:

Table 6: Micronutrients exported in the year 2017–18

	Formulation	HS Code[18]	Value (in lakh rupees)	Volume (in tonnes)
1.	Copper sulphate	28332500	1,681	1,060
2.	Zinc sulphate (other sulphates)	28332990	23,355	24,095
3.	Manganese Sulphate	28332940	16,838	34,048
4.	Disodium Tetra borate Pentahydrate (other borates)	28402090	1,416	924
5.	Ferrous sulphates	28332910	1,613	4,475
6.	Fortified Zn or B	31055900	1,265	16,493

Source: Directorate General of Foreign Trade

18. The HS code for micronutrient fertilisers/elements/chemical compounds which are used for different purposes is the same. Therefore, the numbers provided here include the entire volume of the compound traded under one HS code, and does not present exact value and volume traded as fertilisers.

6. Socio-economic impact of the micronutrient sector in India

6.1. Role of micronutrients in doubling farmers' income

In the mid-1960s, the agriculture strategy focused on (a) increasing productivity with the use of better technology and varieties, and increased use of quality seed, fertilisers, irrigation and agro-chemicals, (b) incentive structure in the form of remunerative prices for a few crops and subsidies on farm inputs (c) public investments in agriculture and (d) facilitating institutions. This strategy yielded results as India was not only able to gain self-sufficiency in self-consumption but also started exporting crops.

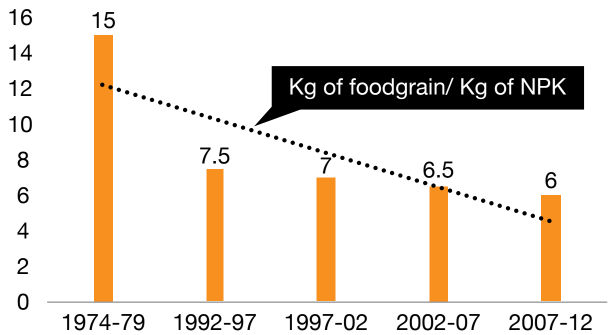
However it is seen that the general view of agriculture in India is by and large in the context of increasing the output instead of the welfare of farmers. Recently, farmers who are dependent on agriculture as a main source of livelihood are facing distress. Keeping all this in mind, the Central Government in 2016 announced to its intention to double farmers' income (DFI) by shifting the focus from agricultural output and food security to income security.

The intention of the Government of India is to double the income including farm and non-farm activities in a span of six years since the announcement requires a compound annual growth rate of 12.25% from the base year 2016.[19]

As underlined in the earlier sections, non-availability/ less availability of micronutrients in the soil leads to the stunting of growth in plants, decreased yields and increased susceptibility to diseases. Agronomic biofortification is an agronomic strategy to increase micronutrient content and bioavailability for human nutrition in the edible parts of crops by adding micronutrient fertilisers to the soil or plant leaves. In addition to enhancing the crop's nutritional quality, micronutrients, when efficiently translocated to seeds, also leads to enhancing seed vitality that allows for good seed germination and better seedling growth.

As a likely consequence of the increased uptake of micronutrients by the plants, enhanced growth and yield have been observed. However, if we continue to apply the mix of nitrogen, phosphorus and potassium (NPK), a decline in productivity has been observed. The graph below presents the crops' response to repeated application of NPK over the years.

Figure 12: Crop response to fertiliser



Source: Centre for Green Technology and Management and PwC Analysis

It therefore becomes important to have a balanced fertiliser use to ensure that nutrients are available in optimum amounts in the soil. Balanced nutrition through use of micronutrients is the key to achieve the goal of doubling the farmer's income.

To further emphasise how the balanced use of fertilisers helps in reducing costs and increasing the income of farmers, three case studies are presented in the sub-section below:

19. G.P. Singh et al., Doubling farmers income by 2022, Indian Institute of Wheat and Barley Research, Indian Farming, 68(01), 24 – 26, January 2018

Case study 1: Soil testing helps![20]

Farmer
Sanjay Thalkar from Yeola, Nashik, India

His story:
Sanjay Thalkar, a young tomato cultivator from Yeola, Nashik, believes that soil testing helps him understand the nutrient deficiency in his soil, which helps him plan the dosage of fertilisers accordingly. After following the recommendations given on the soil health card, he was able to save 30 kg nitrogen and 15 kg of phosphorus and potassium fertilisers per acre.

His micronutrient consumption increased by 11 kg per acre. Apart from an **increase in yield by 7 tonnes (more than 30%), there was also an increase in his income by INR 91,000**. He feels that soil testing is really helpful for sustainable production, and wishes to continue with the recommendations in the future.

Case study 2: Evaluation of Boron rates in soybean–corn rotation in Brazil [21]

Study area
State of Mato Grosso do Sul, Brazil

What is the story about?
This story is about an experiment conducted by Brazilian researches to develop recommendations for the Micronutrient Boron. The experiment was conducted for soybean–corn rotation in State of Mato Grosso do Sul, Brazil. Evaluation of Boron rates in two locations with different soil texture: sandy (Navirai) and clay (Maracaju) for two growing seasons (2017/2018 and 2018/2019) was tested. In both locations soybean was planted during the summer (rainy season) followed by winter corn (safrinha). For both crops, B was tested at rates of 0, 1, 2, and 4 kg B ha-1 using sodium tetraborate as the fertiliser source. The fertiliser was broadcast-applied 1 day before planting. In the case of corn, two different times of B fertilisations were tested: 1) 100% at pre-planting of soybean; 2) 50% at pre-planting of soybean and 50% at pre-planting of corn.

The results from 2017/2018 showed grain yield benefit of 384 kg ha-1 of 1 kg B ha-1 over control for soybean in the Maracaju location. The grain yield difference in the Navirai was of 264 kg ha-1.

These case studies show that the use of micronutrients helps increase Crop yields and farm income.

20. soilhealth.dac.gov.in
21. Fundação MS, 2018

6.2. Fighting nutrition deficiencies

According to the World Health Organisation, almost two billion - nearly one in four individuals - suffer from 'Hidden Hunger' or vitamin and nutrient deficiencies, resulting in mental impairment, poor health, low productivity and in worst cases, even death. Children are especially vulnerable to micronutrient deficiencies. The deficiency of zinc in childhood leads to poor growth and stunting, Vitamin A deficiency can cause night blindness and poor immunity, while iron deficiency is found to be directly correlated with poor mental and physical development.

Micronutrient deficiencies are also reported in adults. Such deficiencies in children and adults alike can be correlated to deficiencies in the soil. It is reported that almost 25% of the population in India suffer from zinc deficiency and more than 80% pregnant women suffer from iron deficiency anaemia (IDA).

The use of micronutrients in crops through fortification and other popular methods can help restore the nutrient imbalance in plants and human alike.

6.3. Micronutrients and food security

Food security is commonly defined as 'when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life."[22]

It is estimated by the FAO that by 2050, agricultural production will have to increase by almost 50% to meet the needs of the growing population. The Sustainable Development Goal 2 also focuses on ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture.

> "
> **Healthy soils are the basis of healthy food production!**
>
> Food and Agriculture Organization
> "

It is well understood that food availability is dependent on soil. Nutritious and quality crops can only be grown if soils are healthy, which are prerequisites to food security. It is therefore important to adopt a balanced use of fertilisers. Micronutrients are a must for the quantitative and qualitative enhancement of food productivity and thus a prerequisite for achieving food security.

22. Food and Agriculture Organization

7. Government support and policy framework

Agriculture being a mainstay, there are various policies and schemes that are being implemented. This section comprises briefs of schemes provided by the Ministry of Agriculture, state governments and subsidies offered to the industry.

Soil Health Card Scheme

The Soil Health Card Scheme has been launched under the National Mission for Sustainable Agriculture. SHM aims at promoting Integrated Nutrient Management (INM) with the judicious use of chemical fertilisers, including secondary and micro nutrients in conjunction with organic manures and bio-fertilisers for improving soil health and its productivity. It also aims at strengthening of the soil and fertiliser-testing facilities to provide soil test-based recommendations to farmers for improving soil fertility, ensuring quality control requirements of fertilisers, bio-fertilisers and organic fertilisers under the Fertiliser Control Order, 1985, the upgradation of skills and knowledge of soil testing laboratory staff, extension staff and farmers through training and demonstrations, promoting organic farming practices etc.[23]

What is covered under this scheme?

Assistance is provided for the distribution of micronutrients and soil ameliorants to a maximum limit of INR 2,500/ ha.[24]

National Food Security Mission (NFSM)

The National Development Council (NDC), in its 53rd meeting held on 29 May 2007, adopted a resolution to launch a Food Security Mission comprising rice, wheat and pulses to increase the annual production of rice by 10 million tonnes, wheat by 8 million tonnes and pulses by 2 million tonnes by the end of the Eleventh Plan (2011-12) was launched. Accordingly, a Centrally Sponsored Scheme, 'National Food Security Mission' (NFSM), was launched in October 2007.[25]

What is covered under this scheme?[26]

- Micronutrients for crops: Rice, wheat, pulses and nutri-cereals for 50% of the cost limited to INR 500 per hectare

National Food Security Mission (Oil Seeds & Oil Palm)

National Mission on Oilseeds and Oil palm (NMOOP), an oilseeds and oil palm development programme in India, was started in 2014-15 and continued up to 2017-18. As per the decision of the cabinet secretary regarding the merger/conversions or linkage of schemes/ sub schemes/ programmes, having similar components such as incentives for seed, demonstration, and farm implements including efficient water application tools covered under NFSM and oil seeds was merged under the revamped NFSM from the year 2018-19.[27] The scheme is very popular in Bihar and is used for wheat and maize.

What is covered under this scheme?[28]

- Plant protection chemicals for insecticides, fungicides, weedicides, bio-pesticides, bio-agents, micronutrients, bio-fertilisers etc., subject to a limit of 50% of the cost, limited to INR 500 per hectare.

Nutrient Based Subsidy

NBS is a programme for fertilisers and was initiated in 2010. Under this scheme, a fixed amount of subisdy is decided on an annual basis on each grade of phosphatic and potassic (P&K) fertilisers, except for urea, **based** on the **nutrient** content present in them. The subsidy focuses on promoting a balanced use of fertilisers with a focus on sustained soil quality.

Under the NBS policy, the government has announced a fixed rate of subsidy (on an INR per kg basis) on nutrients, namely nitrogen (N), phosphate (P), potash (K) and sulphur (S), on an annual basis. The scheme is applicable on 22 grades of decontrolled fertilisers, namely DAP, MAP, TSP, DAP Lite, MOP, SSP, ammonium sulphate and 15 grades of complex fertilisers. Additional subsidy is also provided on fertilisers fortified with secondary nutrients and micronutrients such as boron and zinc as per the Fertilizer Control Order.

23. Soil Health Card, Department of Agriculture and Farmers Welfare, available online, www.soilhealth.dac.gov.in

24. A Farmer Friendly Handbook for Schemes & Programmes 2018 – 19, Ministry of Agriculture & Farmers Welfare, Government of India, available online, www.agricoop.nic.in

25. National Food Security Mission, Ministry of Agriculture and Farmers Welfare, Government of India, available online, www.nfsm.gov.in

26. A Farmer Friendly Handbook for Schemes & Programmes 2018 – 19, Ministry of Agriculture & Farmers Welfare, Government of India, available online, www.agricoop.nic.in

27. NFSM – Oil seeds and Oil Palm, available online, www.nfsm.gov.in

28. A Farmer Friendly Handbook for Schemes & Programmes 2018 – 19, Ministry of Agriculture & Farmers Welfare, Government of India, available online, www.agricoop.nic.in

Direct Benefit Transfer (DBT)

Direct Benefit Transfer or DBT is an attempt to change the mechanism of transferring subsidies launched by the Government of India on 1 January 2013. This programme aims to transfer subsidies directly to people through their bank accounts. This policy provides transparency and empowers the farmers to choose and buy the right nutrition mix for their fields.

The government has introduced the DBT system for fertiliser subsidy payments. Under the fertiliser DBT system, 100% subsidy on various fertiliser grades will be released to the fertiliser companies, on the basis of actual sales made by the retailers to the beneficiaries. Sale of all subsidised fertilisers to farmers/buyers will be made through point of sale (PoS) devices installed at each retailer shop and the beneficiaries will be identified through Aadhaar Card, KCC, Voter Identity Card, etc.[29]

Minimum support price

The minimum support price (MSP) is an agricultural product price set by the Government of India to purchase directly from the farmer. This rate is to safeguard the farmer with a minimum profit figure for the harvest, if the open market has a lesser price than the cost incurred. MSP has ensured better value realisation for the farmer, hence ensuring him with a better purchasing power.

Subsidies offered by various state governments:

The table below provides the details of subsidies/ assistance that are offered by various state governments in the micronutrient space:

Table 7: Subsidies offered by State Governments

	State Government	Type of assistance offered
1.	Government of Karnataka	The Government of Karnataka, in collaboration with ICRISAT, Hyderabad, had launched a programme called 'Bhoo Chetana' or 'Reviving soil' to increase crop productivity in dry land areas with the help of improved technology, soil testing, promotion of micronutrients and biofertilisers and technical assistance. In this scheme, micronutrients like Zinc sulphate and Borax were provided ta 50% subsidised rates in the Raith Sampark Kendra. The programme was successful in promoting the use of micronutrients and the consumption of zinc sulphate increased from 372 tonnes in kharif 2009 to 6803 tonnes in kharif 2012. (Success Documentation of Bhoo Chetana Programe, 2014)
2.	Government of Andhra Pradesh	The Government of Andhra Pradesh had proposed to distribute 100% subsidised boron (10.5% B), zinc sulphate and gypsum to farmers as per their soil health card status.
3.	Government of Haryana	The Government of Haryana also extended INR 500 per ha or 50% subsidy on cost incurred on zinc sulphate, iron sulphate and manganese sulphate under the NMSA mission in 2018.
4	Government of Madhya Pradesh	The Government of Madhya Pradesh provided INR 500 per ha or 25% subsidy for promoting use of zinc sulphate under Integrated Cereal Development Programme.
5.	Government of Goa	The Government of Goa has promoted the use of straight micronutrient fertilisers by extending 50% subsidy on use of Zinc sulphate, Magnesium sulphate and boron up to a maximum of INR 8000.
6.	Government of Tamil Nadu	The Government of Tamil Nadu also had provided 50% subsidy on use of xinc sulphate for paddy cultivation.

29. http://fert.nic.in/dbt

Research promotion in micronutrients:

The government funds various soil science research institutes like the Indian Agricultural Research Institute and Indian Institute of Soil Science, Bhopal for extensive research in the field of micronutrients. The All India Coordinated Research Project (AICRP) - micro and secondary nutrients and pollutant elements has been functional since 1988. The AICRP has successfully characterised the deficiency symptoms of all essential micronutrients. The project, in collaboration with NBSSLUP Nagpur, has prepared 55 GIS soil fertility maps that have helped find the average deficiency of major micronutrients in Indian soils. These institutes work with corporates on a contract basis for the evaluation of grades of micronutrient fertilisers.

Policies to support the industry to promote the use of micronutrients:

Subsidy for fortified fertilisers: Any grade of subsidised nitrogen, phosphorus and potassium which is fortified/ coated with zinc or boron will receive an additional subsidy of INR 300 per tonne for boron and INR 500 per tonne for zinc. Also, manufacturers of fortified fertilisers are permitted to sell zincated urea and boronated SSP at a rate that is 10% above the MRP (Fertilizer report 2017, notification). All said, the industry is not satisfied with this support, the reason being that the subsidy does not recover the cost of coating the fertiliser.

Manufacturers of customised fertilisers are permitted to import/ source subsidised fertilisers to use them as raw materials. An approved list of customised fertilisers contains crop-specific and area-specific grades of fertilisers, including micronutrients like zinc and boron which are designed to fulfil the nutritional requirements of the crops in that area. The government has certain criteria for allowing companies to start the production of customised fertilisers. Permission for the manufacture and sale of customised fertilisers is granted only to companies whose annual turnover is INR 500 crores or above. Such manufacturing companies should also have soil testing facilities with an annual analysing capacity of 10,000 samples per annum. The grade of customised fertilisers that the company will manufacture should be based on scientific data obtained from area specific, soil specific and crop specific soil testing results. These manufacturing companies, in association with concerned agricultural universities/KVKs, should also conduct agronomy tests of the proposed grade to establish its agronomic efficacy. Such manufacturing companies should generate multi-location trials (not on farm demonstration) on different crops for minimum one season. Some of these regulations can be relaxed for new players to enter the market and promote sell of customised fertilisers.

Taxation: Micronutrient fertilisers are taxed higher than other fertilisers. Micronutrient mixtures are taxed at 18% GST rate, while straight micronutrient fertilisers are charged 12% GST. The custom duty and GST rate of micronutrients are higher vis-à-vis conventional fertilisers resulting in higher prices of micronutrient fertilisers and low sales. In order to promote balanced fertilization, the Government can consider bringing down the GST on micronutrient fertilisers from 12% to 5%. Coupled with that, State governments can work on developing systems to gather authentic and reliable data for season wise consumption of micronutrients.

Export promotion: The export of micronutrient fertilisers is permitted under the latest amendment of the Fertilizer Control Order, 1985, which was kept under the restricted category till January 2019. Fertilisers are yet not a part of the Merchandise Exports of India Scheme, so they do not get MEIS incentives for exports.

8. Micronutrients: Providing a promising growth space

The micronutrient industry has great potential of providing a promising growth space. In this section, we delve on the factors that will provide growth:

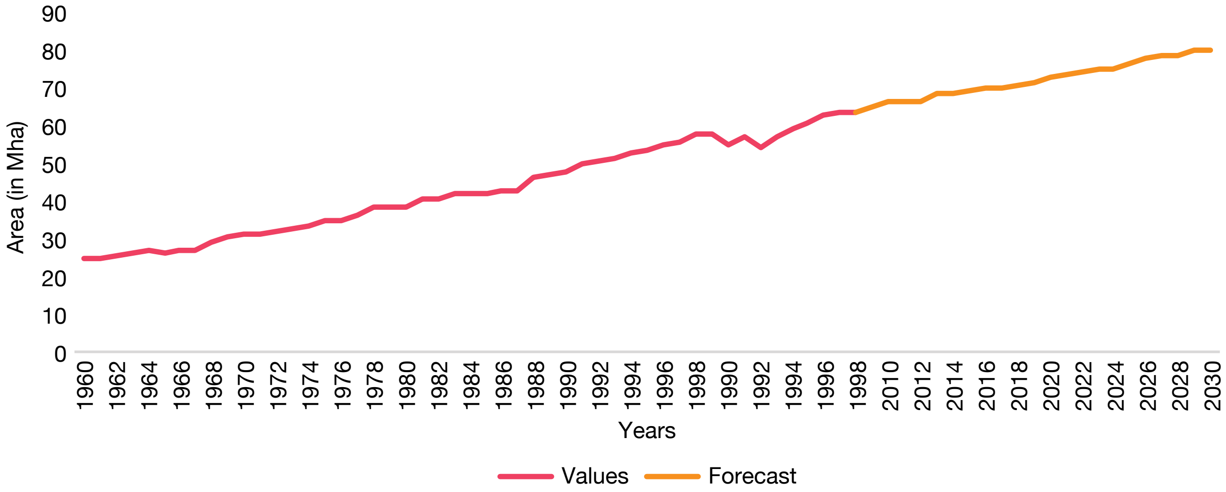
1. **Increasing demand for food and limited land resources**
   The population of the globe is growing at 1.10% annually, adding 83 million people each year. In order to feed this larger, more urban and richer population, food production needs to increase by 70%. Annual cereal production will need to rise to about 3 billion tonnes from 2.1 billion now, and annual meat production will need to rise by over 200 million tonnes to reach 470 million tonnes. (FAO, 2009). Agriculture uses 12% of the world's land surface, 82% of fresh water in Africa and 81% of that in Asia. This will rise to an average of 89% by 2050 (Global Agriculture Productivity Report, 2016). Since land resources are limited and cropping intensity is increasing, micronutrient uptake is also rising. In order to continue with higher production, replenishment of soil with essential micronutrients is necessary.

2. **Focus on productivity**
   Along with expansion of arable land, irrigation and intensification, we will have to focus of increasing the efficiency of agriculture in order to meet global food demand. This efficiency can be measured by Total Factor Productivity; which is the ratio of agricultural outputs like gross crop produced to inputs like seeds and fertilisers. The UN's 2030 Agenda: Sustainable Development Goal 2.3 mentions of "**doubling the agricultural productivity** and incomes of small-scale food producers, including **through** secure and equal access to land, other **productive resources and inputs**, knowledge, financial services, markets, and opportunities for value addition and non-farm employment." To feed the population of India in 2050, land productivity has to be enhanced four times along with a threefold increase in water productivity and six-fold increase in labour productivity while focusing on energy savings and low emission technologies. The annual growth rate in cereals is has decreased over the years from 1965 – 74 to 2005-14 (FAO, 2017). The Total Factor Productivity growth in low income countries has been less for years and it can be propelled by awareness and adoption on improved agricultural practises. Many researches claim that micronutrient application has improved the productivity of farmlands across the globe. Increase in the use of efficient Inputs have shown increase in the productivity in Low middle income and high middle income countries (FAO, 2017). Thus, micronutrient fertilisers will be in demand to increase the productivity of farm.

3. **Rising micronutrient deficiency**
   Global study on micronutrients shows that deficiency of Zn and B can be found in almost every country. In India, Zinc and Boron deficiencies are found in 36.5% and 23.4% of the soils; these figures may increase to 51.2% and 44.7%, if soils under marginal deficiencies are not brought under intensive cultivation. About 188.4 thousand tonnes of micronutrients were removed by 263 Mt of foodgrains produced. If these micronutrients are not added back to the soil, the soil nutrient status will deplete further and hamper crop productivity. Thus, micronutrient fertilisers will be used to replenish the soils in order to continue crop production.

4. **Increase in net irrigated area**
   Based on the data collected from the Directorate of Economics & Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, The net irrigated area is going to increase up to 80 Mha in 2030. It is generally observed that farmers move to high value crops like Fruits and vegetables on availability of irrigation. Since fruits and vegetables are sensitive to micronutrient deficiencies and marketability of produce is affected due to deficiency, farmers use micronutrient fertilisers in these crops.

Figure 13: Net irrigated area in India



Source: Food and Agriculture Organization, 2008

5. **Farmer awareness and acceptance**
   The Government of India launched the Soil Health Card Scheme in April 2014. The Soil Health Card Scheme is an important policy that has a mandate to issue soil health cards to every farmer every three years to know the deficiency status and provide recommendations accordingly. This scheme is helping in increasing awareness about micronutrient deficiencies in Indian soils. Under cycle-1, 2.54 crore samples were collected, 2.36 crore samples tested and 9.33 crore SHCs distributed among the farmers as on 24 September 2017. The use of micronutrient has slightly increased after the launch of this scheme (Impact study of soil health card scheme, MANAGE). Few farmers using traditional micronutrient fertilisers look at it as luxury consumption because the nutrient does not stay for long in the soil. The use of slow release fertilisers will ensure that the micronutrient use efficiency of plants is increased. Many innovative products are being introduced which will help improve the use efficiency of micronutrient fertilisers, which is currently below 5%. Increase in the nutrient use efficiency will show results in the form of yield and quality of produce and encourage farmers to use micronutrient fertilisers.

6. **Positive outlook of government policies**
   The Government of India has taken initiatives to promote balanced nutrition and thereby the use of micronutrients. As a part of balanced nutrition under the National Soil Fertility Mission, reimbursement of up to INR 500 per ha or 50% of the cost incurred on micronutrient fertilisers was provided. Several state governments also provided similar subsidies to farmers to promote the use of micronutrient fertilisers. For instance, under the "Bhoochetana" programme, the Government of Karnataka supplied micronutrient fertilisers at 50% subsidy.

7. **Various organisations encourage the use of micronutrients**
   Global organisations such as the UN-Food and Agriculture Organisation, International Fertiliser Association, International Zinc Association and national organisations like the Fertiliser Association of India, Indian Institute of Soil Science and the Indian Agricultural Research Institute are carrying out research to develop and promote micronutrient products to manage soil deficiency. Various private players in this industry have started their own soil and plant testing facilities. In this way, they are convincing farmers to practise soil testing, know the deficiencies and the adopt use of micronutrient fertilisers.

9. Key takeaways

> **Soil science is the foundation of protective medicine.**
>
> - Andrew Harley, Principal Geochemist, Duraroot Environmental Consulting

Micronutrient deficiencies are found across the globe and in a majority of Indian soils. Major micronutrients in which soils are deficient are zinc, boron and iron. Considering the continuous nutrient uptake due to intensive cropping, these deficiencies could increase in the near future, if fertilisation including micronutrients is not followed.

Most of the Indian soils have a high pH and in such soils micronutrients are not easily available for plant uptake. Hence soil application and foliar sprays of micronutrient fertilisers are very important to provide the necessary nutrition to crops and avoid loss in productivity.

There are many products available to correct micronutrient deficiency. Straight sulphate fertilisers for soil application are the most popular option in India. Chelated micronutrients have better use efficiency. Crop-specific and state-specific micronutrient mixture fertilisers are available for both soil and foliar application. Foliar sprays ensure better uptake and quick response. Customised and fortified fertilisers help in balanced nutrition without extra operation cost, but their production has not picked up because of regulatory policies. Acceptance of fortified fertilisers by farmers looks promising, however policy changes are important for their promotion. Going forward, the use of nanotechnology- and biotechnology-based micronutrients is likely.

Use of micronutrients is concentrated in vegetable and fruit production areas because these crops are sensitive to deficiency and marketability of the produce is affected because of deficiency of micronutrients. The same is not applicable in the case of cereals and pulses because they are low value crops, not very susceptible to deficiencies and farmers believe the marketability of the produce is not affected in these crops.

Farmer awareness is more in areas with good irrigation and in areas with horticulture production. Local and specialised players have larger market shares in the geographies that they deal in. This is because players who deal with fertilisers and pesticides focus more on their core offerings and treat micronutrients as secondary products.

The increasing demand for food and limited landholding have necessitated higher productivity. Rising micronutrient deficiency, increase in the area under irrigation, and fruit and vegetable production are some of the growth drivers for this industry. The positive outlook of the government and rising farmer awareness and acceptance will provide further impetus.

There is a huge gap that exists in the desired and actual levels of micronutrient use in India. The government, industry and farmers need to come together to bridge this gap.

Key recommendations for farmers

1. **Prescription-based application**
   Every farmer in the country should make use of the Soil Health Card Scheme and understand the deficiency status of the soil. One should use the recommendations provided to plan the nutrition schedule of the crops.

   Soil characteristics like pH, calcareousness, excess N and P application should be considered while selecting micronutrient fertilisers. Basal dose/soil application should not be skipped because micronutrients play a very critical role in vegetative stages of plant growth and at this tender stage foliar applications may harm the foliage of plants.

   Alkaline soils can be treated with gypsum or magnesium salts to reduce soil pH. Foliar sprays of preferably chelated micronutrients are recommended in crops grown in alkaline soils.

2. **Application precautions**
   Many farmers tend to mix different spray solutions to save cost and time by applying them together. Though most micronutrient fertilisers are compatible with other chemicals, it is recommended to do a jar test before mixing all the chemicals. If in the jar the solution turns into a precipitate then the solutions are not compatible and should not be sprayed together. The solutions which are compatible should also not be kept for long. They should be used as soon as possible after mixing

   Care should be taken not to mix micronutrients with phosphate based solutions as they may get fixed and become unavailable to the plants. The same also applies with phosphate rich water soluble fertiliser grades.

3. **Awareness and adoption**
   Farmers need to be more vigilant while purchasing micronutrient products, and should buy products from reputed dealers and not hesitate in clarifying doubts to procure the right product that is right for their soil. The source of information like newspapers, magazines, television shows, even WhatsApp groups and farming apps should be accessed to know more about new products and their use.

   Farmers who are aware about micronutrients but do not use any products form a considerable portion of the total farmer population. The major reasons are that they believe that bulk fertilisers containing N, P and K are sufficient for crop growth. Trials on a small part of their fields will help them gain more confidence about the benefits and impact of including micronutrients in the fertilisation schedule.

Key recommendations for policymakers

1. **Revisit the policy framework**
   Fertilisers, being included in the Essential Commodities Act, are regulated products. Hence, the Government has always tried to promote the use of primary fertilisers such as urea, DAP, SSP and MOP by selling them at subsidised rates. But this has led to overuse of chemical fertilisers and unbalanced plant nutrition. The ratio of N: P: K in Indian soils is currently at 6.7: 2.4: 1 against the desirable 4:2:1 ratio. Micronutrients have been generally the lesser focused group as compared to macronutrients.

   There is a need to revisit the subsidy structure for fertilisers and promote a balanced use of secondary nutrients and micronutrients along with macronutrients. Micronutrient mixture fertilisers are gaining popularity and chelated fertilisers are known to have high-use efficiency. A limited period support for the promotion of these products will help increase consumption.

2. **Nationwide campaign on balanced plant nutrition**
   Micronutrient deficiencies in India are widespread. The adverse effects of these on agricultural productivity, food security and human health make it an issue of national importance. Scientists, channel partners, companies, farmers and the government need to join hands to fight this threatening issue.

   A nationwide high decibel campaign on balanced nutrition needs to be launched which should target an increased awareness about the use of micronutrient fertilisers. Short-term incentives to farmers for a limited period of time could be planned in order to encourage trial of micronutrients. Successful replication of the 'Bhoo Chetana' model in all states could be a good move.

3. **Promote fortified fertilisers**
   The Government of India has encouraged the production of fortified fertilisers (zincated urea, boronated SSP, etc.) by allowing manufacturers to use 20% of subsidised fertilisers for fortification and charge 10% higher MRP for fertilisers coated with zinc and boron.

   Under the Nutrient Based Subsidy Scheme, there is also a provision of additional subsidy of INR 500 per tonne and INR 300 per tonne for fortification with Zn and B. Despite policy initiatives and although 23 fortified fertilisers have been notified by the Fertilizer Control Order, 2018, the production of fortified fertilisers has not picked up much. This is because the cost of coating far exceeds the regulated MRP. If necessary, a comprehensive cost benefit study and subsequent policy changes in this area could be one of the best ways to promote micronutrient fortified fertilisers.

4. **Soil and plant testing infrastructure**
   The number of well-equipped soil and plant testing laboratories with well-trained personnel is very low in India. Most of the soil testing lacks the capability for testing micronutrients. The quality of the equipment and turnaround time are not up to the mark.

   The practise of petiole testing prevails in very few high-value agricultural areas. Even there, the time required to obtain results discourages farmers from adopting such measures as they fear damage to the crop or reduction in yield because of delay in fertilisation.

   The Soil Health Card Scheme was a successful initiative, but more coordinated efforts are needed to inculcate a habit of regular soil testing in farmers through sustained communication and awareness drives. There is an immense scope of Public Private Partnerships for both extension and operations.

5. **Rationalise the tax structure**
   Currently, fertilisers are classified under Chapter 31 of the First Schedule to the Customs Tariff Act, 1975 (Import Tariff). However, in case of micronutrients, the classification was changed from Chapter 31 to Chapter 28 (inorganic chemicals) with effect from 6 April, 2016. This change in classification has resulted in much higher rate of customs duty on import of micronutrients, raw materials and products, which has led to an increase in the farmer's price.

   The GST on micronutrient fertilisers is 12% while that on fertilisers is 5%. If efforts are made to rationalise the tax structure and custom duty on micronutrient fertilisers is on par with other fertilisers, it will help reduce the farmer prices of micronutrient fertilisers.

6. **Investments in R&D**
   More focus on R&D in the field of micronutrients is needed. As impact of micronutrients deficiencies go beyond soil and crop ecosystem and also affects the food chain, the nutritional security of the people of the country is becoming a crucial concern.

   Systematic studies on micronutrients in soil-plant-animal human continuum need to be conducted to find out the effect of micronutrient deficiencies in soils, on animals and human health.

   There is a need to design a dynamic system to delineate and periodically reassess micronutrient status in soils using geographical positioning system (GPS). An IT-based monitoring and forecasting system for micronutrient deficiencies in different cropping systems is needed for better preparedness and planning of fertilisation programmes.

   More research is also needed in the development of integrated micronutrient management technologies, using available organic materials and bio-agents like vesicular arbuscular mycorrhizal (VAM) fungi for sustainable soil health management

Key recommendations for industry

1. **Agri input biggies to lead the way**
   Micronutrients need to be made popular to the masses and this is possible only if companies already having a considerable market share in the fertilisers and pesticides segment aggressively take up and drive this product category. These companies should have a dedicated team on-field to stay in touch with farmers through farm visits and farmer meetings to promote micronutrient products. Most of these companies have a strong feet on street across geographies, but focus remains on the core offering only. There is need for the large fertiliser and agrochemical companies to take the on leadership role and include soil health and Integrated Nutrient management in their strategic goals.

2. **Make in India**
   Many local players import micronutrient mixtures and resell them in India. This helps them to reduce the risk of demand supply imbalance and underutilisation of capacity. Manufacturing the product in India will save costs, provide employment and also reduce dependency on suppliers. Manufacturing the product also helps gain trust of the farmers and dealers.

   Export of micronutrients are expected to significantly increase going forward with the removal of export restrictions. The latest amendment (January 2019) in the Fertilizer Control Order , 1985, which enables the export of micronutrient fertilisers with either N, P or K is subject to approval from Department of Fertilizers. With this, there can be an increase in the value of micronutrient fertiliser exports from India, setting a foundation for a dedicated "Make-In- India" programme for micronutrients.

3. **Crop-specific and customised fertilisers**
   Crop-specific grades have witnessed good acceptance among farmers. Since micronutrient's use is concentrated in horticultural crops, crop-specific grades can help attract respective growers. Convenience and specific need-based nutrition are some benefits which farmers will value.

   Customised fertilisers were introduced in India in 2008, but in 10 years the sale has not picked up. Out of 36 grades notified under FCO, 26 grades are for basal and 10 grades are used as top dress. Of these, 23 grades are with Zn, and 19 with B, content varies from 0.1 to 1.0%. In 2015-16, the total sales of customised fertilisers was 59,891 tonnes which reduced down to 39,590 in 2016-17 (FAI, 2018). New players can enter into this market as going forward, with rising awareness and area under horticultural crops, sales of customized fertilisers is going to rise.

4. **Fortified products**
   Use of micronutrients fortified is agreeably the most convenient and cost-effective method to restore micronutrients in the soil. Coating of primary fertilisers with a micronutrient element can help ensure the uniform application of nutrients to plants without a separate application operation. Fortification options can also be explored for liquid fertilisers/ crop protection products. Currently very few players are operating in this space, primarily because the subsidies are not commensurate with the additional costs of fortification.

However, this provides companies with an opportunity to be the first movers. It enables them to stand out in the market by enhancing the value of their existing fertilisers/crop protection offerings.

There are 26 approved formulations of fortified fertilisers in India, zincated urea (2% Zn) and boronated SSP (1.2% B) being the most important ones. Popularisation of more such offerings will be a win-win situation for the farmers as well as the industry.

5. **Investing in channel engagement and training**
   Channel partner engagement is necessary as dealers highly influence purchasing behaviour of farmers. There is a lack of awareness about the use of micronutrients at the farmer's level and hence there is no strong demand for micronutrient products. Most farmers tend to avoid the use of micronutrients unless they are growing high-value crops. Hence, dealers have to push the product to farmers using false commitments. Companies should consider this fact and try to provide reasonable margins, adequate credit windows and desired marketing support. Also, companies need to focus more on training and sensitising dealers regarding the importance of micronutrients and encourage them to increase awareness among farmers for the regular use of micronutrients.

6. **Tapping pesticide channel**
   In the past, fertiliser dealers have been the dominant channel partners in the sale of all plant nutrition based products including micronutrients. This trend has changed in the last few years.

   Pesticide shops are the most preferred place by farmers to buy micronutrient products. Farmers believe micronutrients are like 'tonic' for crop health. Mostly micronutrients are applied as a curative measure, on recommendation of dealer or fellow farmer, when deficiency symptoms like yellowing appear. Hence, pesticide dealers are an equally important channel for the sale of micronutrient fertilisers.

   Micronutrient companies need to adequately appeal to these channel partners and need to educate them about best application practices.

7. **Adopting nutrient stewardship**
   As per the 4R nutrient stewardship principle of fertiliser application (IPNI, Canada, 2007) in order to maximise productivity and ensure sustainability, it is very important to use the right source at the right rate, right time and at the right place. For deciding the "right" it is important to know the fertility status which can be measured by soil and plant analysis. There are various factors that affect the availability of micronutrients in soil which should be taken into consideration while recommending the micronutrient fertilisers (right source and right rate) and method of application (right time and right place). It is in the best interests of the industry to follow these principles of nutrient stewardship and integrate the same in the business strategy for longer product life cycles and better value creation for its customers.

8. **Collaboration scope between global and local manufacturer**
   Global collaborations and technology transfers can help create value for the players by marrying R&D capabilities, quality focus, raw material availability of global suppliers with business understanding and distribution strength of local players. Many such tie-ups have taken place in the past, with a reasonable amount of success. These partnerships need to go beyond transactional trading relationships and should strive to be deeper associations to create better synergies and unlock value for companies as well as the end consumers.

About IZA

International Zinc Association (IZA) is a non-profit organization founded in 1991. It is the only global industry association dedicated exclusively to the interests of zinc and its users. Operating internationally and locally through its regional affiliates, IZA helps sustain the long-term global demand for zinc and its markets by promoting such key end uses as corrosion protection for steel and the essentiality of zinc in human health and crop nutrition.

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