Importance of Micronutrients in Indian Agriculture

By Arvind K. Shukla, Sanjib K. Behera, T. Satyanarayana, and Kaushik Majumdar

Different Micronutrient Status of Indian Soils

The analysis of more than 2.0 lakhs soil samples, collected from 508 districts of the country during 2011-2017 under the leadership of ICAR – Indian Institute of Soil Science, Bhopal, revealed that on an average of 36.5, 12.8, 7.1, 4.2 and 23.2% soils are deficient in Zn, Fe, Mn, Cu and B, respectively (**Figure 1**). Maps of available micronutrients in soil help in understanding the level of micronutrient deficiency and toxicity and their judicious management for sustainable production, improvement in food quality, and animal/human health. Therefore, global positioning system (GPS) and geographical information system (GIS) based district-wise maps have been prepared for various states of India for formulating the remediation strategies for correcting micronutrients deficiencies in crops.

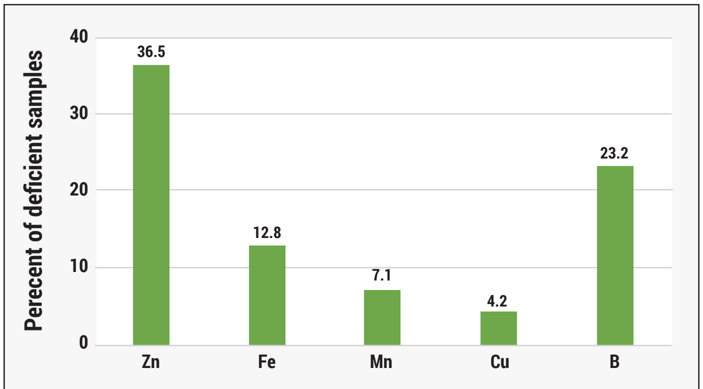

Figure 1. Micronutrient deficiency in Indian soils (2017).

Zinc deficiency varied among states with a minimum of 9.6% in Uttarakhand to as high as 75.3% in Rajasthan (**Figure 2**). Out of 508 districts delineated, 117, 100, 80, 63, 38 and 110 districts had deficiency in the range of 0-10, 10-20, 20-30, 30-40, 40-50 and > 50%, respectively. The most Zn deficient soils are the ones that are coarser in texture (sandy/loamy sand), high in pH (> 8.5 or alkali/sodic soils) and or low in organic carbon (< 0.4%), or calcareous/high in $CaCO_3$ (> 0.5%) and intensively cultivated (Shukla et al., 2014). Initially, the incidence of Zn deficiency was observed more in cereals, particularly rice and wheat belts of the country, but with passage of time, distribution of Zn deficiency has covered the whole country across the crops and cropping systems (Shukla and Tiwari, 2016). In general, low Zn deficiency has been recorded in soils having acidic pH as compared to soils having high pH; however, soils of northern India, except Rajasthan, also displayed medium deficiency range as compared to previous studies due to regular use of $ZnSO_4$ fertilizer (Sadana et al., 2010). On the other hand, increase in Zn deficiency in areas where low deficiency was recorded earlier has resulted from intensification of agricultural systems, faster depletion rate of available Zn pools (Shukla et al., 2016).

Out of 508 districts, 290 districts were having very high Fe content (**Figure 2**), especially in acidic soil areas. In India, the problem of iron deficiency is mainly in calcareous and other alkaline soils having pH > 7.5. The availability of Fe gets reduced under drought or moisture stress condition due to conversion of Fe^{2+} iron to less available Fe^{3+} iron. On the other hand, the soils of north-eastern districts, Odisha and Kerala are reported to have Fe toxicity problem in rice paddies. Manganese deficiency in Indian soils is relatively low. Similar to Fe, Mn availability is also influenced by soil moisture, and affect the incidence and severity of Mn deficiency in crops grown with low moisture content.

On the other hand, Mn is more mobile in imperfect-

SUMMARY

Micronutrients play important role in Indian agriculture towards sustainable crop production. The importance of micronutrients need to be viewed in food systems context, as their inclusion in balanced fertilization schedule would optimize micronutrient supply and availability in the entire food consumption cycle. Indian soils are generally poor in fertility especially in micronutrients as these have consistently been mined away from their finite soil source due to continuous cultivation for a very long time without addition of micronutrient fertilizer resulting in emerging micronutrient deficiency. In addition, green revolution led-increased demand of micronutrients by the high-yielding crop cultivars (especially rice and wheat) as well as adoption of intensive cropping practices, use of high-analysis fertilizers with low micronutrient content, decreased use of organic manures and crop residues, growing of crops in soils with low micronutrient reserves and other natural and anthropogenic factors adversely affecting phyto-availability of micronutrients aggravated the situation (Takkar and Shukla, 2015).

KEYWORDS:
soil fertility status; soil survey; nutrient interactions

ABBREVIATIONS AND NOTES:
B = boron; Cu = copper; Fe = iron; Mn = manganese; Zinc = zinc

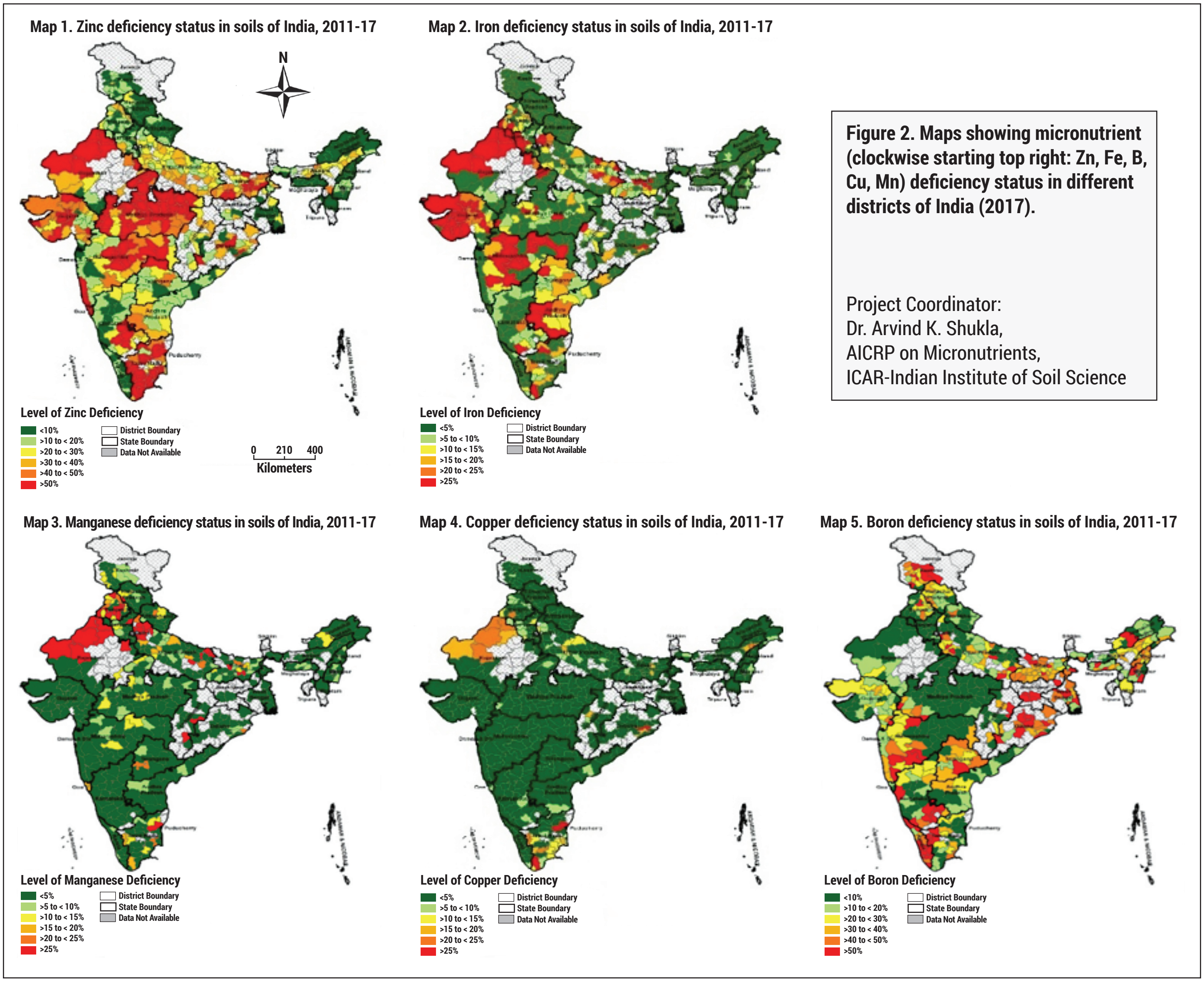

Figure 2. Maps showing micronutrient (clockwise starting top right: Zn, Fe, B, Cu, Mn) deficiency status in different districts of India (2017).

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ly drained soils (water logged) and sometime exhibited Mn toxicity in rice grown in paddy fields under continuous submerged conditions. Out of the soil samples analysed from 508 districts, more than 376 districts exhibited very high Mn content (**Figure 2**) and soils of 36 districts showed Mn deficiency > 25%. In India, Cu deficiency is not a such major concern showing deficiency in 4.2% soils only. Boron deficiency is more common in highly calcareous soils of Bihar and Gujarat and acid soils of West Bengal, Odisha and Jharkhand. In India, B deficiency has been recognised next to Zn. Availability of B to plants is governed by soil pH, $CaCO_3$ and organic matter contents, interactions of B with other nutrients, plant type and variety, and environmental factors. The concentrations of total B content ranges from 2.6 to 630 mg/kg (Takkar, 2011) and available (hot water soluble – HWS) B in Indian soils ranged from 0.04 to 250 mg B/kg with an average of 22 mg/kg soil. In general, B deficiency was higher in eastern region of the country and has resulted due to its excess leaching in sandy loam soils, alluvial and loess deposits. Molybdenum is least studied micronutrient in India. Molybdate anions (MoO_4^{2-}) are strongly adsorbed by soil minerals and colloids (at pH < 6.0) and sometimes also trapped due to formation of secondary minerals. Hydrous aluminium silicates may also fix Mo strongly. Soils formed from shale and granite parent materials had high Mo concentrations; whereas, those derived from sandstone, basalt and limestone had low Mo contents. Most of the soils are adequate in Mo but its deficiency is noticed in some acidic, sandy and leached soils. Molybdenum is most readily taken up by plants in soils with a pH above 7 and is relatively unavailable in acid soils. Thus, Mo deficiencies are most likely to occur on acid and severely leached soils and severely affecting mainly legumes, crucifer vegetables and oilseeds.

With due course of time, multi-micro and secondary nutrients deficiencies have emerged in different areas of the country. Currently, an average of 9.9, 8.3, 6.2, 5.8, 3.7, 3.3, 2.8 and 2.4% samples were found to be deficient in S+Zn,

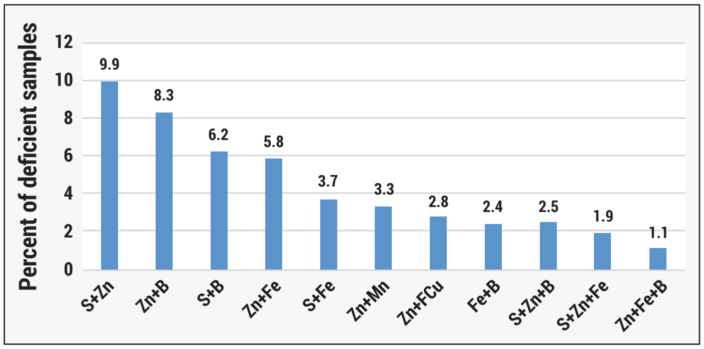

Figure 3. Multi- micro and secondary nutrient deficiency in soil (2017).

Zn+B, S+B, Zn+Fe, S+Fe, Zn+Mn, Zn+Cu and Fe+B nutrient combinations, respectively (**Figure 3**). Three nutrient deficiencies like S+Zn+B, S+Zn+Fe and Zn+Fe+B were recorded in about 2.5, 1.9 and 1.1% soils, respectively. Four or more than four nutrient deficiencies were very less (less than 0.5%) in most of the states. The results clearly reveal that deficiency of single micronutrient is most predominant as compared to the combination of two or three or four or more than four elements simultaneously. In the light of this, use of multi-micronutrient mixtures should be avoided as their use would be uneconomical. Only the deficient micronutrient as revealed by the soil tests should be used to mitigate the deficiency and minimize environment pollution.

Crop Response to Micronutrient Application

Crop responses to micronutrient application vary widely depending upon soil and crop type (Takkar et al., 1989). Crop responses to Zn application in large number of crops has been reported across the country based on more than 15,000 trials conducted at cultivator's field from 1967 to 2016. Depending upon the level of increase in relative economic yield (REY) of different crops, a soil is classified as marginal or non-responsive, responsive, very responsive, and highly responsive to Zn when incremental REY was <200, 200-500, 500-1000, > 1000 kg/ha, respectively. Out of 4,144 trials conducted on farmers' fields during 1967-84, 58 and 42% exhibited response and no response to Zn application, respectively (Takkar et al., 1989). The number of responsive trials increased over the years to 63% during 1985-2000, 72% during 2000-2010, and 80% during 2011-2016 (**Figure 4**; Shukla and Behera, 2011). On average, crop responses to soil and foliar application of Fe ranges from 0.45 to 0.89 t/ha for cereals, 0.3 to 0.68 t/ha for millet, 0.34 to 0.58 t/ha for pulses, 0.16 to 0.55 t/ha for oilseeds, 0.20 to 1.53 t/ha for vegetables, and 0.39 to 9.68 t/ha for cash and other crops. Soil and or foliage application of Mn resulted in marked response of crops on Mn-deficient soils. The responses ranged from trace to 3.78 t/ha for wheat, trace to 1.78 t/ha for rice, 0.03 to 1.02 t/ha for soybean, 0.40 to 0.70 t/ha for sunflower, 3.63 to 4.30 t/ha for onion, 0.30 to 0.80 t/ha for tomato. Crop responses to Cu

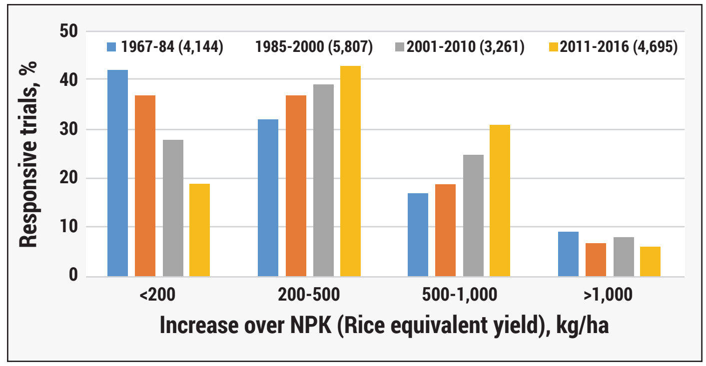

Figure 4. Changes in crop responses to Zn with time in trials at farmers' field.

application ranged from trace to 1.78 t/ha of cereals, 0.20 to 0.30 t/ha of millets, trace to 0.80 t/ha of oilseeds, 4.43 to 6.18 t/ha of onion, and 0.30 to 0.50 t/ha of sugarcane. Soil application of 0.5 to 2.5 kg B/ha gave a response of 108 to 684 kg grain/kg of B or 10 to 44% over NPK and helped in sustaining the high productivity of cereals, pulses, oilseeds and cash crops in B-deficient soils of Bihar, Orissa, West Bengal, Assam and Punjab. Response of crops to Mo application ranged from 0.24 to 1.01 t/ha for rice, 0 to 0.47 t/ha for wheat, 0.08 to 0.19 t/ha for soybean, and 0.10 to 0.40 t/ha for green gram.

Role of Micronutrients in Food Grain Production

The increasing trend in consumption of micronutrients fertilizer vs food grain production of the country over the years (**Figure 5**) shows the importance of micronutrients in sustainable food production. According to an estimate, the

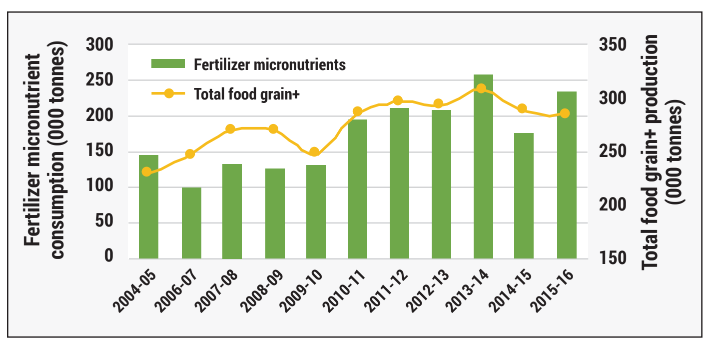

Figure 5. Micronutrient fertilizer consumption vis-a-vis food grain production in the country during last decade.

contribution of Zn and B fertilizer to present food crop production comes around 29 M t rice equivalent yields (Shukla and Behera, 2011). The contribution from other micronutrients should not be underestimated as their use has been increasing consistently and enhancing crop productivity. As per recent estimate of micronutrients consumption, the use of $ZnSO_4$ fertilizer was the highest (1,88,305 t) followed by iron sulphate (21,188 t), boric acid/borax (19,976 t), manganese sulphate (2,740 t) and copper sulphate (1,369 t) during 2015-16 (FAI, 2016). Of the total Zn used, 70% goes to the field crops and remaining 30% to vegetable and fruit crops, while the reverse is true for Mn, Fe and Cu.

Role of Micronutrients in Enhancing Use Efficiency of Macronutrients

The partial factor productivity of macronutrients (NPK) fertilizer has declined over the years. One of the reasons for this decline is emerging deficiency of micronutrients. Although needed in trace amounts, micronutrients play a macro role in enhancing the use efficiency of NPK as recorded in several studies (Shukla et al., 2009). Decline in system productivity of rice-wheat sequence has been recorded in different parts of the country due to omission of micronutrient from the balanced fertilization schedule (**Table 1**). The results obtained in long-term experiments at PDCSR, Modipuram, Meerut showed 16.7% cumulative increase in productivity of rice-wheat system with Zn application over NPK treatments after 15 years. The productivity loss due to omission of Zn from balanced fertilization schedule ranged between 3.5 and 17.5% at nine sites across the country. Another study conducted in rice-rice system revealed that the highest increase in P use efficiency was recorded with addition of Zn (35.4%) followed by B (28.7%) and Mn (15.6%) in balanced fertilization schedule. On an average, the agronomic efficiency of fertilizer K was enhanced by 35.1, 32.4, 33.7 and 10.3% with addition of S, Zn, B and Mn in balanced fertilization schedule, respectively. Addition of micronutrients in balanced fertilization schedule increased internal utilization efficiency of NPK (Tiwari, 2008).

Table 1. Loss in system productivity (kg/ha) due to omission of micronutrients from balanced fertilization schedule in rice-wheat cropping system.

Location	System productivity with NPK fertilization (REY*)	Loss in system productivity (kg/ha) due to omission of micronutrients from balanced fertilization schedule			
		Zn	B	Mn	Cu
Modipuram	17,574	2,057 (11.7)	1,738 (9.9)	1,440 (8.2)	-
Kanpur	15,371	1,619 (10.5)	-	-	-
Faizabad	12,992	2,279 (17.5)	1,499 (11.5)	1,061 (8.2)	-
Varanasi	12,823	1,096 (8.5)	486 (3.8)	494 (3.9)	665 (5.2)
Pantnagar	13,305	1,230 (9.2)	567 (4.6)	-	-
Sabour	14,301	-	-	-	-
Ranchi	11,664	489 (4.2)	528 (4.5)	-	-
Palampur	10,037	354 (33.5)	795 (7.9)	-	-
R. S. Pura	13,493	804 (6.0)	-	248 (1.8)	344 (2.5)

Values in parenthesis depict percentage loss; *Rice equivalent yield.

Micronutrient Management for Higher Crop Production

Micronutrient management needs to be carried out based on the demand and supply of micronutrient in soil-plant system. It varies with crops, soil types, severity of deficiency, source, method, time, rates and frequency of application. While planning for replenishment of the micronutrients removed by the crop and/or depleted from soil through micronutrient management, important aspects like micronutrient requirements of the crops and cropping systems, ranges between their deficiencies and toxicities, low use efficiency of micronutrients, and residual availability etc. need to be considered (Shukla et al., 2014).

Out of the several Zn sources evaluated for their efficacy under different soil-crop situations, $ZnSO_4 \cdot 7H_2O$ proved better or equal with other sources in correcting the Zn deficiency (Takkar et al., 1989; Shukla et al., 2009; Shukla and Behera, 2012). However, in some studies, chelated Zn proved more effective than $ZnSO_4 \cdot 7H_2O$ for maize and rice. The optimum rates of Zn application varied with severity of Zn deficiency, soil types and nature of crops. Results emanated from large number of field studies indicated that 2.5 to 10 kg Zn/ha as $ZnSO_4 \cdot 7H_2O$ proved most effective in mitigating its deficiency and in sustaining high soil productivity in most of the crops grown on diverse Zn-deficient soils. As the efficiency of soil applied Zn is very low (2-5%), efforts have been made to develop efficient and inexpensive methods of Zn application. Application of Zn to soil through broadcast and mixed or its band placement below the seed proved superior to top dressinzg. Other Zn application methods are side-dressing or side-banding, foliar application of 0.5 to 2.0% $ZnSO_4 \cdot 7H_2O$ solution and soaking or coating of seeds in Zn solution. The results of seedling root dip with ZnO are contradictory in sustaining high agricultural productivity of rice, sugarcane and vegetables. Seed soaking, rice seedling root dip in ZnO slurry and even foliar application could not catch up with the farmers so far because of certain constraints and limitations.

Iron chlorosis is generally observed in upland crops especially rice, sorghum, groundnut, sugarcane, chickpea grown in highly calcareous soils, compact soil with restricted aeration, soils with low in Fe and high in P and bicarbonate. Ferrous sulphate, (19-20.5% Fe) is the major source used for managing Fe deficiency in the country. However, Fe-EDTA (9-12% Fe), Fe-EDDHA (10.0% Fe), pyrite, biotite, and organic manures (FYM 0.15% Fe), poultry and pig manure (0.16% Fe), sewage sludge have also been used as sources of Fe to correct its deficiency in crops. By and large foliar application of 10-12 kg $FeSO_4$/ha or soil application of 50-150 kg/ha $FeSO_4$ alleviated Fe deficiency in most of the crops (Takkar et al., 1989). The rates of soil application of Fe were very high, because of rapid rate of oxidation of Fe^{+2} to Fe^{+3} and as such were uneconomical. Similarly high cost of Fe-chelates discourages farmers to use it as Fe fertilizer source. For horticultural crops foliar spray of $FeSO_4$ is recommended, which have beenmore effective and efficient than soil application in correcting Fe-chlorosis in tomato, chilli, groundnut and sugarcane.

Severe Mn deficiency is difficult to manage with soil application due to oxidation of soil-applied Mn, especially in high pH soils. Foliar application of $MnSO_4 \cdot H_2O$ is an immediate effective measure to combat Mn deficiency in wheat though it has to be applied every year. The fertilizer $MnSO_4 \cdot H_2O$ proved 1.5 and 10 times more effective than that of Mn-frits and MnO_2, respectively in increasing significantly the wheat grain yield. Both soil and foliar application of Mn helped to mitigate its deficiency and sustained the high productivity of wheat. However, foliar spray of 0.5% $MnSO_4$ solution was found more effective and economical than soil application of 50 kg $MnSO_4$/ha.

Copper deficiency in Indian soils is very less. Either soil or foliar application of Cu to soybean-wheat cropping system, on Typic Ustipsamments of Ludhiana, proved equally effective in correcting its deficiency and gave significant response of 0.2 t/ha with soil application of 5.0 kg Cu/ha to the first crop. Foliar spray of 0.2% $CuSO_4$ solution increased soybean grain yield from 2.18 to 2.35 t/ha. Residual effect of soil applied Cu on the following wheat was non-significant.

Boron deficiency is one of the serious nutritional problems limiting crop production in acid and calcareous soils. Soil application of borax or sodium tetra-borate decahydrate ($Na_2B_4O_7 \cdot 10H_2O$, fertilizer grade, 10.5% B) is commonly used to correct its deficiency. Boric acid (H_3BO_3, 17% B), solubor ($Na_2B_4O_7 \cdot 5H_2O$+ $Na_2B_4O_7 \cdot 10H_2O$ fertilizer grade, 19% B) are mostly used as foliar spray. However, rates of B application for achieving sustainable optimum productivity varied with crop, season and type of soil. In a B-deficient sandy loam calcareous soil of Bihar, the optimum rates for chickpea and winter maize were 2.08 and 1.68 kg B/ha, respectively. Application of 1.5 kg B/ha gave optimum yields of *Rabi* (winter) crops such as mustard, maize, sunflower, onion and lentil and the rates were higher 2.0-2.5 kg B/ha for *kharif* (summer) crops: groundnut, maize, onion, yam, bean and black gram (Sakal and Singh, 1995). The rates of B were relatively low (0.5-0.75 kg B/ha) for sesame and linseed in coarse-textured Entisols; more moderate (0.75 and 1.5 kg B/ha) for maize, wheat and rice; 1-2 kg B/ha for chickpea, pigeon pea, groundnut, sunflower and mustard in calcareous and clay textured Vertisols (Dangarwala et al., 1994); and 2.0 kg B/ha for potato in acid soils (Inceptisol) of Garhwal. It was also superior to foliar spray (0.2% + lime twice) or potato tuber soaking. But both soil and foliar application of B proved equally effective for soybean. By and large, soil application of B is a better method of its management than the foliar and seed soaking.

Conclusion

Adoption of intensive and modern cropping practices with high-yielding crop cultivars and unbalanced fertilizer application resulted in emergence of widespread micronutrient deficiency in soils and crops of India leading to reduced crop yield and low micronutrient concentration in agricultural produce. According to results from the analysis of more than 2.0 lakh soil samples collected from 508 districts of the country, on average 36.5, 12.8, 7.1, 4.2 and 23.2% soils are deficient in Zn, Fe, Mn, Cu and B respectively. More than 50% samples are found deficient in Zn and B in 110 and 63 districts of the country, respectively. Over the years, Zn deficiency has declined in soils of the country because of regular and more use of Zn fertilizer whereas deficiency of Fe and Mn increased slightly. In addition, multi-micro and secondary nutrient deficiencies like S+Zn, Zn+B, S+B, Zn+Fe, S+Fe, Zn+Mn, Zn+Cu and Fe+B, S+Zn+B, S+Zn+Fe and Zn+Fe+B have emerged in different parts of the country. Responses of different crops to micronutrient application have been recorded in different micronutrient deficient soils. Inclusion of micronutrients in balanced fertilization schedule increased internal use efficiency of NPK. Therefore, micronutrient management depending upon crops, soil types, severity of deficiency, source, method, time, rates and frequency of application needs to be undertaken for sustainable agricultural production and maintenance of human health. **BCSA**

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References

Dangarwala, R.T. et al. 1994. Annual Report of AICRP on Micronutrients (ICAR), Gujarat Agricultural University, Anand Campus, Anand.

Sakal, R. and A.P. Singh. 1995. *In* H.L.S. Tandon (ed.). Micronutrient Research and Agricultural Production. New Delhi: Fertilizer Development and Consultation Organisation. pp.1-31.

Shukla, A.K. et al. 2014. Indian J. Fert. 10(12): 94-112.

Shukla, A.K. and S.K. Behera, 2012. Indian J. Fert. 8(4): 100-117.

Shukla, A.K. and P.K. Tiwari. 2016. Micro and Secondary Nutrients and Pollutant Elements Research in India. Coordinators Report- AICRP on Micro- and Secondary Nutrients and Pollutant Elements in Soils and Plants, ICAR-IISS, Bhopal. pp.1-196.

Shukla, A.K. et al. 2016. Soil & Till. Res. 163: 282-289.

Sadana, U.S. et al. 2010. Better Crops South Asia 5: 24-26.

Takkar, P.N. and Shukla, A.K. 2015. *In* State of Indian Agriculture – Soil. H. Pathak, S.K. Sanyal and P.N. Takkar (eds.). NAAS, New Delhi, India, pp. 121-152.

Takkar, P.N. 2011. Keynote address. Indian J. Fert. April 2011, pp 142-148.

Takkar, P.N. et al. 1989. Twenty Years of Coordinated Research on Micronutrients in Soils and Plants, Indian Institute of Soil Science, Bhopal IISS, Bulletin 1. pp 394.

Shukla, A.K. and S.K. Behera. 2011. Indian J. Fert. 7(10): 14-33.

Shukla, A.K. et al. 2009. Indian J. Fert. 5:11-30.

Tiwari, K.N. 2008. J. Indian Soc. Soil Sci. 50 (4): 327-336.

Shukla, A.K. 2014. Understanding the mechanism of variation in status of a few nutritionally important micronutrients in some important food crops and the mechanism of micronutrient enrichment in plant parts, NAIP Funded Research Project. AICRP on Micronutrients, IISS, Nabibagh, Berasia Road, Bhopal.