Indian J. Fert., Vol. 11 (5), pp.16-27 (12 pages)

Status of Micronutrient Deficiencies in Soils of Haryana
Impact on Crop Productivity and Human Health

Arvind K. Shukla[1], R. S. Malik[2], Pankaj K. Tiwari[1], Chandra Prakash[1], Sanjib K. Behera[1], Harendra Yadav[2] and R. P. Narwal[2]

1. AICRP on Micronutrients, ICAR–Indian Institute of Soil Science, Bhopal
2. Chaudhary Charan Singh Haryana Agricultural University, Hisar

Corresponding author : pankajkumar 2311@gmail.com

Micronutrient deficiency is major constraints in crop production as well as crop quality. The deficiency of micronutrients in soils leads to lower micronutrient content in edible plant parts and thereby causing a health problem in animal and human beings. Level of micronutrients in soils is determined by geologic substrate and subsequent geochemical and pedogenic processes. However, their availability depends on soil pH, organic carbon content and absorptive surface like $CaCO_3$ and clay content and other physical, chemical and biological conditions of the rhizosphere. The analysis of 5673 soil samples collected across the Haryana state showed a wide variability in status of available micronutrient deficiency in soils. The current status of Zn, Fe, Mn, Cu and B varied from 1.11 to 36.5, 0.0-55.0, 0.0-48.6, 0.0-13.0 and 0.0-13.7%, respectively with an average deficiency of 15.3, 21.6, 6.1 5.2 and 3.3 %. Compared to micronutrient deficiency estimated in previous years, Zn deficiency has declined due to regular use of zinc sulphate however, deficiency of Fe and Mn has increased significantly. Areas with multiple micronutrient deficiency is limited, thus standard fertilisers are sufficient to mitigate specific micronutrient deficiencies in specific areas. Depending upon the crop, status of micronutrient deficiencies and their supplementation, positive response by almost all the crops to external application corroborated with the micronutrients deficiency status in soils. The strong linkage between soil and plant micronutrients with animal and human health was evident from the studies conducted. However, in order to address micronutrient deficiency in animal and human being, new strategies responsible for higher loading of micronutrients in crop need to be developed.

INTRODUCTION

Haryana, one of the agriculturally important states of India contributes about 7% to the national food grain production with only about 1.33% of geographical area. Multiple cropping with two or more cereals or four to five vegetable crops are being cultivated, if moisture is not a limiting factor (13). Soils of Haryana are one the most important arable soil types in North India, improving their productivity is considered to be an effective means of ensuring national food security. Besides soils being deficient in primary nutrients, crops grown in most soils suffer from deficiencies of one or more micronutrients, even though the soils often contain apparently adequate total amounts of the micronutrients.

The status of any nutrient in soils indicates its nutrient supplying capability to the crops growing on it. When seen along with crop demand, this is the major determinant for external nutrient input. Only a fraction of the total nutrient present in the soil exists in readily or potentially available form and, therefore a knowledge of available nutrient status of soils is very valuable in planning fertilisation of agriculture, it serves as an indicator of soil fertility and thus overall fertility status of a soil has to be assessed for each nutrient separately. Until now, micronutrients have mostly been addressed as one of the soil problems but micronutrient deficiencies and complexities have now been observed abundantly in crops produced from micronutrient deficient soils and these in turn produce nutrient deficient foods and fodder. Human and animals depending on such foods have also shown mineral deficiency symptoms (21).

The nature and extent of micronutrient deficiencies vary with soil type, crop genotype, management and agro-ecological situations. With the intensive cropping of high yielding varieties of rice and wheat in the state, deficiency of zinc (Zn) initially, and subsequently deficiencies of iron (Fe) in rice and manganese (Mn) in wheat emerged as threats to sustaining high levels of foodgrain production (23). Micronutrient deficiencies are now frequently observed in intensively cultivated areas of the state where cereals, oilseeds, pulses and vegetable crops are grown. Due to widespread and regular application of Zn fertilisers, the occurrence of Zn deficiency has declined in recent years, but multiple-micronutrient deficiencies may become a problem in future, if not addressed properly (4, 13, 21). In order to tackle the problems of micro- and secondary nutrient deficiencies in the Haryana state, the Indian Council of Agricultural Research (ICAR) formulated an All India Coordinated Scheme of Micronutrients in 1967 at Hisar. Since then, the centre is working on emerging issues on micro- and secondary nutrient problems and the amelioration measures in the state.

In order to apply nutrient based on soil fertility, it is necessary to know the location specific variability in nutrient supply to overcome the mismatch of fertiliser rates and crop nutrient demand. The distribution of available micronutrients including multiple micro-nutrient deficiencies is immensely needed to understand and establish link between soil and available micronutrients and animal-human health. In animal nutrition, Zn an essential micronutrient, and positive relationships between soil Zn contents or availability, Zn contents of forage and fodders, and animal Zn status have been clearly established. In many of these studies in animal nutrition, direct linkages between low soil micronutrient contents and low nutrient contents of forage and fodders have been clearly established. A typical example is a study in Haryana, India, where low levels of Zn in buffalo milk could be directly linked to low Zn levels in local soils and in fodder produced on these soils (27). In this paper, efforts had been made to assess available micronutrient status in Haryana soils and its mapping in different categories which would be helpful in devising management decision for better crop production and human health. During the current study, the spatial variability of plant accessible micronutrients *viz*., Zn, Fe, Mn, Cu and B were investigated using geostatistical tools and geographical information system to create nutrient maps and provide useful information for the application of inputs as per soil status and crop demand.

Soil Sampling, Analysis and Preparation of Deficiency Maps

A total of 5,673 surface soil samples (0-15 cm depth) covering all the *talukas* and districts of the state were collected by adopting the standard procedures of soil sample collection during the year 2009-2014, immediately after harvest of predominant rice crop. The sampling size varied with the size of the district, cropped area and cropping intensity from all 21 districts of the state, i.e., Ambala (86), Bhiwani (551), Faridabad (95), Fatehabad (464), Gurgaon (116), Hisar (607), Jhajjar (95), Jind (440), Kaithal (385), Karnal (362), Kurukshetra (396), Mewat (94), Mahendragarh (347), Palwal (249), Panchkula (76), Panipat (326), Rewari (90), Rohtak (142), Sirsa (510), Sonipat (140) and Yamuna-nagar (102).

The soil samples were analysed for micronutrients (Zn, Fe, Mn, Cu and B) by adopting standard procedures for soil analysis. Analysis of Zn, Fe Mn, and Cu was performed using Diethylene Triamine Penta Acetic Acid (0.005 DTPA+0.1 M Triethanolamine and 0.01M Ca Cl_2 solution buffer) as outlined by Lindsay and Norwell (1978) while hot water soluble B was analysed suggested by Berger and Truog (1939). The Soil micronutrient maps were prepared using kriging (geostatistics techniques) method in ArcGIS. Descriptive statistical analysis was carried out first to determine the mean, maximum, minimum, standard deviation and coefficient of variation of the variables of data. Critical limits used for the study were 0.60 mg DTPA-extractable Zn kg^{-1} soil, 4.50 mg DTPA-extractable Fe kg^{-1} soil, 0.20 mg DTPA-extractable Cu kg^{-1} soil, 2.50 mg DTPA-extractable Mn kg^{-1} soil and 0.50 mg hot water-soluble B kg^{-1} soil.

MICRONUTRIENTS STATUS OF SOILS OF HARYANA

A. Delineation and Mapping of Micronutrients Deficiency

1. DTPA-extractable zinc and iron

Zinc soil fertility is a good index of Zn content in fodder and grain as significant correlation is found between available Zn content of soils and Zn content in grain even under farmers' fields. The critical limits of Zn used for this study was 0.6 mg Zn kg^{-1}soil however it varies with soil and crop type. For clear prediction of possible deficiencies, the critical limit has to be refined with reference to the soil characteristics and plant parts for individual crops as the soils and crops vary widely in their nutrient supplying and utilization efficiency. Zinc deficiency in crops is the common micronutrient problem world over. Therefore, Zn malnutrition has become a major health burden among the resource poor people (21).

Systematic survey and analysis of 5,673 soil samples analysed under the aegis of AICRP-MSPE indicated deficiency of Zn to the extent of 15.3%, however, it varies across soil types, agro-ecological zones and more importantly management and productivity of crops and cropping systems. The deficiency of Zn in Haryana is much lower than the national average of 40%. The reason for declining Zn deficiency in Haryana is inadvertent use of zinc sulphate. The zinc sulphate consumption in the state is reported to be 14,651 tonnes making it third largest zinc sulphate user state after Punjab and Andhra Pradesh (3). The Zn deficiency was reported to be less than five percent in Ambala, Faridabad, Kaithal, Kurukshetra, Panchkula, Rewari and Sonipat **(Table 1)**. In the soils of Hisar, Fatehabad, Karnal, Rohtak, Jind, Palwal districts, the Zn deficiency ranged from 5-15%. Interestingly, out of 102 soil samples collected in Yamunanagar, not even a single sample was found to be in Zn deficient category. In terms of quantitative availability of Zn in soils of state, it ranged from 0.08 to 42.07 mg kg^{-1} soil. Among the 21 districts, the highest Zn deficiency was recorded in Bhiwani and Mahendragarh districts (more than 36%).

In Indian soils, Fe is another limiting micronutrient for crops as plant Fe deficiency is known to occur since long in many parts of the country. In most soils, Fe is present in large quantities as it constitutes about 3-5% of soil, making it fourth most abundant element in the crust, after oxygen, silicon and aluminium. However, most of the Fe in soils is unavailable for plant absorption (10). For example, Fe deficiency is common in calcareous soils (which have high pH), because its availability to plant decreases with increasing pH. On the other hand, Fe availability is generally high in acid soils, moreover, Cu, Zn, Mn and phosphate ions are Fe antagonists and their higher level in soils reduces Fe uptake by plants.

Metabolically, Fe is essential for chlorophyll and protein formation, photosynthesis, electron transfer, oxidation and reduction of nitrates and sulphates and other enzyme activities. Its deficiency causes interveinal chlorosis in newly emerging young leaves due to reduced chlorophyll synthesis resulting in poor growth and loss in yield (11). Among crops, Fe deficiency is frequently noticed in sugarcane and upland rice, pulses and horticultural crops. The deficiency of Fe is further aggravated under excess of carbonate and bicarbonate ions, ionic imbalances, higher pH and low water potential.

The Fe status in soils of Haryana state has been a cause of concern for the stakeholders since last decade. On average, 22% soils are deficient in available Fe, however, it ranges from 0.12 to 81.43% and districts like Mahendragarh (55.04%), Hisar (48.27%), Fatehabad (46.12%), Sirsa (38.24%), Bhiwani (29.22%) and Rohtak (26.06%) have been most affected **(Table 1)**. Of the 21 districts, soils of Ambala, Faridabad, Gurgaon and Sonipat did not show Fe deficiency. Soil samples collected from Yamunanagar, Rewari, Panipat, Panchkula, Mewat, Kaithal and Kurukshetra exhibited Fe deficiency to the tune of 1 to 2.50% only.

2. *DTPA-extractable manganese and copper*

The parent material, geomorphic, physico-chemical, biological processes of soil control the total Mn content as well as its distribution in different forms in soils and its supply to crops grown on it. Although total manganese is present in large amount in most of the soils, its availability becomes a problem in sandy loam soils which frequently undergoes wetting and drying. In India, the deficiency of Mn has been observed in light textured and calcareous soils (8). If the soil is alkaline, the availability of Mn becomes a constraint as its availability is low at high pH (19, 22).Widespread deficiency of

Table 1 – Available zinc and iron status (DTPA-extractable) in soils of different districts of Haryana

District	DTPA-Zn			DTPA-Fe		
	Range	Mean±SE	PSD	Range	Mean±SE	PSD
Ambala	0.32-9.60	3.34±0.25	3.49	4.82-23.56	16.29±0.43	0.00
Bhiwani	0.13-6.44	0.94±0.03	36.48	1.66-23.74	6.99±0.16	29.22
Faridabad	0.28-7.32	2.29±0.16	5.26	7.01-33.40	17.51±0.69	0.00
Fatehabad	0.14-6.83	1.63±0.05	13.79	0.69-30.24	7.11±0.26	46.12
Gurgaon	0.32-3.82	1.51±0.07	18.10	4.95-34.28	9.35±0.50	0.00
Hisar	0.08-5.54	1.62±0.04	14.99	0.68-33.00	6.68±0.24	48.27
Jhajjar	0.10-3.88	1.23±0.07	15.79	1.20-57.80	15.60±1.33	14.74
Jind	0.09-5.12	1.65±0.05	8.86	0.12-40.09	18.86±0.51	9.32
Kaithal	0.35-25.28	2.80±0.13	4.94	0.44-42.61	22.79±0.35	1.30
Karnal	0.34-5.55	1.74±0.07	14.36	2.25-21.48	12.92±0.27	7.73
Kurukshetra	0.20-4.11	1.90±0.04	3.03	2.34-24.62	14.13±0.21	1.77
Mewat	0.42-2.86	1.21±0.05	10.64	4.44-32.32	10.61±0.59	1.06
Mahendragarh	0.20-4.00	0.95±0.03	36.02	1.14-16.32	4.68±0.11	55.04
Palwal	0.14-42.07	2.29±0.30	6.43	2.26-44.70	14.97±0.74	10.04
Panchkula	0.36-6.97	2.76±0.17	1.32	3.58-44.30	26.46±1.28	1.32
Panipat	0.31-6.81	1.21±0.06	26.38	2.06-43.48	15.22±0.47	2.45
Rewari	0.46-6.77	2.09±0.12	1.11	4.35-21.36	9.76±0.43	2.22
Rohtak	0.30-5.61	1.32±0.08	14.08	1.34-81.43	11.83±0.83	26.06
Sirsa	0.18-6.93	1.77±0.05	16.47	0.62-30.02	8.43±0.28	38.24
Sonipat	0.44-4.26	1.99±0.09	2.86	4.80-36.30	15.88±0.48	0.00
Yamuna nagar	0.92-8.00	2.55±0.14	0.00	1.78-52.26	31.06±1.12	1.96
Haryana	**0.08-42.07**	**1.70±0.02**	**15.30**	**0.12-81.43**	**12.29±0.12**	**21.60**

manganese (Mn) has been reported in arid and semi-arid soils (15, 25). Manganese is a main constraint for sustainable wheat production in coarse textured soils, low in organic matter content, with high calcium carbonate content and high pH. A wide spread deficiency of Mn in wheat and berseem was reported in the northwest India in the early 1980s when farmers adopted a rice-wheat cropping system on the soils, which were coarse in texture and low in organic matter (20). Status and distribution of DTPA extractable Zn and Fe in districts of Haryana are given in **Map 1** and **Map 2**.

The data given in **Table 2** revealed that DTPA-Mn in the surface soils of Haryana varied from 0.15- 48.10 mg Mn kg^{-1}soil with an overall deficiency of 6.10%. The deficiency of Mn was found to be 48.62, 10.05, 9.27 and 6.53% in the districts of Karnal, Hisar, Fatehabad and Bhiwani, respectively. However, most of the districts *viz.* Jind, Rohtak, Palwal, Panipat, Ambala, Faridabad, Gurgaon, Jhajjar, Kaithal, Mewat, Mahendragarh, Panchkula, Sonipat and Yamuna nagar did not have problem of Mn deficiency in soils (<1.0%).

After Zn and Fe, problem of Cu deficiency in soils of the state is coming up to an alarming situation. Soils with high organic matter favour complexation of Cu with organic substances, thus, could result in Cu deficiency in plants. Though Haryana soils are very poor in organic matter but Cu deficiency has been observed. Deficiency of Cu negatively impacts grain, seed, and fruit formation (depending on the crop) to a greater degree than its effect on the vegetative growth. The Cu deficiency in Haryana is generally attributed to high pH and calcareousness of soils (1).

The DTPA-extractable Cu in soils of Haryana ranged from 0.04 to 21.22 mg kg^{-1} soil and overall deficiency was observed to be 5.20%. However, deficiency of Cu in soils of Mahendragarh (12.97%), Bhiwani (9.26%), Fatehabad (9.05%), Hisar (8.24%), Karnal (8.01%) and Sirsa (5.69%) districts has been observed to be more than 5% **(Table 2)**.

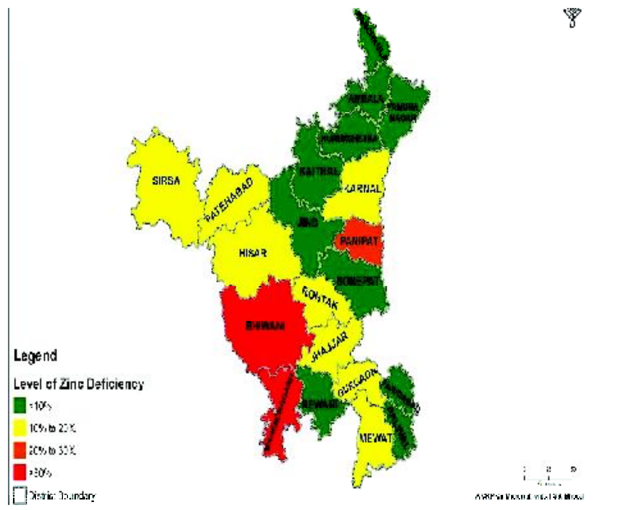
Status and distribution of DTPA extractable Mn and Cu in districts of Haryana have been shown in **Map 3 and Map 4**.

3. Hot Water Soluble Boron

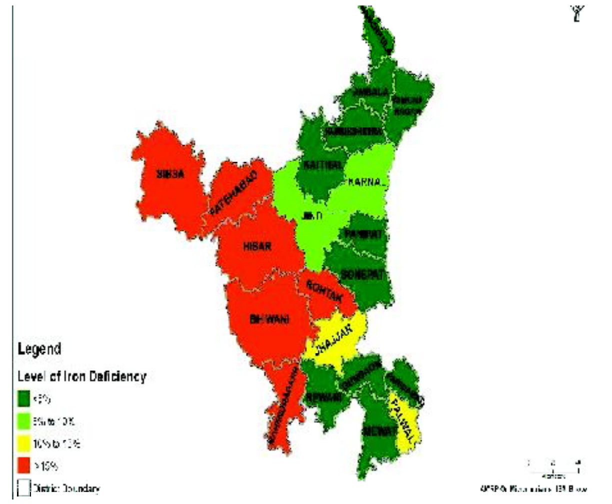
Boron (B) is a unique non-metal micronutrient required for normal growth and development of plants. It is mobile in soils and more often gets leached down the soil profile with excess moisture. Its availability is low in alkaline-calcareous soils due to its precipitation with $CaCO_3$. Soil concentration range between B deficiency and toxicity is quite narrow. Boron concentration and its bioavailability in soils is affected by several factors including parent material, texture, nature of clay minerals, pH, liming, organic matter content, sources of irrigation, inter-relationship with other element and environmental conditions like moderate to heavy rainfall, dry weather and high light intensity (12). Therefore, knowledge of these factors affecting B uptake is essential for the assessment of B deficiency and toxicity under different conditions. Upon

Table 2 – Available manganese and copper status (DTPA-extractable) in soils of different districts of Haryana

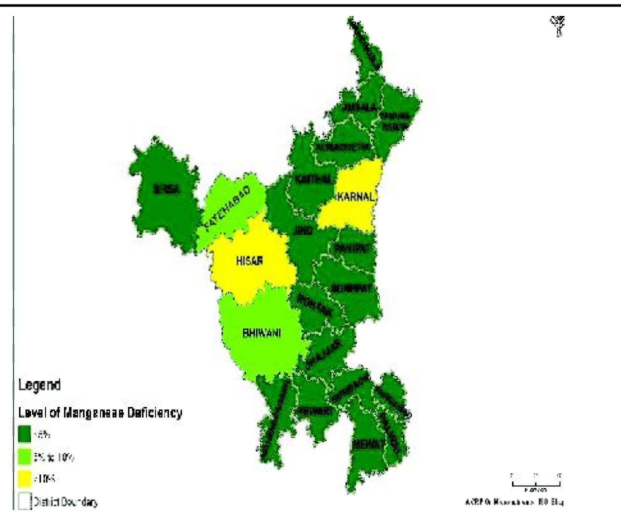
District	DTPA-Mn			DTPA-Cu		
	Range	Mean±SE	PSD	Range	Mean±SE	PSD
Ambala	3.97-19.61	13.74±0.42	0.00	0.13-6.28	1.99±0.11	1.16
Bhiwani	0.49-18.00	9.48±0.20	6.53	0.12-3.52	0.64±0.02	9.26
Faridabad	8.21-19.53	15.62±0.18	0.00	0.16-6.93	1.46±0.13	1.05
Fatehabad	0.74-15.24	5.51±0.13	9.27	0.08-21.22	2.43±0.21	9.05
Gurgaon	4.67-21.47	11.96±0.31	0.00	0.20-3.30	0.62±0.04	1.72
Hisar	0.37-34.86	9.10±0.31	10.05	0.08-6.94	1.09±0.04	8.24
Jhajjar	5.94-48.10	19.68±0.82	0.00	0.27-3.02	1.20±0.07	0.00
Jind	3.42-22.39	14.62±0.27	0.91	0.21-10.83	2.39±0.08	0.00
Kaithal	6.40-18.95	16.48±0.09	0.00	0.05-17.26	3.86±0.12	1.56
Karnal	0.15-17.48	4.97±0.28	48.62	0.04-4.28	1.27±0.07	8.01
Kurukshetra	1.96-17.66	9.53±0.20	1.01	0.36-5.15	1.72±0.04	0.00
Mewat	2.80-26.56	16.76±0.53	0.00	0.12-1.90	0.80±0.04	4.26
Mahendragarh	2.75-14.40	8.34±0.14	0.00	0.09-2.52	0.54±0.02	12.97
Palwal	2.48-48.00	9.14±0.35	0.40	0.08-12.63	1.50±0.10	4.82
Panchkula	6.31-23.26	14.50±0.44	0.00	0.24-4.06	1.24±0.09	0.00
Panipat	2.31-23.36	8.85±0.32	0.31	0.08-2.38	1.13±0.02	0.92
Rewari	1.72-22.73	13.65±0.37	1.11	0.18-1.96	0.69±0.04	2.22
Rohtak	0.26-17.41	8.86±0.27	0.70	0.06-3.56	1.18±0.06	4.93
Sirsa	0.52-17.47	10.09±0.21	4.71	0.06-3.96	0.89±0.03	5.69
Sonipat	3.59-22.50	10.38±0.25	0.00	0.48-3.52	1.95±0.06	0.71
Yamunanagar	3.10-22.57	16.08±0.34	0.00	0.40-4.30	1.74±0.09	0.00
Haryana	**0.15-48.10**	**10.41±0.08**	**6.10**	**0.04-21.22**	**1.51±0.03**	**5.20**



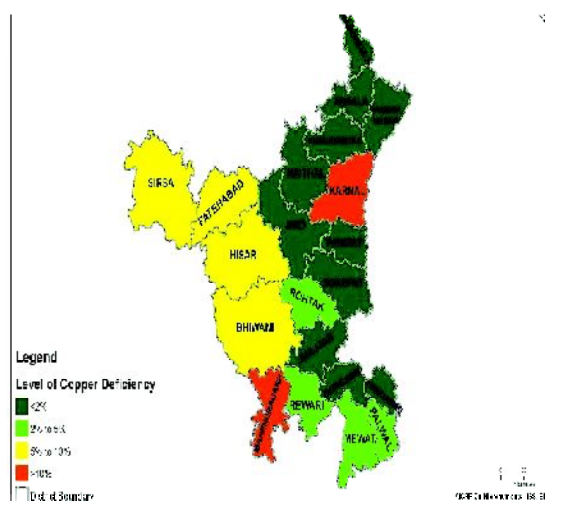
Map 1 – Status and distribution of DTPA-extractable Zn in the different districts of Haryana



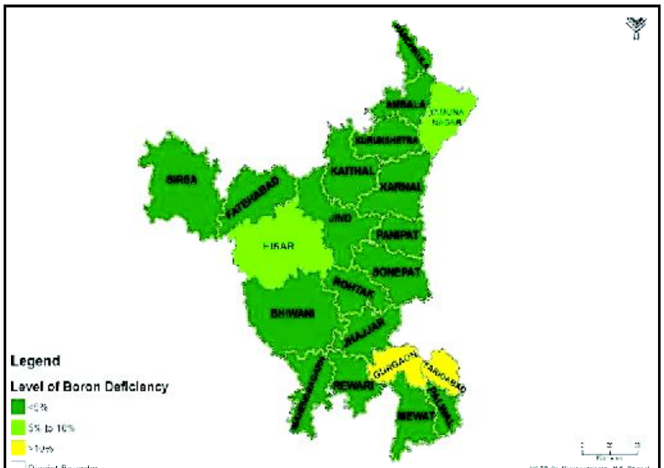
Map 2 – Status and distribution of DTPA-extractable Fe in the different districts of Haryana



Map 3 – Status and distribution of DTPA-extractable Mn in the different districts of Haryana



Map 4 – Status and distribution of DTPA-extractable Cu in the different districts of Haryana



Map 5 – Status and distribution of hot water soluble B in the different districts of Haryana

mineralization from organic matter or B addition to soils through irrigation or fertilization, a proportion of it remains in the soil solution while remaining is absorbed by soil particles and other soil constituents. Boron deficiency in soils of the state has been recorded to be 3.30% **(Table 3)**. Except Faridabad, Gurgaon, Yamunanagar and Hisar the deficiency of B in other district was recorded below 5%.

Status and distribution of hot water soluble B in districts of Haryana have been shown in **Map 5**.

B. Frequency Distribution of Micronutrients and Fertiliser Need

Soil samples falling below 0.6 mg Zn kg^{-1} are considered deficient in Zn, those falling between 0.6 to 1.20 mg kg^{-1} are considered as medium in Zn supply and those above 1.80 mg kg^{-1} are classed as high Zn samples. In order to develop better nutrient

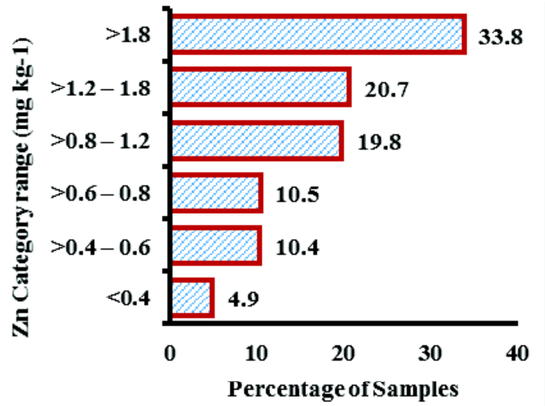


Figure 1 – Frequency distribution of Zn availability in soils of Haryana state

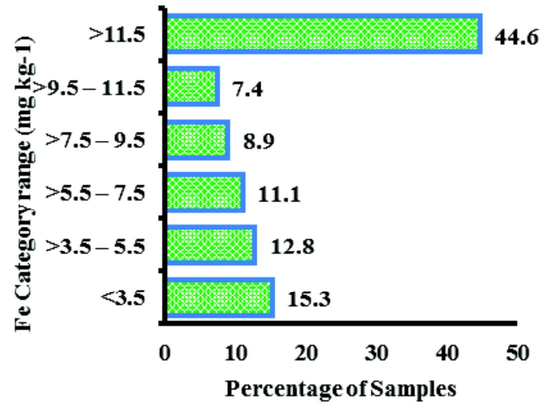


Figure 2 – Frequency distribution of Fe availability in soils of Haryana state

prescription, it is useful to categorize samples in lower range of frequencies. On average, it was noticed that 5.3% of the total samples fall in Zn deficient category, however another 10.5% samples which fall in the category of >0.6 to 0.8 mg kg^{-1} may be considered as potentially deficient. This category where Zn availability is between 0.6-0.8 mg kg^{-1}, which has improved due to increasing awareness among farmers during the latter part of the last decade is potentially susceptible for near future **(Figure 1)**.

About 19.8% soils (having >0.8 to 1.2 mg Zn kg^{-1} soil Zn content) may potentially respond to Zn application depending upon the type of crops grown and agro-climatic conditions. About one third of the soils are having adequate level of Zn content (>1.8 mg kg^{-1} soil) and Zn application to those soils may be skipped. However, in soils which has available Zn level between >1.2 to $\leq$ 1.8 mg Zn kg^{-1} may be given only Zn maintenance doses to sustain that level.

Of the total soil samples about 15.3% are highly deficient in Fe while 12.8% are vulnerable to Fe deficiency and respond to Fe application. Further, 11.1 % samples falling in the range of >5.5-7.5 mg Fe kg^{-1} soil may be considered as potentially deficient category **(Figure 2)**. Intensive cropping in these soils may render them in Fe deficient category, if maintenance doses are not provided. About 45% soils are having enough Fe content in soil to support the intensive farming provided sufficient moisture in available in the fields.

Table 3 – Available boron status (Hot water soluble) in soils of different district of Haryana

District	Range	Mean±SE	PSD
Ambala	1.30-4.05	2.33±0.06	0.00
Bhiwani	0.15-9.50	1.71±0.03	4.17
Faridabad	0.35-1.50	0.78±0.03	13.68
Fatehabad	0.30-9.50	2.00±0.06	3.88
Gurgaon	0.20-4.05	1.07±0.05	10.34
Hisar	0.15-6.20	2.12±0.05	6.75
Jhajjar	0.35-4.05	1.94±0.07	1.05
Jind	0.35-9.50	1.79±0.05	1.59
Kaithal	0.55-4.05	1.88±0.03	0.00
Karnal	0.15-3.10	1.48±0.03	4.42
Kurukshetra	0.25-6.95	1.51±0.03	2.27
Mewat	0.35-2.70	1.29±0.04	1.06
Mahendragarh	0.15-9.50	1.11±0.04	4.32
Palwal	0.50-2.70	1.54±0.03	0.40
Panchkula	0.55-2.40	1.50±0.06	0.00
Panipat	0.16-5.10	1.45±0.03	3.07
Rewari	0.85-1.85	1.33±0.02	0.00
Rohtak	0.35-5.50	1.41±0.06	2.82
Sirsa	0.45-8.50	1.91±0.06	0.78
Sonipat	1.20-3.35	2.13±0.04	0.00
Yamunanagar	0.10-2.10	1.13±0.05	9.80
Haryana	**0.10-9.50**	**1.69±0.01**	**3.30**

The frequency distribution of the Mn in soils of the state revealed that about 10.8% of the samples had Mn level of less than 3.5 mg Mn kg^{-1} soil. Further, about 10% samples fall in the range of 3.5 to 5.0 mg Mn kg^{-1} soil and may be considered potential deficient in future. About 50% soils of the state having Mn content more than 9.5 mg kg^{-1} and considered sufficient to meet the crop demand for longer period **(Figure 3)**. Of total analysed soil samples, 5.2% samples contained <0.2 mg Cu kg^{-1} soil. While another 14.6% samples fall in the category of >0.2-0.4 mg Cu kg^{-1} soil, may be potentially susceptible to Cu deficiency in future **(Figure 4)**. More than 60% soils have adequate amount of Cu to meet demand in future.

After 3.3% deficient category of B, 4.7% samples has been observed to be in the potentially prone to be B deficient as it contains >0.5-

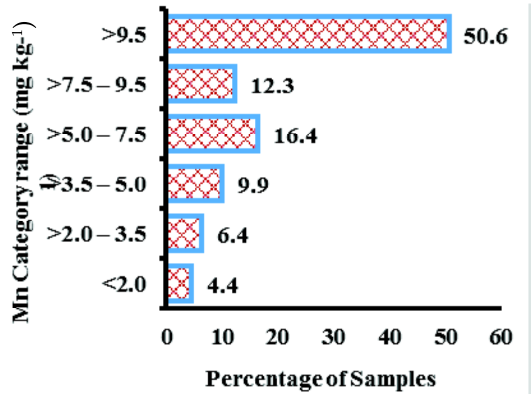


Figure 3 – Frequency distribution of Mn availability in soils of Haryana state

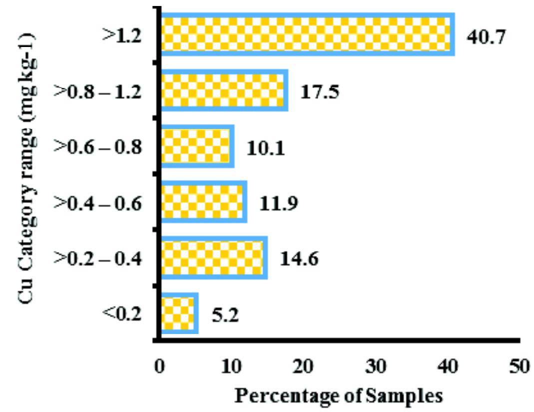


Figure 4 – Frequency distribution of Cu availability in soils of Haryana state

0.7 mg B kg^{-1} soil **(Figure 5)**. The soils which are potential to be deficient in future, may respond to B application, depending upon the crop need and nature of crop.

C. Multiple Micronutrient Deficiencies

In the preceding sections, individual micronutrients have been dealt in detail, however; in soils and in crops, and also in human nutrition, micronutrient deficiencies rarely occur in isolation (5, 6). Therefore, in soil plant system, there may often be a need to address several micronutrient deficiencies simultaneously.

Continuous use of high analysis fertilisers under intensified cropping and neglect of organic manures manifested the occurrence of wide spread micronutrient deficiencies; especially of Zn and Fe in soils of the state after 1960. However, it is evident that the deficiency of a single micronutrient prevails compared to two, three and four micronutrient deficiencies in the state **(Table 4)**. Except the one or two combinations having Zn and Fe, multiple micronutrient deficiencies in the states seldom exceeded 2%. Thus, application of single micronutrient fertilisers in the state is sufficient instead of multi-micronutrient mixtures with higher cost of production.

D. Temporal Changes in Micronutrient Deficiencies

As compared to Zn status in previous years (1999-2009), a substantial improvement in Zn status of the state has been observed in recent years (2009-2014). Except Ambala, Karnal, Kurukshetra and Panipat districts, Zn deficiency in other districts has either decreased or remained stagnant. Build up in Zn status of soils in the districts like Rewari, Faridabad, Mahendragarh, Yamunanagar, Bhiwani and Hisar, has been significant. Overall, the change in Zn status of the state soils has improved and as a result the magnitude of Zn deficiency declined by 10.5% **(Figure 6)**. The improvement in Zn status of soils in during recent years is attributed to inadvertent use of Zn fertilisers in state.

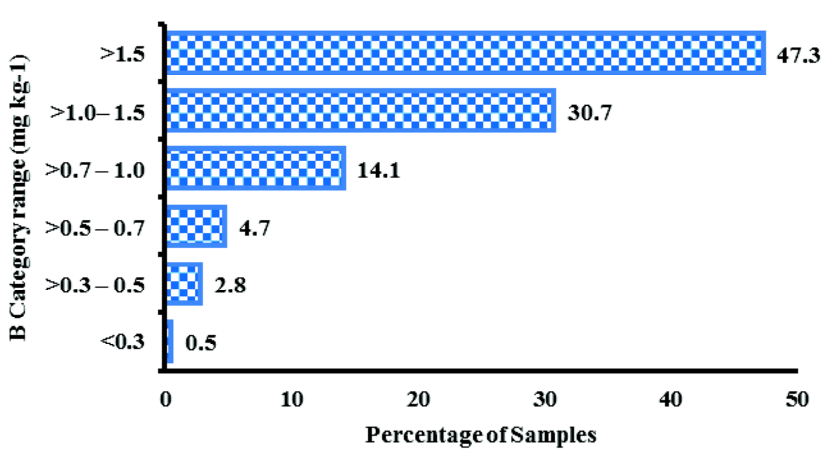


Figure 5 – Frequency distribution of B availability in soils of Haryana state

Like Zn deficiency, Fe status in Haryana soils have also improved during the last half decade. As evident from **Figure 7**, the Fe deficiency in soils of the state has reduced by 6.4% to its status before 2009 (27.97%). More than 10% decrease in Fe deficiency in soils of Bhiwani, Rewari, Yamunanagar, Sonipat, Hisar, Jind and Sirsa districts, were observed. Very little or no change has been observed in Jhajjar, Gurgaon, Ambala, Mewat, Panchkula, Kaithal and Kurukshetra districts, however, increase in deficiency has been evident in the districts like Mahendragarh, Fatehabad, Karnal, and Rohtak districts. In fact Fe status fluctuates greatly in soils due to moisture regime. Its

Table 4 – Status of deficiency of multiple micronutrients in soils of different districts of Haryana

District	Zn+B	Zn+Cu	Zn+Fe	Zn+Mn	Fe+Mn	Zn+Fe+Mn	Zn+Cu+Fe+Mn
Ambala	0.0	1.2	0.0	0.0	0.0	0.0	0.0
Bhiwani	1.1	7.1	10.9	2.5	4.4	1.6	0.4
Faridabad	1.1	1.1	0.0	0.0	0.0	0.0	0.0
Fatehabad	0.6	4.7	11.0	1.1	2.8	0.9	0.9
Gurgaon	1.7	0.9	0.0	0.0	0.0	0.0	0.0
Hisar	2.8	3.0	12.9	4.8	9.7	4.8	1.5
Jhajjar	0.0	0.0	4.2	0.0	0.0	0.0	0.0
Jind	0.0	0.0	2.3	0.0	0.0	0.0	0.0
Kaithal	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Karnal	0.0	0.6	0.0	11.9	1.1	0.0	0.0
Kurukshetra	0.3	0.0	0.8	0.5	0.0	0.0	0.0
Mewat	0.0	3.2	1.1	0.0	0.0	0.0	0.0
Mahendragarh	1.7	6.3	25.6	0.0	0.0	0.0	0.0
Palwal	0.0	1.2	1.2	0.0	0.0	0.0	0.0
Panchkula	0.0	0.0	1.3	0.0	0.0	0.0	0.0
Panipat	1.5	0.0	0.9	0.0	0.0	0.0	0.0
Rewari	0.0	1.1	0.0	0.0	0.0	0.0	0.0
Rohtak	0.7	1.4	6.3	0.0	0.0	0.0	0.0
Sirsa	0.0	2.2	10.0	1.6	2.5	1.4	0.8
Sonipat	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Yamuna nagar	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Haryana	**0.7**	**2.2**	**6.4**	**3.0**	**4.0**	**1.7**	**0.3**

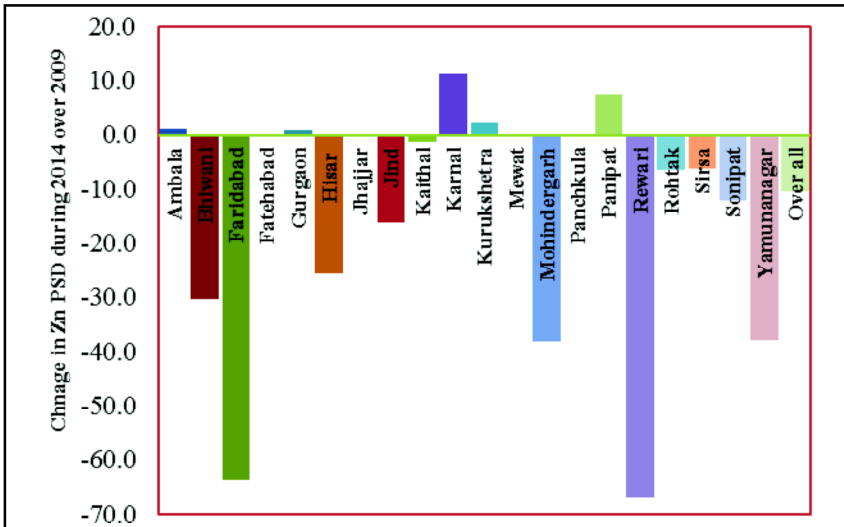


Figure 6 – Temporal Changes in DTPA-extractable Zn deficiency in soils of different districts of Haryana

concentration may be influenced by weather and organic manure application in soils where Fe^{3+} is reduced to Fe^{2+} and enhances the solubility of Fe in the soil (26). The increase in DTPA- Fe content with increase in SOC is supported by the overall positive relation between DPTA-Fe and organic carbon (24). Improvement in pH (due to continuous fertilization through urea) may also contribute in enhancing Fe availability in soils.

On average, there has hardly been any change in Mn content in soils of the state, except some improvement in soils of Sonipat, Bhiwani, Hisar, Rohtak, and Mahendragarh districts. The improvement in Mn status has resulted in decreased level of Mn deficiency. It is difficult to explain such improvement in available Mn however, there could be possibility of difference in sampling time. Because usually analysis of samples collected after wheat harvest during summer season often results in low Mn level because of its oxidation in higher state as compared to wet season. Exceptionally, the problem of Mn deficiency has aggravated in Karnal, an intensively cultivated district of the state **(Figure 8)**. Except Bhiwani, deficiency of Cu in soils of the state has increased during the period as mentioned earlier. Overall, 1.9% more soils have been observed under the Cu deficient categories **(Figure 9)**. During the period of comparison, B deficiency has improved in soils of the state. The greatest improvement was noticed in Bhiwani followed by Panipat. Though there is increase in B deficiency in soils of some district but it is not much significant except Karnal **(Figure 10)**.

RESPONSE OF CROPS TO APPLICATION OF MICRONUTRIENTS

Fertiliser response trials are most important tools to monitor the nutrient deficiencies in soils and plants as they confirm the actual state of the nutritional disorders in soil and plants and the levels of benefits which can be accrued on

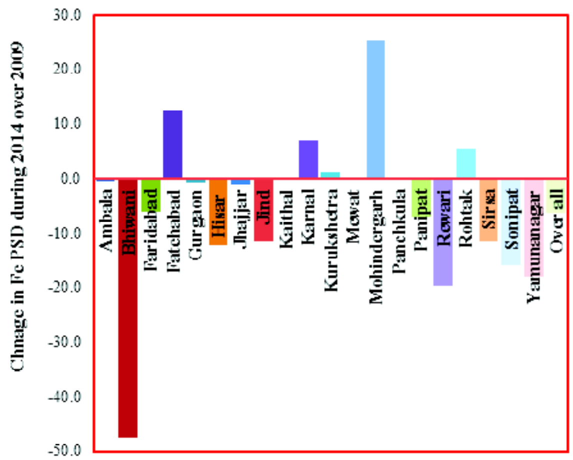


Figure 7 – Temporal Changes in DTPA-extractable Fe deficiency in soils of different districts of Haryana

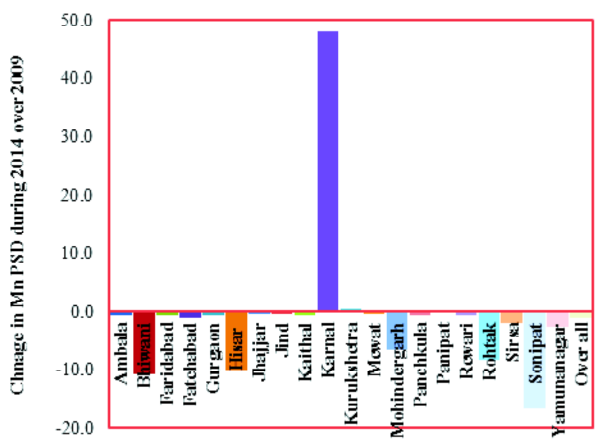


Figure 8 – Temporal Changes in DTPA-extractable Mn deficiency in soils of different districts of Haryana

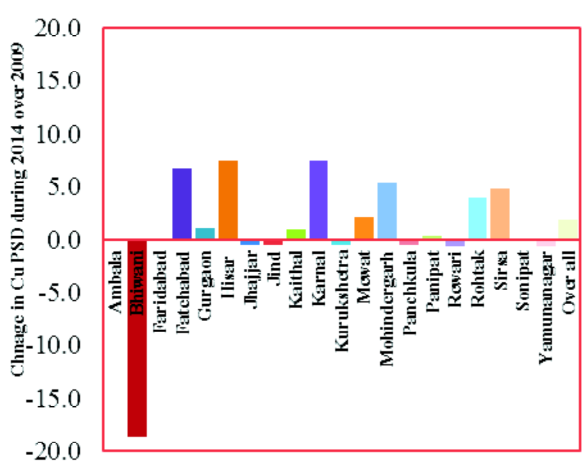


Figure 9 – Temporal Changes in DTPA-extractable Cu deficiency in soils of different districts of Haryana

the application of said element to be deficient. In order to demonstrate the magnitude of deficiency or response of the crops to micro and secondary nutrients, number of experiments were conducted on research farms as well as on farmer's fields. Generally, deficiency of micronutrients was noticed due to intensive cultivation of high yielding varieties of various crops coupled with non-inclusion of micronutrients in fertiliser schedule. Consequently, efficiency of major nutrients was reduced under micronutrient deficient conditions which in turn decreased the crop productivity.

In Haryana, a large number of field experiments were conducted on cultivator's fields to study the response of micronutrients to crops at recommended rate. The response to application of micronutrients varied greatly with crops, level of deficiency as well as with micronutrients applied **(Table 5)**. In case of Zn applied at 5 kg Zn ha^{-1}, the average increase in grain yield among the cereals was maximum in rice (0.58 t ha^{-1}) followed by wheat (0.35 t ha^{-1}) than other crops while pearl millet was found to be least responsive. Mustard, an important oilseed crop of the state, also responded positively to the Zn application. The magnitude of response to cotton and groundnut was almost similar being 0.22 and 0.31 t ha^{-1}, respectively. When Fe was applied at 10 kg Fe ha^{-1} in the form of $FeSO_4$, the response was noticed in almost all the soils where Fe availability was inadequate. Similarly, increased yields of crops were realized when Mn and B were applied to the crops.

MICRONUTRIENTS AND ANIMAL-HUMAN HEALTH

Deficiencies of micronutrients (Zn, Fe, folic acid) during pregnancy are known causes of low birth weight and reduced immunity. Most of the micronutrients necessary for human and animal growth are either essential or beneficial to crop plants too. Boron

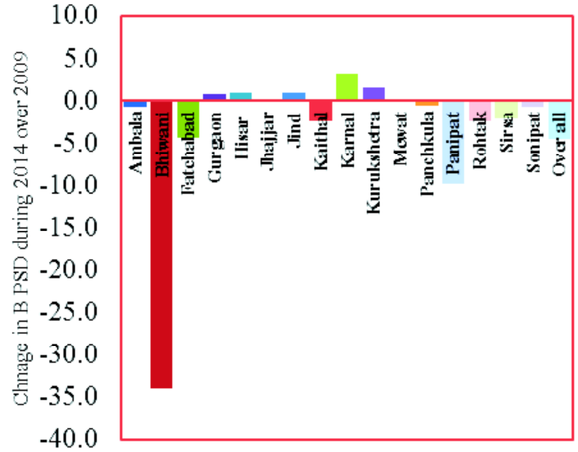


Figure 10 – Temporal Changes in hot water soluble B deficiency in soils of different districts of Haryana

is included as beneficial trace elements for human to protect against losses of Ca and Mg by post-menopausal women. Each essential element has a specific role in the metabolism as a co-factor in several enzymatic reactions or as necessary constituent of important structural proteins that cannot be partly or wholly replaced by any other elements. Trace elements are required less than 100 mg kg^{-1} in dietary food but shortage of any micronutrient leads to poor health, disease, morbidly, mortality and infertility and/ or even to death (23). Deficiencies of trace elements like Zn, Cu and Mg have been implicated in various reproductive events like infertility, pregnancy wastage, congenital anomalies, pregnancy induced hypertension, placental abruption, premature rupture of membranes, still births and low birth weight (16).

Globally, about three billion people are suffering with malnutrition of micronutrients besides protein deficiency malnutrition syndrome. Deficiencies of micronutrients are common in children and more so in women because of blood losses occurred during menstrual and childbirth. Increased deficiencies of micronutrients in soils and crops are leading to global burden of disease, hunger, increased susceptibility to sickness and loss of working hours. Micronutrient deficiencies, especially Fe and Zn among pregnant women are widespread in low-income countries, including India. Among the underprivileged populations, pregnant women have limited access to food and hence their dietary intake of calories, protein, vitamins, and micronutrients is inadequate (23).

In our country, nearly half of the soils on which food crops are grown, are deficient in plant available Zn, leading to reductions in crop production and also nutritional quality of the harvested grains. 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 is reported in human populations in India (21). In country, 11.4% of the women in the reproductive age group are below 145 cm, and 35.6% suffer from chronic energy deficiency and about 58.7% of pregnant mothers suffer from anaemia (7). The situation is no different in Haryana state, as evident from a community based cross sectional survey conducted by Pathak *et al.* (2004) in 6 villages of rural areas of district Faridabad in Haryana state which indicated that nearly 73.5, 2.7, 73.4, and 26.3 per cent pregnant women were deficient in Zn, Cu, Fe and folic acid, respectively. The highest concurrent prevalence of two, three, four and five micronutrient deficiency invariably included Zn and/ Fe. Inadequate calories intake and consuming less than 50% of the recommended Zn, Fe, and Cu make them more vulnerable. The consumption of food items which are rich in micronutrients (pulses,

Table 5 – Response of crops to application of micronutrients

Crops	No. of experiments Response (t ha^{-1})	Range	Mean
Zinc			
Wheat	456	0.02-3.21	0.35
Rice	75	0.08-1.27	0.58
Maize	26	0.06-1.68	0.25
Pearl millet	200	0.01-0.67	0.17
Mustard	7	0.06-0.38	0.17
Gram	5	0.02-0.18	0.13
Cotton	2	0.06-0.34	0.22
Groundnut	2	0.20-0.41	0.31
Iron			
Wheat	6	0.23-0.45	0.38
Chickpea	3	0.09-0.22	0.19
Pearl millet	9	0.24-0.34	0.31
Manganese			
Wheat	12	0.34-0.86	0.69
Boron			
Cotton	8	0.09-0.24	0.14
Mustard	12	0.13-0.28	0.23

Table 6 – Average percentage of mineral nutrient deficiency in blood serum, hair and milk in cattle in Haryana			
Deficiency percentage based on	**Zn**	**Cu**	**Mn**
Serum mineral status	-	40.0	-
Hair mineral status base	50.3	-	47.8
Milk mineral status base	42.9	29.0	-

vegetables, fruits, nuts and oilseeds, animal foods) was infrequent. In another similar study, a high prevalence of Zn deficiency was found among the nulliparous non-pregnant women in a rural community of Haryana state (17).

A survey in the state revealed that when feed and fodder produced on low Zn and/ Fe deficient soils were fed to cattle, the animals showed higher percentage of deficiency in their blood serum, hair and milk as given in **Table 6**. The deficiency of micronutrients was found widespread, as deficiency of minerals in common ranged between 20-60% for Zn, and 33-64% of Cu in blood serum and milk samples while hair showed Mn deficiency too.

Similar study aimed to assess the effect of micronutrient status in soil-plant-animal continuum revealed that soil of Dahima village of Hisar, Haryana had deficiency of 74.45 for Fe, 68.9% for P and 4.8% for Zn, and the fodders grown on these soils do not meet the normal mineral requirement of animal body. Analysis of animal blood plasma serum revealed maximum deficiency of 37.5% of Cu followed by 12.5% of P.

CONCLUSION

The current status of Zn, Fe, Mn, Cu and B deficiency in soils of the state has been assessed as 15.3, 21.6, 6.2 5.2 and 3.3 %, respectively. Despite this deficiency, a considerable portion of soils which are categorized just above the deficiency level need special attention because improper management of these soils may again render them in deficient category. As in case of Zn, this category might have been result of increased use in Zn by the farmers in the state. As of now, the critical micronutrients in Haryana soils is Fe, followed by Zn, Mn, Cu and B. It has been proved that application of micronutrient fertilisers was useful in mitigating the deficiency in plants and also helped in exploiting the potential of crops. The response to micronutrient had been noticed in deficient soils which varied with crop, soil and genotype. In the state, multi-micronutrient deficiencies are rare, application of multi-micronutrient mixtures may be avoided as deficiency and toxicity range of micronutrients is very narrow. Further, there is need to develop micronutrient application strategies for enhancing the micronutrient loading, particularly Zn and Fe, in edible plant parts under various soil types as per their available nutrients status in soil. Micronutrients enriched grain has great potential in improving health of malnourished children and pregnant women of the state, especially in rural areas. The animals, when fed with micronutrients dense fodder and feed has shown increased concentrations of these vital micronutrients in milk, serum and hair.

REFRENCES

1. Behera, S.K. and Shukla, A.K., Depth-wise distribution of zinc, copper, manganese and iron in acid soils of India and their relationship with some soil properties. *Journal of Indian Soc. Soil Sci.,* 61(3):244-252 (2013).

2. Berger, K.C. and Truog, E., Boron determination in soils and plants using the quinalizarin reaction. *Industrial Engg. Chem*., 11:540-545 (1939).

3. FAI, Speciality Fertiliser Statistics FAI, New Delhi. pp 87 (2011).

4. Gupta, A.P., Micronutrient status and fertiliser use scenario in India. *J Trace Elements Medicine Biology,* 18:325–331 (2005).

5. Jiang, T., Christian, P., Khatry, S.K., Wu, L. and West, K.P. Jr., Micronutrient deficiencies in early pregnancy are common, concurrent and vary by season among rural Nepali pregnant women. *J. of Nutri.*, 135:1106-1112 (2005).

6. Kang, B.T. and Osiname, O.A., Micronutrient problems in tropical Africa. *Fert. Res*., 7(1-3):131-150 (1985).

7. Kapil, U., Multiple Micronutrient Supplements will not Reduce Incidence of Low Birthweight. *Indian J Community Medicine*, 34(2):85-86 (2009).

8. Katyal, J.C. and Sharma, B.D., DTPA-extractable and total Zn, Cu, Mn and Fe in Indian soil and their association with some soil properties. *Geoderma,* 49:165–179 (1991).

9. Lindsay, W.L. and Norvell, W.A., Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Sci. Soc. America J.*, 42:421- 428 (1978).

10. Meng, F., Wei, Y. and Yang, X., Iron content and bioavailability in rice. *J. Trace Elements Medicine Biology,* 18:333-338 (2005).

11. Mengel, K. and Geurtzen, Iron chlorosis on calcareous soils. Alkaline nutritional condition as the cause for the chlorosis. G. *J. Plant Nutri.,* 9:161-173 (1986).

12. Moraghan, J.T. and Mascagni, H. J., Environmental and soil factors affecting micronutrient deficiencies and toxicities. In: Micronutrients in agriculture pp. 371-425, *Soil Sci. Soc. Am.*; Madison, USA (1991).

13. Narwal, R.P., Malik, R.S., Ram Kala, Singh, M.V. and Dahiya, R.R., Four decades of Micro- and

Secondary Nutrients research in Haryana, Research report of AICRP, pp-96 (2010).

14. Narwal, R.P., Annual Progress report of AICRP on micro- and secondary nutrients and pollutant elements in soils and plants, CCSHAU, Hisar, pp-85 (2006).

15. Nayyar, V.K., Sadana, U.S. and Takkar, P.N., Methods and rates of application of Mn and its critical levels for wheat following rice on coarse textured soils. *Fert. Res.*, 8:173–178 (1985).

16. Pathak, P. and Kapil, U., Role of trace elements zinc, copper and magnesium during pregnancy and its outcome. *Indian J. Pediatrics*, 71:1003-1005 (2004).

17. Pathak, P., Kapil, U., Kapoor, S.K., Dwivedi, S.N. and Singh, R., Magnitude of zinc deficiency among nulliparous non-pregnant women in a rural community of Haryana State, India. *Food and Nutrition Bulletin*, 24:368-371 (2003).

18. Pathak, P., Kapil, U., Kapoor, S.K., Saxena, R., Kumar, A., Gupta, N., Dwivedi, S.N. and Singh, R., Singh, P., Prevalence of multiple micronutrient deficiencies amongst pregnant women in a rural area of Haryana. *Indian J. Pediatrics*, 71:1007-1014 (2004).

19. Sharma, B.D., Arora, H., Kumar, R. and Nayyar, V.K., Relationships between soil characteristics and total and DTPA-extractable Zn, Cu, Mn and Fe in Indo-Gangetic plains. *Communi. Soil Sci. Plant Anal.*, 35:799–818 (2004).

20. Sharma, B.D., Seth, A., Saini, R.S. and Dhaliwal, S.S., Distribution of different forms of Mn and their association with soil properties in arid zone soils of Punjab, India *Arch. Agron. Soil Sci.*, 57(1):15-26 (2011).

21. Shukla, A.K., Tiwari, P.K. and Chandra, Prakash, Micronutrients Deficiencies vis-a-vis Food and Nutritional Security of India. *Indian J. Fert.*, 10(12):94-112 (2014).

22. Sidhu, G.S. and Sharma, B.D., DTPA-extractable micronutrients status in soil under rice-wheat system and their relationship with soil properties in different agro-climatic zones of Indo- Gangetic Plains of India. *Communi. Soil Sci. Plant Anal.*, 41:29–51 (2009).

23. Singh, M.V., Micronutrient nutritional problems in soils of India and Improvement for human and animal health. *Indian J. Fert.*, 5(4):11-16, 19-26 and 56 (2009).

24. Sood, A., Sharma, P.K., Tur, N.S. and Nayyar, V.K., Micronutrient Status and their Spatial Variability in Soils of Muktsar District of Punjab – A GIS Approach. *Journal of Indian Soc. Soil Sci.*, 57(3):300-306 (2009).

25. Takkar, P.N. and Nayyar, V.K., Preliminary field observation of manganese deficiency in wheat and barseem. *Fert News*, 26 (33):22–23 (1981).

26. Takkar, P.N., Micronutrient research and sustainable agricultural productivity in India. *Journal of Indian Soc. Soil Sci.*, 44:563-581 (1996).

27. Yadav, S. and Khirwar, S.S., Soil-plant-animal relationship of zinc in milch buffaloes of Jind district in Haryana, *Indian J. Animal Sci.*, 70:965-967 (2000).■