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# Micronutrients Deficiencies vis-a-vis Food and Nutritional Security of India

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Role of micronutrients in food production is well recognized and documented but its importance in nutritional security and human health is increasing in current era. Most of the nutrients that are required for human health come from the soil through either plants or animal products consumed by humans. Micronutrient deficiencies are rampant in the country and on average 43.0, 12.1, 5.4, 5.6 and 18.3% soils are deficient in Zn, Fe, Cu, Mn and B, respectively. The deficiency of two elements, particularly Zn+B in acid soils and Zn+Fe in semi-arid soils is coming up in many cropping systems as an alarm for future. Soil micronutrients maps developed, covering large areas to improve our understanding regarding micronutrients problems would be helpful in taking policy decisions regarding distribution of micronutrient carrying fertiliser materials to the location deficient in respective micronutrients. Besides this, the delineation results will be of immense use in developing location specific recommendations to enhance micronutrients content in food crops. Micronutrients availability in soil is reflected in their concentration in soil seed/ fodder and which in turn decides its bioavailability and bioassimilation in human and livestock. The seeds grown on micronutrients deficient soils contain micronutrients 2 to 3 times lower than those grown on micronutrients adequate soils. A bioassimilation study suggested that consumption of micronutrients dense food is expected to have a huge impact in combating micronutrients malnutrition. Strategies developed to unlock the native Zn and Fe from the soil and external application through foliar feeding could enhance sizeable amount of bioavailability micronutrients in plant food. This article highlights current scenario of micronutrients status in Indian soils, its contribution to total food grain production and its relation to food and nutritional security of the country.

## INTRODUCTION

**It is estimated** that by the year 2050, world human population will climb to 9.7 billion, and India's population is projected to overtake that of China, will rise to 1.6 billion, from its current level of 1.2 billion (45). Skewed use of major fertiliser nutrients without micronutrients is a major concern for achieving the agricultural intensification required to feed the growing world population nutritious food. A challenge for Agricultural scientists is to feed the world population with nourishing food. On the other hand, expectations for higher grain productivity in the past, caused decreased content of micronutrients in grains (7, 38, 39, 55). The issue of micronutrients deficiency is related with food and nutritional security (22, 15, 54). Micronutrients are major limitation across the world and controls crop productivity as well as produce quality (especially micronutrients concentration). Micronutrients deficiencies are difficult to diagnose and consequently the problem is termed 'hidden hunger' (46). Pressure on a fixed land base to produce more food has driven a shift in production toward cereals. Cereals are generally low in micronutrients compared to many other food crops and growing them on micronutrients deficient soils further reduces their concentration in these crops. Indian diets are mainly consist of cereals like, rice and wheat, which are inherently low in micronutrients, and thus it raised concern for animal and human health.

Research efforts that relate micronutrient deficiency in soils with human health and its remediation are only at infancy in India. Zinc deficiency in human diet was reported as early as 1961 and expressed its syndrome as hypogonadism, dwarfism, hepatosplenomegaly, anaemia and geophagia (41). The research work on micronutrients in soil and human health is very scantly despite the obvious connection between soil micronutrients status and human health are known since time immemorial. Today, most agricultural systems in the developing world do not provide enough nutrients. Many fall short of supplying enough micronutrients (14 trace elements and 13 vitamins) to meet human needs, even though the production of energy and protein via cereal crops appears to be adequate to feed the world.

In order to understand the relationship between micro-nutrient supply and human health there is immense need to understand level of micronutrients deficiencies in soils. Micronutrients distributions in soils are often not completely independent of each other. Some elements are related to parent materials, and these relations may persist in soils. Availability can be defined as the quantity of a soil nutrient that is accessible to plant roots over some useful period such as a growing season (48). Because plant roots accumulate micronutrients directly from the soil solution, the total pool of soil micronutrients is not directly available. The distribution of available micronutrients is governed by exchange phase, chelated with or contained in organic matter, adsorbed or fixed on clays, adsorbed or occluded in or on oxide minerals or carbonates, or be constituents of residual primary minerals. Distribution of available micronutrients including multiple micronutrients deficiencies is immensely needed to established link between soil and available micronutrients and human health. As the case with plants and soils, Fe and Zn deficiencies are also the most widespread micronutrient deficiencies in humans.

**Georeferenced Micronutrients Deficiency in Indian Soils**

Information on status of micro- and secondary nutrients for different soil types, districts, regions as well as for the country is highly essential to determine the nature and extent of their deficiencies/ toxicities and to formulate strategies for their correction as well as industries. To study the changes in micronutrients status of soils and crops through its cooperating centres, the Indian Council of Agricultural Research-All India Coordinated Research Project on Micro- and Secondary Nutrients and Pollutant Elements in Soils and Plants (ICAR-AICRP-MSPE) initiated the work on delineation of soils in various agro-climatic zones since its inception in 1967. Through the intensive effort of delineation programme, ICAR-AICRP-MSPE has been continuously reporting the status of micronutrients in soil-plant system.

The Global Positioning System (GPS), a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the earth where there is an unobstructed line of sight to four or more GPS satellites has helped enormously to the delineation programme taken under AICRP-MSPE. With the advent of GPS technology, its use in delineation programmes has been introduced to collect samples from different sites under the project since 2009 and so far 97,464 soil samples with GPS point-wise data have been collected from 210 districts of the 16 states of the country. The GPS based soil sampling helps in preparation of the micronutrient fertility maps which are useful for planners and policy makers and other stake holders. Besides this, the GPS based technologies renders help in revisiting the sites for reassessment after an interval of time.

A soil is considered deficient in a given nutrient when addition of that nutrient as fertiliser produces increased growth, even though the quantity of nutrient added may be small compared with the total amount in the soil (50). The deficiency of any nutrient in soil-plant system is quantitatively governed by its critical limits. Critical limit of any nutrient in soils refers to a level below which the crops will readily respond to its application. The deficiency and sufficiency level of micronutrients according to the critical limits has been identified by the respective centres of ICAR-AICRP-MSPE. This level varies with nutrient, crops, soil, and the extractants used. Critical limits of micronutrients identified in a particular soil type may not be applicable in other soil types. For instance, critical limit for Zn had been established as 0.60 mg $kg^{-1}$ soil in almost all the states except in Gujarat (0.50 mg $kg^{-1}$ soil) and Tamil Nadu (1.20 mg $kg^{-1}$ soil). Similarly critical limit for Fe varies from 3.50 to 7.00 mg $kg^{-1}$ soil and same for Cu is established as 0.20 mg $kg^{-1}$ soil except in Bihar and Tamil Nadu where in a critical value of 0.60 mg $kg^{-1}$ soil is considered. Likewise the critical value of Mn and Cu in soil also varies according to the variation in soil type and agro-climatic situations.

The availability of cationic micronutrients (Zn, Fe, Cu and Mn) in soils is assessed through Diethylene Triamine Pentaacetic Acid (DTPA) extraction. The deficiency of DTPA- micronutrients varies widely among soil types, agro climatic conditions, types of crops grown and other agronomic practices. The plant available zinc in Indian soils, extracted with DTPA constitutes a very small portion (<1%) of total zinc. The DTPA-extractable Zn in Indian soils ranges from 0.01 to 52.93 mg $kg^{-1}$ soil. Overall, 43.0% of 97,464 samples collected across the country were deficient in available Zn. As evident from **Table 1** deficiency of Zn in different states varied among states with a minimum of 1.4% in Himachal Pradesh and 9.6% in Uttarakhand to as high as 65.5% in Tamil Nadu. Besides Tamil Nadu, Zn deficiency in states like Madhya Pradesh (61.7), Maharashtra (54.0) and Bihar (41.4), was reported more than 40%. Almost one third of the soils of Uttar Pradesh were found to be deficient in available Zn while about every fourth sample was low in available Zn content in states like Assam, Gujarat, Odisha, Andhra Pradesh and Telangana. Owing to the variations in soil texture, pH and organic matter content of the soils, wide variations in the proportion of Zn-deficient soils have been observed in different districts within states.

The Fe is another cationic micronutrient, which limits the growth and development of crops when not available in sufficient quantity. Since Fe is found in two forms in the soils *viz.* $Fe^{2+}$ and $Fe^{3+}$, its availability to plant varies from cropping system and soil characteristics. Iron is present in soil in different forms like the pool of immediately available Fe, the available Fe, Fe available on decomposition and potential medium to long-term sources of available Fe (19). Though Indian soils are comparatively rich in plant available Fe, its availability in some states like Gujarat, Haryana, Maharashtra, Telangana and Andhra Pradesh is posing threat to the crop production. In soils of different states of the country, Fe availability (DTPA-extractable Fe) varies from 0.01 to

1461.70 mg $kg^{-1}$ soil. Though analysis results of 97,464 georeferenced soils samples indicated that overall Fe deficiency in India stayed close to 13%, but in some of the states like Gujarat (23.9%), Haryana (21.6%), Maharashtra (21.5%), newly created Telangana (17.0) and Andhra Pradesh (16.8%) its deficiency is increasing rapidly **(Table 1).**

The DTPA-extractable Cu content in soils of different Indian states ranges from 0.02 to 378.70 mg $kg^{-1}$ soil. While, overall Cu deficiency is less than 6 percent (5.4% to be precise) however, it is a cause of concern in the states like Tamil Nadu and Uttar Pradesh where 13.0 and 6.3%, samples were found deficient in Cu, respectively. Intensively cultivated states of northern India like Haryana and Punjab are also experiencing Cu deficiency in certain pockets.

Due to its increasing deficiency in north Indian states like Punjab and Haryana as well as Tamil Nadu, southern states of the country, Mn nutrition has drew attention of stakeholders in recent years. Available Mn (DTPA-extractable) content in Indian soils which varies with cropping pattern and agro-climatic situations, ranges from 0.01 to 444.90 mg $kg^{-1}$ soil with a mean value of 21.78 mg $kg^{-1}$ soil. Its overall deficiency in the country has been analysed to be 5.5% but its deficiency is alarming in Punjab, Tamil Nadu, Haryana and Himachal Pradesh **(Table 1)**.

Boron is another important micronutrient limiting production of many crops in the country. Boron content in soils, which is extracted from soil with hot water varies from 0.01 to 237.50 mg $kg^{-1}$ soil with an average of 1.24 mg $kg^{-1}$ soil. Owing to B deficiency in soils, yield of almost all the crops grown in states like Odisha, West Bengal, Gujarat, Bihar, Maharashtra, Assam and Tamil Nadu is generally low despite application of recommended dose of N, P, K and Zn fertilisers. From the results of 73,630 samples analyzed for hot water available B, deficiency of B in highly calcareous soils of Bihar and Gujarat and acid soils of West Bengal, Odisha and Jharkhand are more common **(Table 1)**. Little more than half of the samples analyzed from Odisha state fell in the category of low B availability.

The major reason of greater B deficiency reported in earlier years was that researchers have targeted known problem areas for sampling. Contrasting to that now more and more samples are brought under B analysis irrespective of the problems of deficiency reported in plants, the deficiency percentage has declined.

**Multi-micronutrients Deficiency**

In recent years, multi-micronutrients containing fertilisers have been available aplenty in market and are also being used. Above and beyond individual nutrients deficiency, deficiencies of multiple micronutrients in crops in Indian soils due to depletion in fertility are an emerging issue in agriculture. Though the deficiency of a single micronutrient prevails compared to two, three and for micronutrients deficiencies, the two micronutrients deficiency in certain states of the country are

**Table 1 – Deficiency status of available (DTPA-extractable) micronutrients and hot water soluble B (HWS-B) in soils of different states of India**

| State | DTPA-extractable micronutrients | | | | | Hot water soluble B | |
|---|---|---|---|---|---|---|---|
| | No. of samples | Percent samples deficient | | | | No. of samples | Percent samples deficient |
| | | Zn | Fe | Cu | Mn | | |
| Andhra Pradesh | 6723 | 22.3 | 16.8 | 1.0 | 1.7 | 3216 | 2.8 |
| Assam | 5216 | 25.5 | 0.0 | 3.8 | 0.0 | 5216 | 11.9 |
| Bihar | 7304 | 41.4 | 12.3 | 1.8 | 7.8 | 3597 | 33.3 |
| Gujarat | 5470 | 23.1 | 23.9 | 0.4 | 6.3 | 5470 | 17.9 |
| Haryana | 5673 | 15.3 | 21.6 | 5.2 | 6.1 | 5673 | 3.3 |
| Himachal Pradesh | 642 | 1.4 | 7.8 | 0.2 | 22.1 | 161 | 8.7 |
| Jharkhand | 443 | 20.3 | 0.0 | 0.5 | 0.0 | 443 | 56.0 |
| Madhya Pradesh | 7580 | 61.7 | 9.6 | 0.2 | 1.6 | 3330 | 2.4 |
| Maharashtra | 8278 | 54.0 | 21.5 | 0.2 | 3.8 | 489 | 54.8 |
| Odisha | 2349 | 22.7 | 1.8 | 0.3 | 1.1 | 2349 | 52.5 |
| Punjab | 2181 | 16.6 | 6.2 | 3.6 | 15.2 | 1083 | 17.5 |
| Tamil Nadu | 31080 | 65.5 | 10.6 | 13.0 | 7.9 | 31080 | 19.9 |
| Telangana | 4799 | 26.9 | 17.0 | 1.4 | 3.8 | 2776 | 16.1 |
| Uttar Pradesh | 4788 | 33.1 | 7.6 | 6.3 | 6.5 | 4323 | 16.2 |
| Uttarakhand | 2575 | 9.6 | 1.4 | 1.4 | 4.7 | 2575 | 7.0 |
| West Bengal | 2363 | 11.9 | 0.0 | 1.2 | 0.9 | 1849 | 46.9 |
| **All India** | **97464** | **43.0** | **12.1** | **5.4** | **5.5** | **73630** | **18.3** |

**Table 2 – Deficiency status of multi-micronutrients in soils of different states of India**

| State | Two micronutrients | | | | Three micronutrients | | |
|---|---|---|---|---|---|---|---|
| | Zn+Fe | Zn+Cu | Zn+Mn | Zn+B | Zn+Fe+Mn | Zn+Cu+Mn | Zn+Fe+B |
| Andhra Pradesh | 6.40 | 0.40 | 0.61 | 0.81 | 0.16 | 0.03 | 0.16 |
| Assam | 0.00 | 1.50 | 0.00 | 4.47 | 0.00 | 0.00 | 0.00 |
| Bihar | 4.01 | 0.89 | 2.67 | 16.49 | 1.11 | 0.11 | 1.25 |
| Gujarat | 6.00 | 0.24 | 2.30 | 4.83 | 0.86 | 0.00 | 1.30 |
| Haryana | 6.38 | 2.22 | 1.80 | 0.74 | 0.85 | 0.37 | 0.46 |
| Himachal Pradesh | 0.00 | 0.00 | 0.31 | 0.00 | 0.00 | 0.00 | 0.00 |
| Jharkhand | 0.00 | 0.00 | 0.00 | 11.74 | 0.00 | 0.00 | 0.00 |
| Madhya Pradesh | 7.56 | 0.12 | 1.35 | 1.50 | 0.59 | 0.01 | 0.24 |
| Maharashtra | 12.32 | 0.11 | 2.74 | 30.47 | 1.82 | 0.06 | 0.20 |
| Odisha | 0.34 | 0.17 | 0.26 | 12.22 | 0.04 | 0.00 | 0.17 |
| Punjab | 1.79 | 1.93 | 4.68 | 1.85 | 0.46 | 0.28 | 0.18 |
| Tamil Nadu | 8.45 | 10.69 | 6.00 | 13.50 | 1.71 | 2.12 | 1.38 |
| Telangana | 6.21 | 0.58 | 0.92 | 2.05 | 0.33 | 0.13 | 0.47 |
| Uttar Pradesh | 2.99 | 2.46 | 2.34 | 6.80 | 0.77 | 0.48 | 0.67 |
| Uttarakhand | 0.27 | 0.62 | 0.93 | 0.78 | 0.12 | 0.31 | 0.00 |
| West Bengal | 0.00 | 0.55 | 0.47 | 3.73 | 0.00 | 0.04 | 0.00 |
| **All India** | **6.29** | **3.97** | **3.04** | **8.63** | **1.01** | **0.76** | **0.86** |

emerging at increasing rate.

Within a time frame of last two decades multiple nutrient deficiencies were reported in crops for Zn+Fe, Zn+Cu, Zn+Mn and Zn+B **(Table 2)**. Multi-micronutrients deficiencies for Zn+Fe, Zn+Cu, Zn+Mn and Zn+B are observed at more localized level which is expected be much more prevalent than based on only Zn, Fe, Mn and Cu in future. The Zn + B deficiency was found more prevalent in acid leached Alfisols, red and Lateritic soils of India.

As evident from the **Figure 1 and 2**, these deficiencies are seldom more than 10% for two nutrients and less than 2% for three nutrients (Zn+Fe+Mn, Zn+Cu+Mn and Zn+Fe+B); the application of single micronutrients is sufficient instead of multi-micronutrients mixtures with higher cost of production. Among the two micronutrients combination deficiency of Zn+B was prevalent in states like Maharashtra (30.5%), Bihar (16.5%), Tamil Nadu (13.5%), Odisha (12.2%) and Jharkhand (11.7%). A combination of Zn+Fe deficiency was reported in Maharashtra, Telangana, Tamil Nadu, Madhya Pradesh, Andhra Pradesh, Haryana and Gujarat. Although the deficiency combination seldom exceeds 10% except in Maharashtra.

Though individually Zn and Mn deficiency is increasing in Punjab but in combination (Zn+Mn) deficiency is coming up in rice-wheat growing areas of the state. In most of the states the deficiencies of three micronutrients combination is not alarming as it seldom exceed 2%. In most of the states, such deficiencies are negligible however, localized deficiency may occur in pockets or fields.

## Periodical Changes in Deficiency Status of Micronutrients

With a perspective of effective planning for the production/ distribution of micronutrients

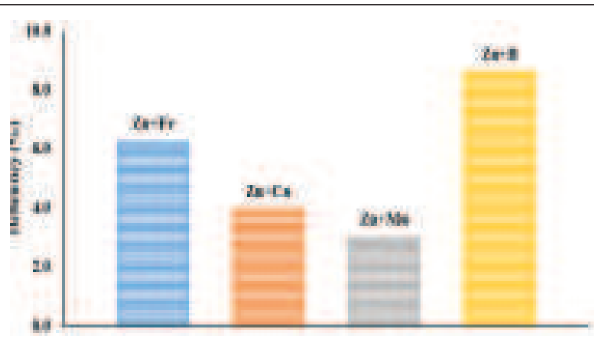



*Figure 1 – Extent of deficiency of two micronutrients in Indian soils*

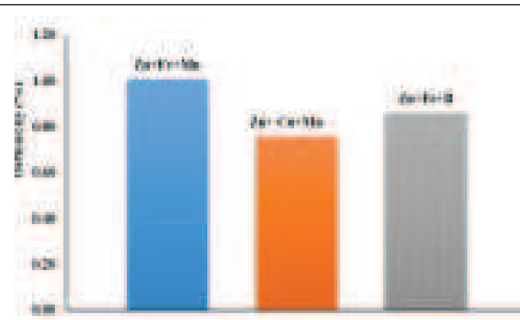


*Figure 2 – Extent of deficiency of three micronutrients in Indian soils*

**Table 3 – Periodical changes in deficiency status of available (DTPA-extractable) micronutrients in soils of different zones of India**

| Zones | No. of samples | 1980- 2008* | | | | No. of samples | 2009-2014 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Zn | Fe | Cu | Mn | | Zn | Fe | Cu | Mn |
| East | 54061 | 47.3 | 0.4 | 1.4 | 4.9 | 17675 | 29.8 | 5.3 | 2.1 | 3.5 |
| North | 64906 | 51.2 | 12.8 | 1.3 | 3.1 | 15859 | 19.3 | 11.4 | 4.5 | 7.9 |
| South | 68863 | 59.9 | 21.6 | 5.1 | 9.6 | 42602 | 54.3 | 12.3 | 9.8 | 6.5 |
| West | 63717 | 34.7 | 7.6 | 19.4 | 2.4 | 21328 | 48.8 | 17.9 | 0.2 | 3.6 |
| **All India** | **251547** | **48.6** | **11.2** | **7.0** | **5.1** | **97464** | **43.0** | **12.1** | **7.0** | **5.5** |

*Source: AICRP-MSPE database.

carrying fertilisers in the areas where it is really required, the zone-wise deficiency of the micronutrients have been worked out from the above data and compared with the earlier data **(Table 3)**. The deficiency of Zn in different zones has changed by a significant margin, for example the Zn deficiency has gone down considerably in northern and eastern parts of the country while it has increased in western states like Gujarat, Maharashtra and parts of Madhya Pradesh. The changes in Zn status in soils of southern states has not been in the line of other parts like north Indian. Since Fe deficiency is linked with soil moisture regime, as the irrigation facilities has increased in northern and southern part of the contrary. Consequently, in recent years, increase in Fe deficiency in western and eastern states (especially Bihar) has been observed while decline in other two zones has been noticed. On average, not much change in Cu status was observed but regional changes has been seen clearly. The Cu deficiency has declined in western parts due to use of micronutrients mixtures and Cu containing pesticides. Increase of Cu deficiency in southern zone may be explained due to adoption of higher critical limit in Tamil Nadu. The increasing Mn deficiency in northern state like Punjab, Haryana and Himachal Pradesh has necessitated its application in crops like wheat and rice.

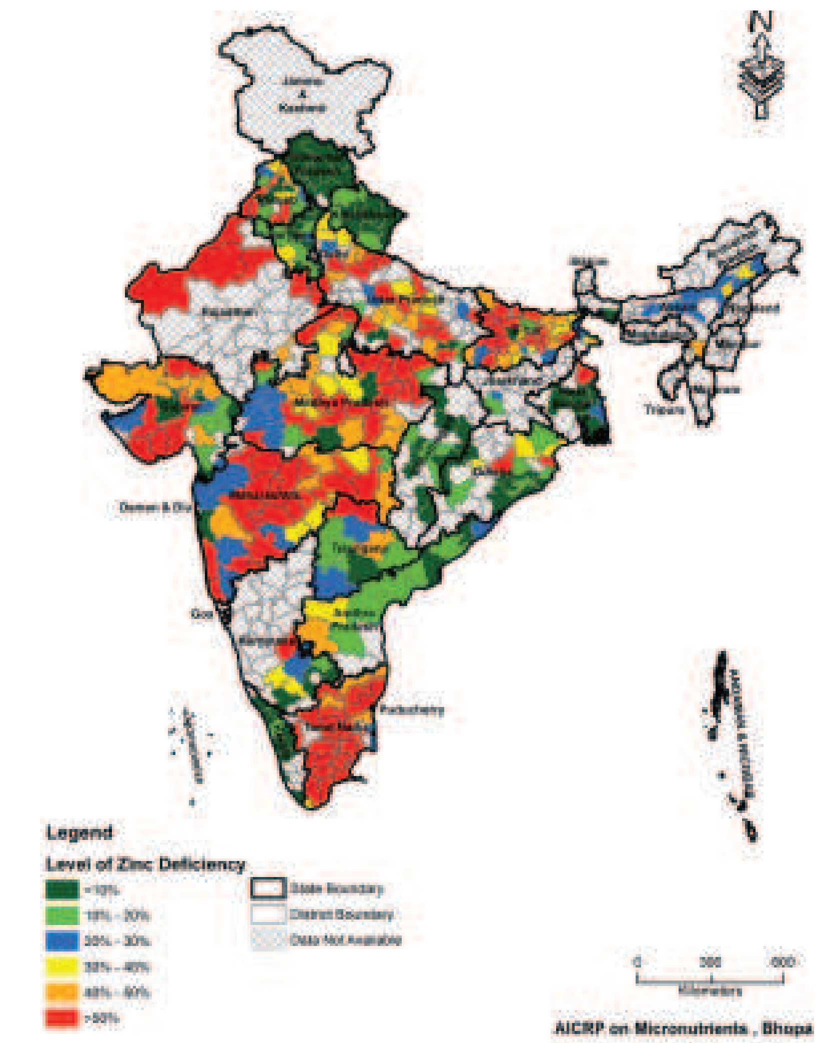
## Micronutrients Mapping

Soil micronutrient maps covering large areas improve our understanding of the nature and extent of micronutrient problems, and aid in determining their relationships with climate, soil properties, and soil genetic characteristics. Micronutrient availability to plants can be measured in direct uptake experiments, or estimated with techniques that correlate quantities of micronutrients extracted chemically from soils to plant uptake and response to micronutrient fertilization. Rational management of micronutrient fertility and toxicity requires an understanding of how total and plant-available soil micronutrients vary across the land. Based on large experimental evidences it has been concluded that the total content of micronutrients *per se* is a poor predictor of their supplying power to the plants and the available micronutrient pool that represents the native level of plant usable forms is more often the basis to decide on the occurrence of deficiency or sufficiency status (20, 40, 36).

A variety of approaches have been used to survey and map the geographic distribution of soil micronutrients contents and availability at scales ranging from global to sites within single production fields. These maps can be useful in delineating specific areas where deficiencies or toxicities are likely for agriculture, and in determining localized need of specific micronutrient fertiliser and to establish relationships between soil micronutrient content and some human and livestock health problems. Advances including the global positioning system (GPS), geographic information systems (GIS), inductively coupled plasma (ICP) spectrometry, and geostatistics, facilitate soil micronutrients mapping and provide quantitative support for decision and policy making to improve agricultural approaches to balanced micronutrient nutrition and precision agriculture. In this paper we have used information gathered from different AICRP (MSPE) reports for the period of 2004 to 2014 and some information downloaded from website www.iiss@nic.in. We have prepared micronutrients (Zn, Fe, Cu, Mn and B) deficiency status maps for farmers, planners, policy makers and other stake holders, especially fertiliser manufacturer/ supplier so that proper use of micronutrient should be ensured for maximum economic gain and quality produce (micronutrients enriched food).

### *Mapping Zn Deficiency Status*

Maps of Zn deficiency has been prepared based on the current status of Zn availability in soils of the different districts. Map 1 depicted Zn deficiency status in soils examined from 379 districts of the country revealed that 84 districts, particularly in acid soils of states like Himachal Pradesh, West Bengal, Odisha, Kerala, Uttarakhand and Karnataka fall in the category where Zn deficiency is reported to be less than 10%. Some districts of Haryana and Punjab also fall in this range due to regular use of Zn fertiliser in these states. Fifty three districts fall in the range where Zn deficiency status varied from 10-20%, 44




*Map 1 – Spatial variation in available Zn deficiency status in soils of different districts of India*

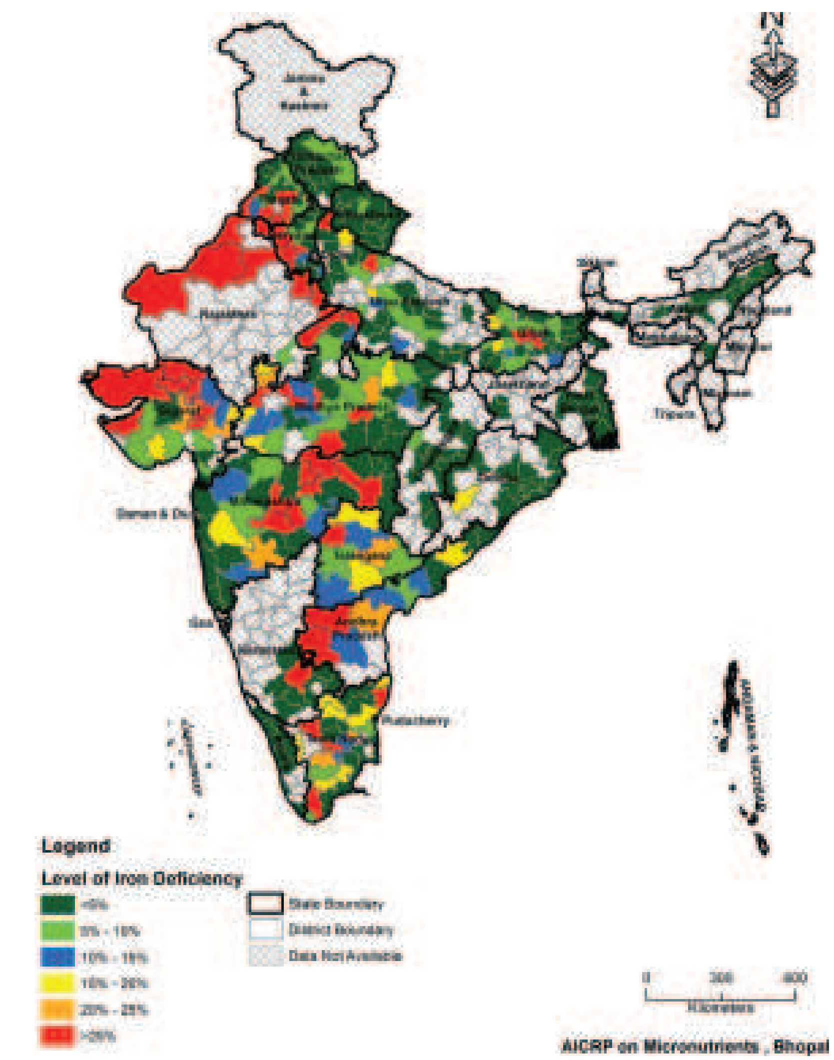
districts in 20-30%, 38 districts in 30-40% and 40 districts in the category of 40-50%. Even after regular use of Zn fertiliser in many parts of the country Zn deficiency in 120 districts is more than 50%, indicating about one third soils of the country. Most of the districts fall in states like Tamil Nadu, Madhya Pradesh, Maharashtra, Bihar, some part in Uttar Pradesh, Gujarat and Rajasthan. Surprisingly, six districts in Punjab (Ferozpur, Kapurthala, Mansa, Muktsar, Roopnagar and Sangrur) are shown with more than 50% deficiency, however, the average Zn deficiency of the states has declined from 49 to 17%. Although Zn deficiency is reported less in acid soils but three districts (Angul, Bhadrak and Boudh) of Odisha also fall in this category.

Data depicted in maps of Zn deficient soil areas in India indicated that about one-third of the country's vast area was acute deficient in Zn. Earlier the incidence of zinc deficiency were observed more in cereal belts of the country, particular rice and wheat growing areas (21) now the distribution of Zn deficiency has changed and has extended to coarse cereals and pulse growing areas too. On average, Zn deficiency has declined in northern parts of the country and increased in western and Sothern parts of the country. Increased Zn deficiencies in areas where low deficiency was reported earlier, developing over time due to intensification of agricultural systems inducing imbalance use of macronutrient, increasing Zn demand of new cultivars, altering Zn availability, and hastening depletion of readily-available soil Zn pools. Soil mining of Zn by agricultural crops should not be a concern except in those rare cases of extremely low total soil Zn content.

### *Mapping Fe Deficiency Status*

Indian soils are high in total and available iron content ranging from 4000-273000 mg $kg^{-1}$ and that of available iron 0.36-174 mg $kg^{-1}$ soil. Availability of Fe is low in alkaline soils, which make up approximately 30% of the earths. Many alkaline soils also have high bicarbonate concentration, which can inhibit Fe uptake. Generally acid and lateritic soils have high available iron content, sometime its level become toxic to many crops. Usually Fe deficiency is related to water stress condition in India. Results of the soil samples analysed from 371 districts of the country indicated that more than half of the districts are having Fe deficiency less than 5% **(Map 2)**. Only 12-15% districts come under high Fe deficiency status in states like, Maharashtra, Gujarat, Rajasthan, Haryana, Punjab, Madhya Pradesh and Tamil Nadu. Some pockets of Uttar Pradesh (Bareilly, Hamirpur, Banda, and Shahjahanpur), Bihar (Begusarai, Samastipur and Vaishali) and Andhra Pradesh (Anantapur, Kurnool and Prakasham) also have as high as 20-30% Fe deficiency. Fe availability is poor in soils of arid and semiarid regions, consequently its content is also low in forage and grains grown in these areas as compared to those grown in soils of humid and sub humid regions.

Though there is no strong relation existing between Fe availability in soil and occurrence of iron anaemia in human (particularly, adolescent girls and pregnant ladies) in various parts of the country. Prevalence of anaemia was



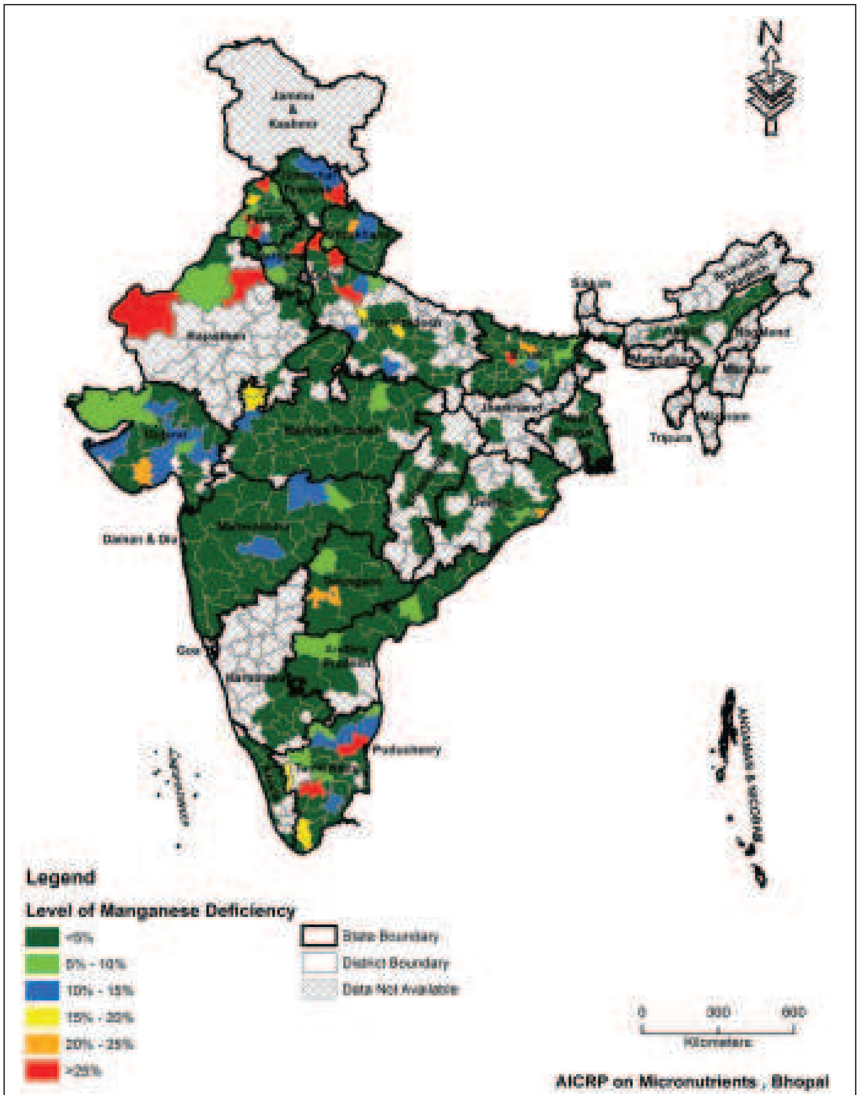

*Map 2 – Spatial variation in available Fe deficiency status in soils of different districts of India*

reported in 84.9% women in 16 districts in 11 states of India though the soils of these districts are not so poor in plant available iron (24). Prevalence of iron deficiency anaemia (IDA) is still reported wide spread in woman and children, as a major micronutrient disorder problem in several parts of the country (33). Severe iron anaemia was found in 34% in adolescent girls of Bikaner, Rajasthan and Gujarat (33). The indications are not so strong that areas having acidic and lateritic soils are less prone to iron deficiency disorder because a major part of iron absorbed by the rice plants remained in the leaf and is not translocated to the seed and further to human system. Prevalence of anaemia in women was noticed in 60-70% in Mandi, Dehradun, Kohima districts whereas 70-80% anaemic women in Lakhimpur Kheri, Badaun and Bishnupur (41).

### *Mapping Mn deficiency status*

Indian soils are adequate in Mn and its concentration varied from 37 to 11500 mg $kg^{-1}$ and available status 0.6-164 mg $kg^{-1}$ to support optimum crop growth (42). Of the soil samples analysed from 373 districts more than 75% are shown with less than 5 % Mn deficiency. Some districts in Punjab, Haryana, Tamil Nadu, Rajasthan and Uttar Pradesh shown with Mn deficiency more than 25% **(Map 3).** Manganese availability issue is predominant over soil Mn content for better crop yield, particularly on calcareous soils (48). Reduction of $Mn^{4+}$ form (plant unavailable form) to $Mn^{2+}$ (plant available form) is either biological or chemical in nature. Manganese deficiency is difficult to overcome by fertilisers as the added Mn is quickly converted to unavailable oxidized form (12). The Mn deficiency can be overcome by foliar application of 0.5-1% (w/v) $MnSO_4.H_2O$ solution, but it has to be applied repeatedly (3-4 times) and it may also prove less efficient under severe Mn deficiency conditions. In Punjab state of India, rice-wheat cropping system has exhausted most of the micronutrient reserves. Leaching losses of manganese (Mn) after rice cultivation is the primary factor of upcoming Mn deficiency in wheat that has imposed a threat on yield. Mn deficiency in soils ranges from negligible to as high as 67% in Bhatinda, Punjab. Prevalence of Mn deficiency in wheat grown in sandy soils of Punjab, Haryana and Uttar Pradesh is increasing due to leaching of soluble Mn to lower layers during submergence of rice in rice-wheat system (41, 24). The average Mn deficiency in this region has been reported to be 22%. Wheat grown in more than 3 lakh ha of coarse textured soils of Punjab showed high responses to Mn fertilization ranging from 200-2960 kg $ha^{-1}$. Foliar sprays of 0.5-1.0% manganese sulphate solution 2-3 times are found more efficient for ameliorating its deficiency in wheat than its broadcasting to soil (24). Jaisalmer and Churu in Rajasthan, Villupuram, Dindigul in Tamil Nadu, Ranga Reddy in Telangana, Badaun, Bijnor and Shahjahanpur in Uttar Pradesh, Rudra Prayag in Uttarakhand and Jagatsinghpur in Odisha are major Mn deficient districts, Mn deficiency varied from 25 to 67%. Sometimes, Mn toxicity is reported in crops grown on acid and lateritic soils (42).

In human, Manganese deficiency leads to glucose intolerance, blood dotting, skin problems, lowered cholesterol levels, skeleton




*Map 3 – Spatial variation in available Mn deficiency status in soils of different districts of India*

disorders, birth defects, changes of hair color and other neurological symptoms. Crops like wheat grown in Mn deficient soils or hidden hunger of Mn are not only produce low yields but lead to infertility in cattle due to low Mn content in fodders and grain. The evidence increased infertility were recorded in cattle fed with low Mn fodder grown in low Mn highly calcareous soils (free $CaCO_3$ 20-48%) around Pusa, Bihar (41). The productivity of these animals were low and their blood serum Mn concentration was also lower as compared to cattle fed on fodders grown in Mn adequate soils. Though least information is available regarding Mn deficiency in human however, such relationship need to be established so that consequences of emerging Mn deficiency on human could be addressed duly in time.

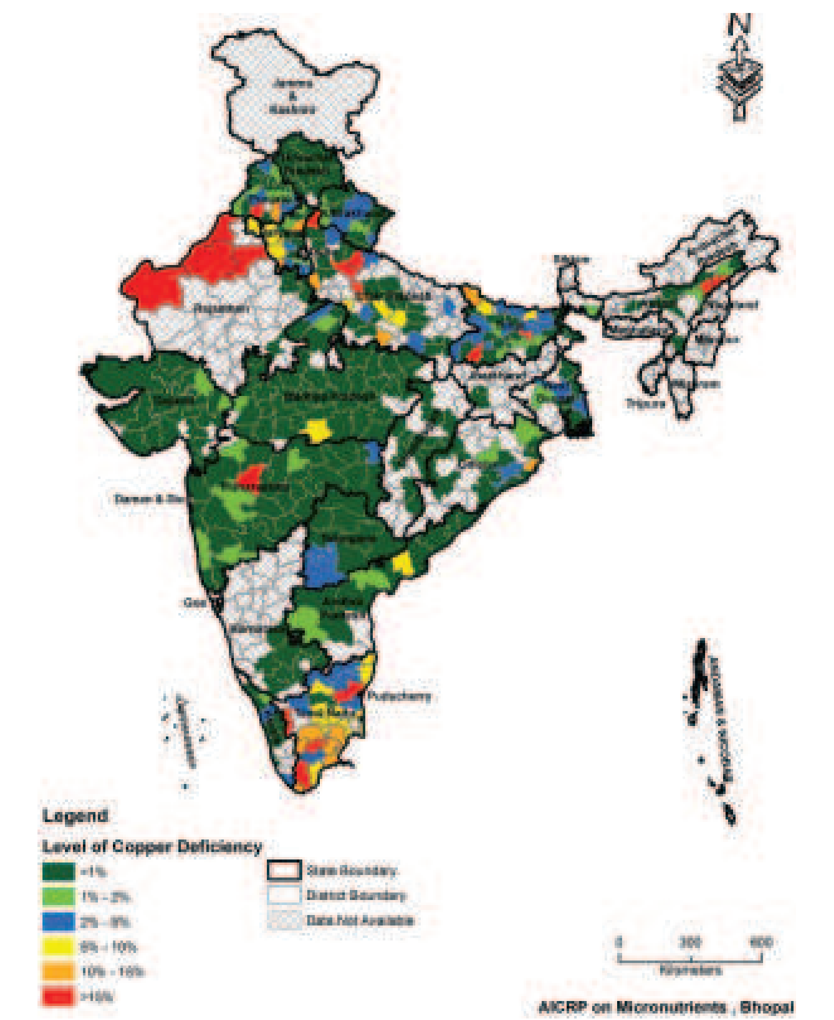
### *Mapping Cu Deficiency Status*

Total copper content in soil ranged from 1.8-960 mg $kg^{-1}$ and that of available content 0. 10 to 378 mg $kg^{-1}$ (38). Copper deficiency is not a severe problem in India, and only about 5-6 percent soils were found deficient in 97,000 georeferenced soil samples tested during 2009-14. Out of 379 districts, 246 districts have Cu deficiency less than 1%. Thus most of the soils do not respond to copper fertilization except peat and Mollisols soils having high organic matter contents. Crop management factors do affect copper concentration in the edible parts of plants. Copper toxicity is reported in copper mining areas and some acid soils. Continuous application of Cu based fertiliser and pesticides may accumulate excess Cu in plants. In some districts of Haryana (Karnal-10.80%, Mohindergarh-13.0%), Tamil Nadu (Kanyakumari-13.3%, Pudukkottai-11.7%, Ramanathapuram-11.6%, Sivagangai-13.7%, Theni-14.9%, Dindigul-12.2% and Tuticorin-14.10%), Uttar Pradesh (Kannauj-10.5%, Banda-11.0% and Mathura-13.0%) and one districts of Punjab (Sangrur-12%) Cu deficiency is increasing and it ranged from 10-15% **(Map 4)**.

The Cu deficiency was recorded highest in Tamil Nadu due to adoption of higher critical limit (0.60-1.20). Though the Cu content is usually higher in acid and laterite soils, however, one district each in Bihar (West Champaran-11.50%), Odisha (Kendrapara-12%) and two districts in Assam (Jorhat-18.5% and Sibsagar- 23.2%) were reported to have Cu deficiency of about 10-20%. Some districts like Arwal, Aurangabad and Khagaria in Bihar, Bikaner, Churu, Jaisalmer and Sri Ganganagar in Rajasthan; Coimbatore, Madurai, Thirunelveli, Villupuram in Tamil Nadu and Farrukhabad, Lakhimpur, Badaun, Shahjahanpur and Bareli in Uttar Pradesh showed Cu deficiency more than 25%. Hence, there is need to apply Cu fertilisers in these districts. In human, neutropenia and leucopoenia, skeletal defects and degradation of nervous system (28), defective melanin synthesis which manifests as depigmentation or hypopigmentation (lack of colour) of hair and skin, keratinization of hair, steely hair are sign of copper deficiency (11).

### *Mapping B Deficiency Status*

In soils, concentration of total B is reported to be in the range of 20 to




*Map 4 – Spatial variation in available Cu deficiency status in soils of different districts of India*

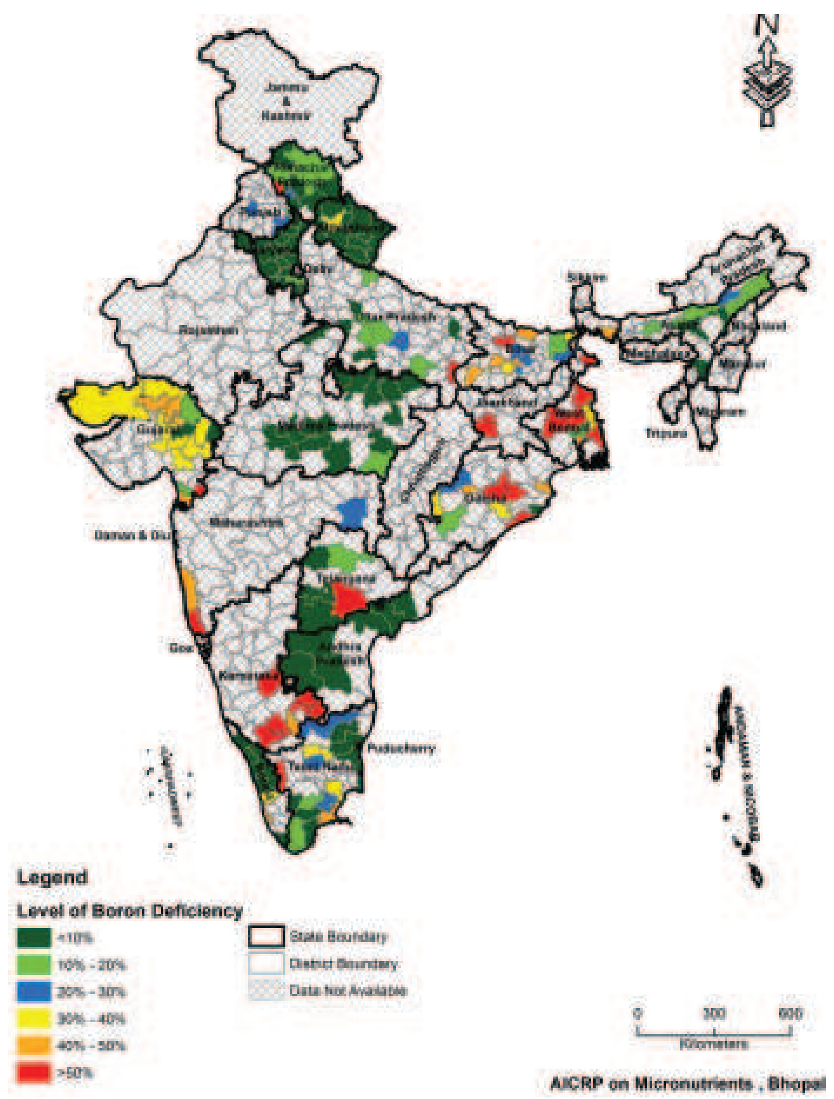
200 mg B $kg^{-1}$ soil (47), and its available concentrations also vary greatly from soil to soil. Boron deficiency is one of the major constraints to crop production, and has been reported in more than 80 countries and for 132 crops over the last 60 years (34). Boron deficiency has been realized as the second most important micronutrient constraint in crops after that of zinc (Zn) on global scale.

Out of about 74,000 soil samples analysed from 193 districts, 84 districts have B deficiency less than 10 %. About 35 districts fall in B deficiency range of 10-20% and 15 to 16 districts each comes in range of 20-30, 30-40 and 40-50% deficiency range (Map 5). Several soil factors and conditions render soils deficient in B. For example, low soil organic matter content, coarse/sandy texture, high pH, liming, drought, intensive cultivation and more nutrient uptake than application, and the use of fertilisers poor in micronutrients are considered to be the major factors associated with the occurrence of B deficiency (47, 29, 30, 23, 25). Parent material is considered a dominant factor affecting supply of B from the soil. In general, soils derived from igneous rocks, have much lower B concentrations than soils derived from sedimentary rocks (18). Soils derived from acid granite and other igneous rocks, fresh-water sedimentary deposits, and in coarse textured soils low in organic matter have been reported with low B concentrations (43). Indian soils are very poor in organic carbon and B deficiency is liked with low organic matter level in the fields. Upon mineralization from organic matter or B addition to soils through irrigation or fertilization, a proportion of it remains in the soil solution while left of it is adsorbed by soil particles and other soil constituents in insoluble forms. Soils of Jharkhand, Odisha, west Bengal, Karnataka and part of Bihar, Tamil Nadu and four districts in Gujarat are highly deficient (more than 50%) in Boron. Boron deficiency has been commonly reported in soils which are highly leached and/or developed from calcareous, alluvial and loess deposits (47, 5, 36, 37). However, calcareous part of the country does not exhibit boron deficiency in crops due to sufficient B in irrigated water. Underground water used for irrigation purpose has been reported to contain toxic amounts of B in many parts (Uttar Pradesh, Rajasthan, Haryana, Punjab, and Gujarat) (8) of India.

Boron deficiency has been reported to result considerable yield reduction not only in brassica-crucifers and pulses but also in cereals and oilseeds (32, 44, 40 38). Perennial citrus fruit orchards papaya, oil palm and coconut are most affected crops. Many researchers in past have estimated a substantial potential net economic benefit from the use of B fertilisers in B-deficient crops (3, 26, 1, 47, 13, 5).

### *Molybdenum*

Most of the Indian soils are adequate in molybdenum (Mo) but its deficiency was found in acidic, sandy and leached soils. The total Mo in Indian soils ranges between 0.1 to 12 mg $kg^{-1}$ and available from traces to 2.8 mg $kg^{-1}$ soil. Very small number of soils have been tested for Mo, mostly from the area where plants exhibiting Mo deficiency. Mo deficiency is highly localized in




*Map 5 – Spatial variation in available B deficiency status in soils of different districts of India*

some parts of MP, Maharashtra and acidic soils of Odisha and West Bengal, particularly where pulse crops are grown. In human, adequate Mo is said to prevent dental caries, mouth and gum disorders, oesophageal cancer, and sexual impotence in old people. Molybdenum deficiency is reported more in eastern high rainfall zone where soils are low in available Mo. In Northern parts of West Bengal, hair and hooves falling problem is reported widely in cattle due to low Mo in alluvial leached soils. Molybdenum is found in higher concentration in grain legumes. Molybdenum, toxicity in animals and humans is reported in some part of Punjab, which affects copper utilization in the body due Mo-Cu interaction (24).

The maps prepared for different micronutrients will improve our understanding and management of spatially variability in soil micronutrient availability in agricultural fields and pave way for precision nutrient management. Field maps showing the spatial distribution of soil micronutrients and other properties can be derived from intensive soil and/or plant sampling carried out along transects or in regular or irregular grids at intervals ranging from several to hundreds of meters.

Several studies have demonstrated spatial correlation in soil micronutrient contents in diverse environments at scales useful for precision agriculture (4, 27). When combined with georeferenced yield monitoring and sampling and analysis of crop micronutrient content, these methods have the potential to detect and delineate areas within fields where micronutrient deficiencies, toxicities, or imbalances limit crop yield or quality. Such problems might be remedied by site-specific variable rate application of micronutrients controlled by prescription maps derived from previous sampling, analysis, correlation, and experiment. The knowledge gained from this research will improve our understanding of the soil factors that affect micronutrient availability, and facilitate efforts to model availability as a function of measurable soil parameters such as total or extractable micronutrient content, CEC, pH, texture, and organic matter. These efforts to characterize the geographic distribution of soil micronutrient content and availability will provide quantitative support for decision and policy making to improve agricultural approaches to balanced micronutrient nutrition.

## Food and Nutritional Security Through Micronutrients

Agriculture provides the nutrients essential for human life. The reality of this is hidden when we use the less definitive term "food"; food may or may not provide all the necessary nutrients. We have produced adequate food but not attained the food security. In fact concept of food security is much different than availability of adequate food. Food security is situation that exist when all people, at all time, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preference for an active and healthy life (14). Whether present agriculture provide adequate amounts of foods containing enough nutrients in balance to meet human needs is a question mark. Thus, providing enough food does not necessarily mean that the food produced will supply enough of all the nutrients needed to support good health. This appears to be the case for the agricultural systems fostered during the 'green revolution'. Indian population is mostly fed upon rice and wheat cereals. While whole cereal grains provide enough carbohydrates (calorie) and protein to stave off famine, they do not provide enough of all the utilizable micronutrients needed to sustain life, being very low in bioavailable amount of micronutrients (especially Zn and Fe) compared to other staple food crops, like pulse. Health perspective has rarely been studied for many of the elements that are required for human health come from the soil through either plant or animal product elements may also be required directly through the consumption of soils. Micronutrients deficiencies is a growing concern in the India, resulting in low productivity and poor nutritional quality of produce, which in turn causing diverse health problems in human being, such as stunted growth in children, mental retardations, impairments of the immune system, rickets, osteoporosis, muscular dystrophy and overall poor health. Tackling micronutrient malnutrition in humans is the priority. To a question "If you had 75 billion dollars to improve the world, how would you best spend it?" a panel of ten distinguished economists of the world, who had met to ponder over urgent global challenges facing the world, raised at Copenhagen Consensus, 2008 unanimously answered, "Reduce micronutrient malnutrition". Problem of micronutrient malnutrition was categorically emphasized because more than half of the humanity - mostly the poor in developing countries - suffers from the devastating consequences of micronutrient malnutrition. No other problem of this magnitude is afflicting such a huge portion of the world population. According to WHO (2002), deficiencies of zinc and iron occupy 5th and 6th place, respectively among top ten leading causes of illness and diseases in low income countries (53).

Essential nutrients that end up in the human diet are supplied through food from either plants that took the elements up from the soil during growth or animal products often the animal obtained those essential elements from plants. Because plants depend on the soil for their nutritional needs, and all higher animals including human depend directly or indirectly on plants for their nutrition, plants from the bare of the food chain and, consequently, a major portion of the nutrients needed for human health originate with the soil. Emphasis in the article has been on linking these two elements to human nutrition while soil health has been dealt for all the micronutrients.

### *Contribution of Zn to Food Crop Production*

The proper Zn management contribute to major food grain crops is estimated 18.44 million tonnes (economic value of Rs. 21, 1619 million), which may further enhance to 24.85 million tonnes rice equivalent yield (economic value of Rs. 23, 2119 million) when sugarcane, cotton and potato are also provided with Zn fertilization **(Table 4)**. In recent years, Zn enrichment in food grains has also

**Table 4 – Contribution of Zn towards production of major crops in India**

| Sl. No. | Crops | Average response to Zn application (t $ha^{-1}$) | Area under crop(M ha) | Percentage are a receiving Zn | Contribution of Zn to crop production*(MT) | Economic gain due to Zn fertilisation** (Rs. in million) |
|---|---|---|---|---|---|---|
| 1. | Rice | 0.54 | 43.91 | 50 | 11.86 | 12,80,88 |
| 2. | Wheat | 0.42 | 28.04 | 30 | 3.53 | 39,536 |
| 3. | Maize | 0.47 | 8.12 | 35 | 1.33 | 13,034 |
| 4. | Sorghum | 0.36 | 7.76 | 10 | 0.28 | 2,744 |
| 5. | Pearl millet | 0.19 | 9.57 | 02 | 0.19 | 1,862 |
| 6. | Gram | 0.36 | 7.54 | 05 | 0.13 | 2,730 |
| 7. | Green gram | 0.26 | 3.10 | 05 | 0.04 | 1,400 |
| 8. | Black gram | 0.24 | 2.97 | 05 | 0.03 | 990 |
| 9. | Pigeon pea | 0.26 | 3.51 | 05 | 0.04 | 1,280 |
| 10. | Groundnut | 0.32 | 6.29 | 15 | 0.30 | 8,100 |
| 11. | Soybean | 0.36 | 8.88 | 20 | 0.64 | 10,560 |
| 12. | Mustard | 0.27 | 5.40 | 05 | 0.07 | 1,295 |
| **Major crops** | | | | | **18.44** | **21,16,19** |
| 13. | Cotton | 0.22 | 9.41 | 10 | 0.20 | 5,600 |
| 14. | Sugarcane | 3.77 | 5.05 | 20 | 3.81 | 5,300 |
| 15 | Potato | 2.96 | 1.80 | 45 | 2.40 | 9,600 |
| **Total** | | | | | **24.85** | **23,21,19** |

* Contribution of Zn to crop production was obtained by multiplying average response with area under crop and percentage area receiving Zn. Average response of each crop was calculated by averaging the responses obtained in thousands of experiments.
**Economic gain due to Zn fertilisation was estimated by multiplying contribution of Zn to crop production with minimum support price for each commodity for the year 2011. Wholesale price of Rs. 4.00/- per kilogram was considered for calculation in case of potato. Source : (36)

been realized a better option for maintaining animal and human health in addition to soils and plants.

### *Economic Well-being and Micronutrients Access*

Though the economic theory predicts that with increased income, individuals should be able to purchase more food and diversify their diets, especially with animal products, thereby improving their micronutrient status. But this does not appear to be the case. For example, in Asia the availability of iron in food has declined even though income (2) and the availability and intake of foods containing high amounts of energy (i.e., cereals) have risen significantly. At the same time, iron deficiency in women, infants, and children in resource-poor families has risen dramatically. Indeed, in South East Asia, iron deficiency now afflicts 98.2 % (over 1.4 billion) of the people in that region. Within the developing world, serious vitamin and trace element deficiencies persist and are not necessarily corrected by increased income within an acceptable period of time (2). Study conducted in India revealed that widespread deficiencies of Zn in Indian soils and crops, low Zn concentrations were found particularly in the diabetic and diabetic-ulcer patients than normal surgical patients without metabolic diseases, however, most of the diabetic patients were richer than normal population (33). Similarly, prevalence of anaemia particularly in women was reported across the country; although there is no strong relationship between iron availability in soil, economic status of people and occurrence of iron anaemia in some cases (41). The Zn deficiency in human population is widespread in India (7) however, economic well-being has improved in last decade. Though micronutrients are needed in small quantities (i.e., micrograms to milligrams per day), they have incredible impact on human health and well-being. Insufficient dietary intakes of these nutrients impair the functions of the brain, the immune and reproductive systems and energy metabolism. These deficiencies result in learning disabilities, reduced work capacity, serious illnesses, and death. Micronutrient malnutrition is a serious global affliction that limits the work capacity of people and seriously hinders economic development (2). Dysfunction of the food system from low micronutrient output is affecting more people every day, for examples global trends in iron deficiency anaemia, (9). Agricultural systems must increase micronutrient outputs as a primary tool to eliminate micronutrient malnutrition (10, 50). Finding sustainable solutions to this developing global nutrition crisis will not be possible without the cooperation of agriculture.

### Linking Soil Micronutrients and Human health

The foundation of human health is laid on the quality of food we eat, which relies ultimately on the vitality of the soil on which it is raised. Soils seriously deficient in minerals cannot produce plant life competent to maintain our needs and with the continuous cropping and shipping away of those concentrates the condition become worse. Nobel Prize winner, Dr. Alexis Carrel stated that minerals in the soil control the metabolism of plants, animals and man. Accordingly, life will be either healthy or unhealthy depending upon plant available nutrients in the soil. Soils without mineral nutrients cannot produce plants with minerals. Due to rampant deficiency of micronutrients in agricultural soils, food grown in these soils lack in the amount of nutrients needed to maintain human health. The food we consume has lost the nutrients we need for good health values in food over the past several decades. Most vegetables and fruits have lost substantial vitamin and mineral content during the last forty years. Our food system is rapidly losing its ability to produce food with nutrient levels suf-ficient to maintain health. Zinc deficiency is a well-recognized micronutrient deficiency problem both in human populations and in crop production globally (7). It is estimated that nearly half of the soils on which food crops are grown, are deficient in plant available Zn (41, 36), leading to reductions in crop production and also nutritional quality of the harvested grains (35, 37). Since cereal grains/seeds contain inherently very low amount of Zn, growing them on potentially Zn-deficient soils further decreases grain Zn concentrations. Since cereal-based foods Rice and wheat are the major source of daily calorie intake hence widespread occurrence of Zn deficiency reported in human populations in India. Studies conducted under All India Micronutrient Project in Nalgonda and Ranga Reddy districts in Andhra Pradesh indicated that soils having low zinc status produced plant, grains with lower zinc content. People feeding on such grains and other vegetation showed lower zinc content in their blood plasma compared to areas which had high available zinc status and lower zinc deficiency in soil (41). Severe iron anaemia was found in 34% in adolescent girls of Bikaner, Rajasthan and Gujarat (33). The concentration of Zn, Cu, Fe and Mn in drinking water and soil is correlated with dental caries in 1516 children (7 to 17 years age) in 10 rural areas in the district of Ludhiana (17). There is an urgent need to replenish the nutrient in top soil and increase the nutritional values of harvested food to sustain human health. Crops require minerals and organic materials to transform nutrients into forms that plants can use for growth. Without minerals and soil organic matter it is impossible to sustain a healthy crop which is the basis for the nutrition values of animals and human. Unless growers replenish nutrients, the mineral content of harvested food will continue to decrease. The decline in nutritional quality of food has been linked to

**Table 5 – Effect of micronutrients application on grain yield, grain Zn/Fe/Mn concentration of different groups of cultivars at different locations**

| Crops | Efficient Cultivars | | | | Inefficient Cultivars | | | |
|---|---|---|---|---|---|---|---|---|
| | Zinc (Zn) | | | | | | | |
| | Grain Yield ($t\ ha^{-1}$) | | Grain Zn ($mg\ kg^{-1}$) | | Grain Yield ($t\ ha^{-1}$) | | Grain Zn ($mg\ kg^{-1}$) | |
| | -Zn | +Zn | -Zn | +Zn | -Zn | +Zn | -Zn | +Zn |
| **1. IISS, Bhopal** | | | | | | | | |
| A. Pigeon pea | 1.41 | 1.54 | 32.6 | 43.8 | 1.06 | 1.41 | 35.1 | 48.2 |
| B. Wheat | 3.72 | 3.87 | 41.0 | 47.8 | 2.85 | 3.37 | 43.0 | 56.3 |
| **2. ANGRAU, Hyderabad** | | | | | | | | |
| A. Rice (dehusked) | 5.98 | 6.18 | 11.0 | 16.7 | 5.36 | 7.92 | 9.5 | 16.9 |
| B. Maize | 5.04 | 6.13 | 24.2 | 27.4 | 4.39 | 6.59 | 23.7 | 29.5 |
| **3. GBPUAT, Pantnagar** | | | | | | | | |
| A. Rice (dehusked) | 3.94 | 5.92 | 13.1 | 26.8 | 3.94 | 5.92 | 13.1 | 26.8 |
| B. Wheat | 3.71 | 3.95 | 20.3 | 43.1 | 3.26 | 4.23 | 15.1 | 43.8 |
| **Iron (Fe)** | | | | | | | | |
| | Grain Yield ($t\ ha^{-1}$) | | Grain Fe ($mg\ kg^{-1}$) | | Grain Yield ($t\ ha^{-1}$) | | Grain Fe ($mg\ kg^{-1}$) | |
| | -Fe | +Fe | -Fe | +Fe | -Fe | +Fe | -Fe | +Fe |
| **4. AAU, Anand** | | | | | | | | |
| A. Pigeon pea | 2.50 | 2.42 | 34.1 | 36.0 | 2.27 | 2.55 | 33.7 | 38.5 |
| B. Chickpea | 3.15 | 3.27 | 59.0 | 62.8 | 2.36 | 2.91 | 56.0 | 67.5 |
| **5. RAU, Pusa** | | | | | | | | |
| A. Rice (dehusked) | 5.04 | 15.6 | 21.4 | 81.7 | 2.99 | 4.06 | 13.8 | 24.3 |
| B. Maize | 5.19 | 5.55 | 46.8 | 66.2 | 5.22 | 6.22 | 41.3 | 63.2 |
| **Manganese (Mn)** | | | | | | | | |
| | Grain Yield ($t\ ha^{-1}$) | | Grain Mn ($mg\ kg^{-1}$) | | Grain Yield ($t\ ha^{-1}$) | | Grain Mn ($mg\ kg^{-1}$) | |
| | -Mn | +Mn | -Mn | +Mn | -Mn | +Mn | -Mn | +Mn |
| **6. PAU, Ludhiana** | | | | | | | | |
| A. Rice | 6.71 | 6.85 | 41.4 | 53.0 | 4.83 | 5.51 | 31.6 | 44.2 |
| B. Wheat | 5.02 | 5.45 | 25.0 | 33.1 | 4.24 | 5.20 | 19.9 | 30.2 |

soil degradation or the "mining" of soil fertility. Along with losing the ability to hold nutrients, the bio-availability of minerals for plant growth has been significantly decreased as a result of the accelerated withdrawal of minerals from the soil without corresponding additions has severely impacted on human health.

## Approaches to Ensure Nutritional Security

Both research and developmental issues related to malnutrition need to be addressed to attain the nutritional security of the people. There are several approaches like dietary diversification, mineral supplementation and food fortification may be helpful in combating micronutrients malnutrition. But, these programs have treated the symptoms of micronutrient malnutrition rather than the underlying causes. While many of these interventions have been successful in the short term for the individuals reached by them, they have proved to be unsustainable and incapable of reaching all the people affected. Indeed, they are least likely to reach those most at risk, namely resource-poor women, infants, and children that live in remote areas either far from a clinic or those who do not have ready access to processed and fortified foods. In spite of these interventions, the problem continues to increase.

To address micronutrient deficiencies in the comprehensive way, several approaches are needed simultaneously. The requisite agricultural research to correct these deficiencies will take some time to come on line even if funded in proportion to the magnitude of the problem. Therefore, all current interventions, where cost-effective, should be continued to treat as many people currently at risk as possible. The development of new food systems to deliver the required nutrients sustainably may be possible research solution to combat micronutrients deficiency in human by enriching the crops produce with micronutrients through biofortification (6). Therefore, even when socio-economic factors make it difficult to change the diet, the nutrient balance of cropping systems where cereals figure prominently can be improved. Our paper addresses this last question, as we consider it the most promising of the sustainable agricultural options that might be delivered in the shortest time.

**Strategies to Enhance Nutritional (Zn and Fe) Quality of Edible Plant Parts: Biofortification**

Enrichment of crops with micronutrients is the best option for elevating micronutrients concentration in food crops, especially in cereals. This can be achieved either by breeding crop cultivars that absorb and transmit more micronutrients to grains or by fertilising crops with micronutrients. Breeding crop cultivars for micronutrient enriched genotype is time taking process whereas fertilising crops with micronutrient is easy and convenient and it takes less time. Although the total concentrations of Fe, Zn and Cu in most soils are sufficient to support mineral-dense crops, the accumulation of these mineral elements is often limited by their phyto-availability and acquisition by plant roots. The concentrations of mineral elements in edible crops can be increased by the judicious application of mineral fertilisers and/or by cultivating genotypes with higher concentrations. The bioavailability of mineral elements can also be increased through crop husbandry, breeding or genetic manipulation (52). Biofortification focuses on enhanc-ing the mineral nutritional qualities of crops *at source,* which encompasses processes that increase both mineral levels and their bioavailability in the edible part of staple crops. The former can be achieved by agronomic intervention, plant breeding or genetic engineering, whereas only plant breeding and genetic engineering can influence mineral bioavailability.

**Genetic Biofortification**

Although Genetic biofortification is a powerful and sustainable strategy but it is long-term process requiring series of breeding activities and huge resources (16). Moreover, it is difficult to ascertain that cultivar developed after long time will be sustainable in soils further mined by that time. Most importantly, newly developed genotypes should be able to extract sufficiently large amounts of Zn/Fe from potentially deficient soils and accumulate it in whole grain at sufficient levels for human nutrition. The soils widespread in major cereal-growing regions have several adverse soil chemical factors that could potentially diminish the expression of high grain Zn/Fe trait and limit the capacity of newly developed (biofortified) cultivars to absorb adequate amount of Zn/Fe from soils to contribute to daily Zn/Fe requirement of human beings.

**Agronomic Manipulation**

Agronomic manipulation is an inexpensive and simple approach which can be utilized to enrich genetically inefficient cultivars by application of micronutrient fertilisers at different rates, methods and at different crop growth stages (38, 7). Fertiliser strategy could be a rapid solution to the problem and can be considered an important complementary approach to the on-going breeding programs. Fertiliser studies focusing specif-ically on increasing Zn concentration of grain (or other edible parts) are, however, very rare, although a large number of studies are available on the role of soil and foliar applied Zn fertilisers in correction of Zn deficiency and increasing plant growth and yield (31).

In India, through NAIP funded project on micronutrients enrichments, efforts have been made to identify genetically efficient cultivars of cereals and pulses for Zn and Fe to develop options for micronutrients biofortification. Genetically efficient and inefficient cultivars were identified based on Yield Efficiency and Uptake Efficiency Index. Interestingly, the genetically inefficient cultivars were agronomically highly efficient. Thus, the efficient cultivars could be utilized by breeders for QTL identification and developing high yielding micronutrient enriched cultivars (genetic biofortification) while the inefficient cultivars were for agronomic biofortification to dense the grains of highly responsive cultivars with micronutrients.

Application of micronutrient either through soil, foliar or both could increase yield as well as concentration **(Table 5)**. However, the variation in yield and concentration were driven by type of crop and genetic makeup of the cultivars (35). In case of efficient cultivars the application of micronutrient had little effect on yield but increase in Zn and Fe concentration was registered in all the crops. At Bhopal the Zn concentration in efficient cultivars of pigeon pea increased by 34% while it was 16.6% in case of wheat. Experiment conducted for Zn enrichment in rice and maize at Hyderabad showed that Zn application could increase 51.8% Zn concentration in rice grain and 13% in Maize. While at Pantnagar, increase in Zn concentration in rice grain and wheat grain was almost doubled in efficient cultivars. In case of inefficient cultivars both grain yield as well as micronutrient (Zn and Fe) concentration increased with the application of micronutrient.

This happens because the genetically inefficient cultivars are agronomically highly efficient and thus responded to external application of Zn. At Bhopal, application of Zn in inefficient cultivars enhanced the grain yield of pigeon pea by 33% while that of wheat by 18%. The increment in Zn concentration was more in case of pigeon pea (37.2%) than that of wheat (30.9%). Inefficient cultivars of rice grown at Hyderabad showed 47.8% increase in yield and 77.8% increase in Zn concentration. In case of maize, the increase in Zn concentration was less than the rice while grain yield enhanced by one and a half fold. The inefficient cultivars of rice grown at Pantnagar recorded 50% increase in yield and double increase in Zn concentration while in case of wheat, yield increased only upto 29.8% but concentration increased approximately three times.

Effect of Fe application on grain yield and Fe concentration in grain was studied in pigeon pea and gram at Anand, Gujarat and in rice and maize at PUSA, Bihar. Similar to Zn application, Fe could hardly influence the yield of efficient cultivars but it had significant effect on Fe concentration in grain. In efficient cultivars of pigeon pea and chickpea grown at Anand exhibited 10% and 6% increase in Fe concentration, respectively while in case of Fe inefficient cultivars, pigeon pea and chickpea yield had increased by 14% and 20%, respectively, and the density of Fe concentration in both the crops enhanced by 20%. At PUSA, seed loading with Fe enhanced by 37% and 46% in efficient cultivars of rice and maize, respectively. In case of inefficient cultivars, increase in grain yield of rice and maize were recorded 35.7% and 19% and concentration by 76% and 53%, respectively. The efficiency of micronutrients depends on right method, right rate and right time of application. There are different approaches to improve the micronutrient content of the edible part. One is to increase the efficiency of uptake and transport into edible tissue and second is to increase the amount of bioavailable micronutrient accumulation in the plant. Mn concentration enhanced by 28% and 39.8% in efficient and inefficient rice cultivars, respectively while in wheat this increase was recorded by 32 and 52 percent.

Strategies for micronutrients (Zn, Fe and Mn) enrichment in different crops were developed using several permutation and combinations of nutrient management options. The cultivars of different crops identified as efficient may be grown in soils low in specific micronutrients. Of the several strategies used, soil +3 foliar feeding has been identified as best option for grain enrichment with Zn, in soils having low Zn status. In adequate Zn soils, 2-3 foliar sprays are sufficient to increase grain Zn concentration in rice, wheat and pigeon pea. Foliar spray of K along with Zn was also an effective strategy for enhancing grain Zn concentration pigeon pea.

Among the Zn management strategies, soil plus foliar feeding was superior over foliar or soil application alone. Zn applied to previous crop also contributed significantly to grain yield and it was at par with treatment receiving soil Zn application in previous crop. In efficient group of cultivars the grain yield remains unaffected due to either of Zn management strategies. Grain Zn accumulation mechanism varied with efficiency of cultivars, its ability to translocate Zn from soil as well as from shoot to grain. The mechanism for increased root uptake in wheat may be related to proliferation of crown root growth, exudation of organic acids or phytosiderophores and increase tolerance to Zn deficiency. In low Zn soil, Zn application to soil is inevitable in order to mitigate Zn deficiency at early growth stage, while in excess Zn soil, foliar feeding is effective option in enhancing grain Zn concentration in Wheat **(Figure 3)**. Across the different Zn management options the highest grain yield was noted in cultivar UP2628 followed by UP 2382 and UP 262.

**Physiological Manipulation**

The physiological basis for micronutrient efficiency in crop plants plays a major role in controlling the accumulation of micronutrients in edible portions of seeds. There are several barriers

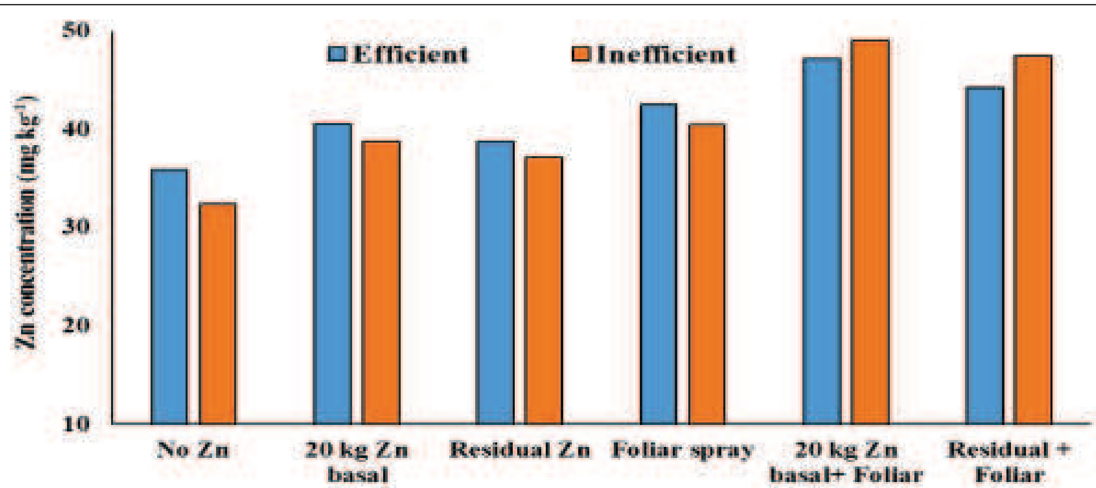



*Figure 3 – Response of different mode of Zn application on Zn concentration (mg kg$^{-1}$) of efficient and inefficient cultivars of wheat*

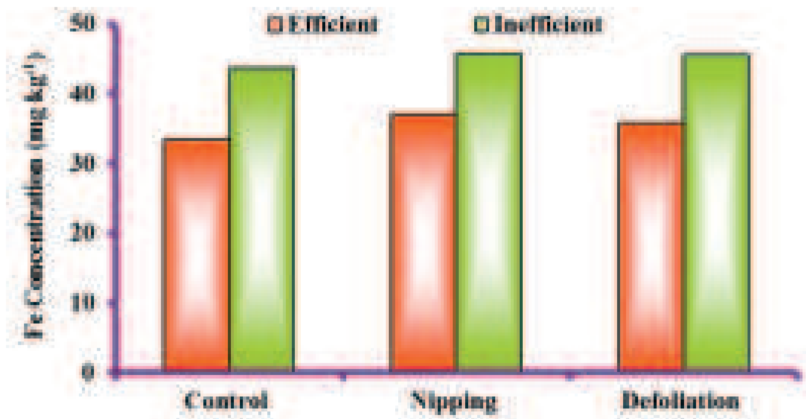


*Figure 4 – Effect of different Physiological interventions on the Fe concentration (ppm) of grains of Efficient and Inefficient varieties of Chickpea*

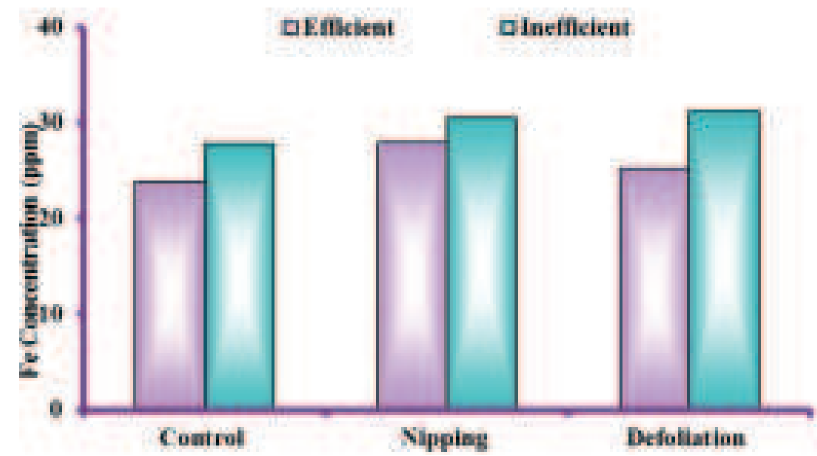


*Figure 5 – Effect of different Physiological interventions on the Fe concentration (ppm) of grains of Efficient and Inefficient varieties of Pigeon Pea*

to overcome in genetically modifying plants to accumulate more micronutrient metals (e.g. Fe and Zn) in edible tissues (49). It has also been recorded that nipping practice enhanced Fe concentration both in efficient and inefficient cultivars of chickpea and pigeon pea grown at Anand, Gujarat **(Figures 4 and 5)**. In chickpea, nipping of apical buds at grand growth stage but before flowering resulted in 11% increase in Fe concentration in grain of efficient cultivars (GG1 and GAG 735 ) while in inefficient cultivars (ICCC4 and GJG 305) this increase in grain Fe was only 5 per cent. Defoliation (25% of leaves) at pre-flowering stages could enhance the Fe concentration in grain by 7 and 4% respectively in efficient and inefficient cultivars. In case of pigeon pea, nipping and defoliation had greater response than that recorded in chickpea. The grain Fe concentration had increased by 17 and 5% in efficient (BDN-2 and PKV Trombay) cultivars after nipping and defoliation, while in inefficient cultivars (C-11 and AAUT 2007-08) the increase was reckoned by 10 and 12 percent, respectively.

**Micronutrients Enrichment *vs.* Antinutrients**

Application of micronutrients have not only influenced the micronutrients concentration in edible plant parts but also affected nutrients and antinutrients content, particularly phytate and methionine. Since Zn supply to crop improved the protein concentration in cereals, hence, methionine concentration also increased with Zn management. Zinc application has increased methionine level more in inefficient cultivars than that efficient cultivars. Although, phytate concentration and antinutrients also increased with application of micronutrients, however, phytate: Zn ratio decreased significantly due to excess Zn absorption in crops supplied with external Zn through soil and/ or foliar feeding. The phytic acid content in different wheat genotypes decreased with increasing levels of Zn with the lowest values obtained when nourished with 20 kg Zn $SO_4$ ha + foliar spray. The greater P uptake under reduced Zn supply or reduced P uptake with increased Zn nutrition may be absorbed between both the elements for the same site of absorption in roots. Due to enhanced grain Zn content with Zn application the phytate to Zn molar ratio exhibited a progressive reduction with increasing levels of zinc. The foliar feeding along with soil application is the best Zn management option to get lowest phytate: Zn ratio. Potassium fertilization along with Zn further enhanced Zn accumulation and thereby reduced phytate: Zn ratio in seed. Similar to wheat, methionine content in pigeon pea increased with increasing levels of Zn. The K fertilization along with Zn further enhanced the methionine content in grain. Due to sizable accumulation of Zn in grains, the phytate Zn ratio also reduced **(Figure 6)**.

**Bioassimilation of Enriched Cereal and Pulse Grains**

Once the grains are enriched with micronutrients (Zn/Fe) bioavailability was assessed using rat models. The results revealed that Zn intake was more from pigeon pea, wheat based diet and the from seeds of inefficient cultivars that contain high Zn. The excretion of Zn/Fe was also higher in rats fed with

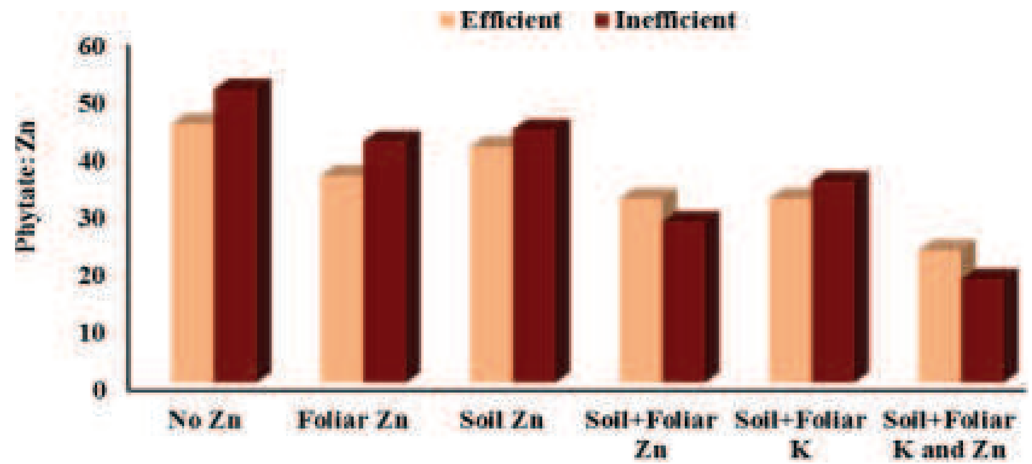



*Figure 6 – Effect of Zn and K management on methionine content in pigeon pea seed and phytate: Zn ratio*

Zn/Fe enriched grain due to excess intake but Zn/Fe supplied through enriched grain was bioavailable to animals as good as Zn/Fe supplied through standard sources. Fe/Zn concentration in different body parts of rats, liver, kidney and femur where comparable in all treatments but total absorption was high from wheat based diet because of its greater intake by rats. When rats were fed with Zn/Fe deficient diet, it had effect on kidney, liver and haemoglobin content.

The feed intake and total body weight gain of rats in wheat-based diets were significantly higher compared to standard diets; however, feed efficiency was not affected. The Zn intake of experimental rat was statistically similar but the excretion was significantly higher in wheat based diets rats. The daily Zn absorption in rats was however significantly higher with standard diet compared to wheat based diets **(Table 6)**. Exceptionally, the rats fed with high Zn wheat seeds showed similar absorption to that of standard diet during digestion trial (last 5 days).

Zinc concentration in the liver of animals on standard and experimental diets varied from 19.70 to 24.73 µg $g^{-1}$ **(Table 7)**. The concentration of Zn in the liver of rats fed with standard diet was significantly higher compared to wheat based diets. The zinc content in kidney (µg $g^{-1}$) was significantly higher in standard diet followed by low Zn, high Zn (inefficient) and high Zn (efficient cultivars). Feeding of rat with high Zn wheat (inefficient) based diet had similar effect to that of standard sources with standard diet. Thus, it was inferred that Zn absorption in liver, kidney, and femur bone of rats from wheat based diet (enriched grain) was as good as Zn supplied through standard sources. It indicates that the enriched Zn in wheat grain was easily bioavailable to rats. The rats consumed more food when Zn was supplied through wheat based diet and accordingly there was more gain in their body weight. Similarly, Zn intake was more when Zn was supplied through wheat based diet and the highest intake was recorded with treatment supplied with high Zn wheat grain through inefficient wheat cultivar. Zinc content in different body parts, liver, kidney and femur were comparable in all the treatment but total absorption was high in wheat based diet because of greater intake of food by rats when fed with wheat based diet.

In similar study on bioavailability of Fe in rat, Fe intake by the rats from different

**Table 6 – Apparent absorption of Zn in rats fed with wheat based experimental diets during digestion trial (last 5 days)**

| Diet | Zinc intake (µg $d^{-1}$) | Zinc excretion (µg $d^{-1}$) | Absorption (µg $d^{-1}$) |
|---|---|---|---|
| Zn through standard source | 689.21±43.3 | $260.33^{a}$±16.1 | $428.88^{b}$±28.1 |
| Zn through enriched wheat grain | 827.46±48.1 | $349.05^{b}$±32.4 | $478.41^{ab}$±19.4 |

$^{ab}$Means with different superscripts in columns for a parameter differ significantly (P<0.05)

**Table 7 – Zn content in Liver, kidney and femur (µg $g^{-1}$) of experimental animals fed with Zn enriched wheat grain**

| Diet | Liver | Kidney | Femur |
|---|---|---|---|
| Zn through standard source | 24.73±0.77 | $30.05^{c}$±0.60 | 94.27±2.19 |
| Zn through enriched wheat grain | 25.22±0.64 | $30.70^{ab}$±0.65 | 94.13±7.92 |

$^{ab}$Means with different superscripts in columns for a parameter differ significantly (P<0.05)

**Table 8 – Apparent absorption ($\mu g\ d^{-1}$) of iron in rats fed with pigeon pea based experimental diets**

| Diet | Iron intake | Iron excretion | Absorption |
|---|---|---|---|
| Fe through standard source | 752.99±39.89 | 336.85$^{a}$±20.36 | 416.15$^{c}$±26.24 |
| Fe through enriched pigeon pea grain | 748.14±30.20 | 401.04$^{ab}$±36.97 | 347.09$^{bc}$±29.21 |

$^{ab}$Means with different superscripts in columns for a parameter differ significantly (P<0.05)

**Table 9 – Fe content in Liver, kidney and femur ($\mu g\ g^{-1}$) of experimental animals fed with Zn enriched wheat grain**

| Diet | Liver | Kidney | Femur |
|---|---|---|---|
| Fe through standard source | 57.60$^{b}$±1.14 | 34.52$^{b}$±1.29 | 99.95$^{b}$±1.82 |
| Fe through enriched pigeon pea grain | 57.59$^{b}$±0.85 | 29.77$^{a}$±1.05 | 92.56$^{a}$±0.94 |

$^{ab}$Means with different superscripts in columns for a parameter differ significantly (P<0.05)

diets varied from 702.90±32.72 to 795.09±46.61 $\mu g\ day^{-1}$ **(Table 8)**. The Fe supplied through pigeon pea efficient cultivars based diet was also absorbed in adequate amount and it was statistically at par with standard diet. The absorption of Fe was inferior when supplied through low Fe seed or through enriched pigeon pea seed (inefficient cultivars) based diet. However, when rats were fed with enriched, pigeon pea seeds (efficient cultivars) the bioavailability of Fe was as good as rat fed with standard purified diet with $FeSO_4$.

In general, accumulation of Fe in liver, kidney, and femur was higher in rats fed with standard purified diets as compared to pigeon pea based diet. However, absorption of Fe from pigeon pea based diet was either comparable to standard purified diets or little inferior than standard diet **(Table 9)**.

## CONCLUSION

Soils improve human health through the nutrients taken up by plants and animals that eat those plants; nutrients that are needed for adequate nutrition as humans consume the plants or animals. Soils also act to harm human health if toxic substance or disease causing organisms enter the human chain from soil or by direct contact with the soil or inhalation of dust from the soil. Therefore, soils from an integral link in the holistic view of health.

If predictive models of micronutrient availability can be developed, they could be used as algorithms in GIS to combine appropriate map layers of model parameters to synthesize maps illustrating micronutrient availability across individual fields. Health will deteriorate, livelihoods will diminish, national morbidity and mortality rates will rise, development will stagnate or decline, discontent and civil unrest will swell, political upheaval will ensue and human suffering will dramatically increase. Insufficient output of even one essential nutrient over a long time will produce these dire consequences. Therefore, it is imperative that the world's agricultural institutions understand that the nutritional health of humans globally is largely dependent on the nutrient outputs that agricultural systems produce. In past, agricultural institutions have not viewed themselves as suppliers of nutrients with an explicit goal to improving human nutrition and health. Such a view must be reached if we are to reduce malnutrition around the world, and prevent much human suffering resulting from the ever increasing demand on our food systems for nutrient resources brought on by the increasing population pressure.

Allocation of funds for agricultural research must take into account the balance of food items that can optimally satisfy nutrient and energy requirements. Research must be devoted to the yield-improvement of nutrient-rich crops (e.g., legumes) that may have declined in production as a consequence of their being out competed by improved cereal cultivars. Finally, attention must be given to increasing the micronutrient density of the major staple food crops in order to help redress the decline in mineral and vitamin intakes. Results outlined in this paper show it is possible to shift the nutrient balance of cereals, and diets dominated by cereals, in the direction of better balance. Finally, attention must be given to increasing the micronutrient density of the major staple food crops in order to help redress the decline in mineral and vitamin intakes. The development of new fertiliser strategies to deliver the required nutrients in food systems sustainably, are needed to address the micronutrients problem in soil-plant animal/ human continuum.

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