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RESEARCH ARTICLE

Micronutrient Research in India: Extent of deficiency, crop responses and future challenges.

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Abstract

Green revolution has greatly increased the food crop production in India, but continuous cultivation of high yielding crop varieties have led to depletion of native micronutrient soil fertility and now most of the soils are showing sign of fatigue for sustaining higher crop production to meet the increasing food demand of the country. In the post-Green Revolution period, deficiencies of zinc (Zn) and boron (B) have constrained sustainable growth in productivity of several field crops. Among micronutrients, Zn deficiency was found widespread in Indian soils. Analysis of soils samples from different states of India indicated that on an average 44, 33, 15, 13, 8 and 6% of the samples were deficient in available Zn, B, iron (Fe), molybdenum (Mo), copper (Cu) and manganese (Mn), respectively. Extensive micronutrient deficiencies lead to decline in factor productivity even with balanced NPK fertilization. Although the crop response to micronutrients application varies with soil type, crops and genotype, agro-climatic conditions and severity of deficiency, an enormous response to micronutrient fertilization has been reported in a wide variety of crops including horticultural crops across the country. The results indicated that soil application of 5 to 10 kg Zn ha^{-1} before sowing is the most suitable method to manage Zn deficiency. The most effective method to ameliorate Fe deficiency is to apply 3-4 foliar sprays of 0.5 to 1.0% ferrous sulphate in standing crop at an interval of 10 days. For management of Mn deficiency 3-4 foliar applications of 0.5-1.0% manganese sulphate are economical than soil application of 40-50 kg Mn ha^{-1}. Response of crops to B application (0.5-2.5 kg B ha^{-1}) was observed on boron deficient soils. The soil application of boron is a better method of fertilization than foliar application or seed soaking.

Introduction:-

In India, origin of micronutrient management research is traced back to a publication by **Iyer and associates (1934)**. Real impetus on micronutrient research came with report of *khaira* disease in mid-sixties **(Nene, 1966)** and establishment of All India Coordinated Research Scheme on Micronutrients in Soils and Plants in India. Typically, in the post green revolution period in India, deficiencies of Zn and B have been found to constrain sustainable growth in productivity of several field crops, where intensive agriculture is practiced. A detailed account of information on micronutrient in soils and plants has been published by **Katyal and Agarwala (1982)**, **Takkar et al., (1989)**, **Singh (2008)** and **Shukla and Behera (2012)** under the aegis of the All India Coordinated Scheme on Micronutrients in Soils and Plants of Indian Council of Agricultural Research (ICAR). Data generated so far show that the zinc-deficiencies are widespread on coarse-textured, calcareous or alkaline and low organic carbon alluvial soils (Entisols and Inceptisols) of Indo-Gangetic alluvial plains of North India; fine textured calcareous black soils (Vertisols) of Deccan Plateau; and highly leached rice growing red and other associated soils (Alfisols, Oxisols and

Ultisols). Continuous leaching of Mn from the surface layers of the coarse-textured soils under rice-wheat cropping system has made this nutrient critical for wheat component of the system. Deficiencies of Fe on low organic matter alkaline soils, Fe and B on calcareous soils, Cu on organic soils, and Mo and B on acid soils have been on the anvil. Inclusion of Zn and B as fertilizers in cropping systems, identification of the micronutrient deficiency-stress tolerant varieties and exploitation of the synergistic micronutrient interactions for sustainable crop production have been major accomplishments during the second half of the 20^{th} century. According to an estimate, the current micronutrient application to crops may need to be doubled by 2050 to meet the food demand of increasing population of the country through intensive cropping or cultivation on marginal lands.

Factors affecting availability of micronutrients:-

Soil reaction:-

Soil pH influences solubility, concentration in soil solution, ionic form and mobility of micronutrient in soil and consequently acquisition of these elements by plants **(Fageria et al., 1997)**. As a rule, the availability of B, Cu, Fe, Mn and Zn usually decreases and Mo increases as soil pH increases. These nutrients are usually adsorbed onto sesquioxide soil surfaces.

Effect of clay minerals:-

The trace elements released during the course of weathering may be locked up in the crystal lattices of the clay minerals and thus become relatively unavailable. Clay minerals bind trace elements with varying degree of forces. Different binding forces account for variation in the extraction rate of different trace element cations by different reagents. Trace elements are readily adsorbed by clay minerals but displaced with difficulty. A few trace elements like B and Mo when displaced by weathering appear as complex anions. Calcium or organic complex may bind these anions.

Organic matter:-

Organic matter affects the availability of the micronutrients. Organic matter content increases the boron availability by preventing its leaching loss and bringing about its accumulation in surface soil. Addition of organic matter to well drained soils have produced varying effects on iron availability. Organic materials such as manure may supply chelating agents that add in maintaining the solubility of micronutrients. Manganese availability is low in basic soils, high in organic matter because of the formation of unavailable chelated Mn^{2+} compounds. Action of organic matter on zinc availability is variable. When immobilization and complexation reactions of organic matter prevail, availability of soil zinc will be adversely affected. On the other hand, formation of soluble chelated compounds of zinc will enhance availability by shielding the retained zinc from fixation reactions.

Inter-relationship with other nutrients:-

Availability of micronutrients in soil are affected by interaction among micronutrients as well as with other nutrient elements. Metal cations including Cu^{2+}, Fe^{2+} and Mn^{2+} inhibit plant uptake of Zn^{2+} possibly because of competition for the same carrier site. High phosphorus availability induces zinc deficiency. Increased rates of potassium accentuate boron toxicity at high levels of boron. Application of acidic nitrogenous fertilizer can aggravate copper deficiencies may be due to increased aluminium levels in soil solution. Excess of nutrients such as Co, Cu, Mn, Mo, Zn and P encourage iron deficiency. Absorption and translocation of molybdenum was enhanced by application of phosphorus due to release of adsorbed MoO_4, thus making it more available to plants.

Micronutrient Status of Indian Soils:-

Systematic delineation work on massive scale for quantification of the micronutrient deficiencies under the aegis of the All India Coordinated Research Project on Secondary, Micronutrients and Pollutant Elements in Soils and Plants [AICRP (MSPE)] using uniform critical levels of deficiency (**Katyal and Rattan, 2003)** has yielded database which has been critical in administering micronutrients. Deficiency of micronutrient has become a major constraint to the productivity, stability and sustainability of crops in many Indian soils and may further deteriorate due to global warming **(Kumar et al., 2011)**. In order to assess the micronutrients status of soil, a large number of soil and plant samples were collected and analyzed for micronutrients, *viz*; Zn, Mn, Fe, Cu, Mo and B under the aegis of All India Coordinated Research Project of Micro and Secondary Nutrients and Pollutant Elements in Soils and Plants and by other state agencies. Indian soils are adequate in total micronutrient contents but low in their available levels. The contents varied widely with respect to soil types, cropping system and management conditions.

Out of more than 3, 00,000 soil samples collected from various states of the India, 44% tested deficient in Zn having less than 0.6 ppm DTPA-extractable content. Per cent samples deficient in Fe, Mn and Cu reported are 15, 6 and 8%, respectively **(Shukla and Behera, 2012)**. Similarly, the analysis of 50,000 soil samples showed B and Mo deficiencies of 33 and 13%, respectively. B deficiency is reported more in acid soils than other parts of the country due to leaching of available B and continuous depletion of total soil reserved B. Coarse texture, high pH, calcareousness, diminishing organic carbon and leaching often accentuated the Zn deficiency **(Katyal and Rattan, 1993)**. Irrespective of these soil properties, irrigated crops whose productivity is two to three times higher than rainfed crops suffered more from Zn deficiency. Across soils and crops, lowland rice is invariably affected by Zn deficiency. Iron deficiency is most common in upland crops particularly grown on calcareous/ alkaline soils of arid region. Adoption of rice-wheat cropping system in place of maize-wheat or groundnut-wheat in non-traditional rice growing areas on highly permeable coarse-textured soils has been responsible for occurrence of Mn deficiency. The deficiency of Mo is common in acid soils of humid region. Deficiency of Cl and Ni has not been reported so far in the Indian soils. Now, multi-nutrient deficiencies are emerging in many states of the country. The Zn+Fe in swell-shrink soils, Zn+Mn or Zn+Fe+Mn in alluvial soils of Indo-Gangatic alluvial plains, Zn+Fe, Zn+B, Zn+Fe+B in highly calcareous soils of Bihar, Saurashtra, Zn+B in acid leached alfisols, red and lateritic soils of India are leading to stagnation or a decline in productivity **(Shukla and Behera, 2011)**.

Crop responses to micronutrients application:-

Literature is abound on crop response to micronutrients in India, especially to Zn and B and has been thoroughly reviewed **(Rattan et al., 2008, Singh et al., 2011 and Murthy, 2011)**. While a good response of crops to Zn is obtained throughout the country, response to B is more in eastern states of India and response to Mn has strong up for wheat in recent years in Punjab **(Singh et al., 2011)**. Soil application and foliar sprays are the most commonly used methods of Zn application. Results from field experiments revealed the superiority of soil application of Zn over foliar application (**Rathore et al., 1995**). The lower efficiency of the foliar mode is primarily due to delayed cure of the deficiency as well as the low concentration of Zn in spray solution.

In a field study carried out at Anand, Gujarat Zn-enriched organics were used for field experimentation in wheat-maize fodder (F) cropping sequence with wheat as direct crop and maize (F) as a residual crop (**Rathod et al., 2012**). The Zn-enriched poultry manure and biogas slurry at Zn 2.5 kg ha^{-1} improved the average wheat grain yield by about 68 and 43%, respectively, over control (1.82 t ha^{-1}) whereas the same was higher by 32 and 17% over Zn application as zinc sulphate equivalent to 2.5 kg ha^{-1}, respectively. Improvement in grain and straw yield of wheat due to Zn-enriched organics was comparable at both levels of Zn-enrichment *i.e.*2.5 and 5.0 kg ha^{-1}.

Of the different materials carrying Fe, ferrous sulphate is the most commonly used inorganic carrier for correcting Fe deficiency in crops. Soil application mode was not so effective and economical as compared to foliar feeding of Fe. In a field study conducted at Bihar it was observed that three foliar sprays of 1-2% ferrous sulphate solution at 10 days interval prevented Fe chlorosis and significantly increased the crop yield **(Sakal, 2001)**. Application of 1% ferrous sulphate solution as foliar spray increased the grain yield of rice from 21.2 to 25.8 q ha^{-1}, barley from 41.8 to 42.2 q ha^{-1}, blackgram from 8.8 to 12.4 q ha^{-1}and chickpea from 17.2 to 19.6 q ha^{-1}. Mixing of 0.2% solution of citric acid in ferrous sulphate solution slightly improved the efficacy of spray as citrate ions help in the mobility of Fe within the plants. In a field trail on iron deficient soil, a response to 820 kg ha^{-1} of wheat over control was attained with 100 kg $FeSO_4$ ha^{-1} and 1% foliar spray of $FeSO_4$ (3 sprays) at an interval of 10 days, respectively (**Gupta et al., 2007**).

Though both soil and foliar application of Mn resulted in a significant increase in grain yield of wheat, but the rates of soil applied Mn (40-75 kg ha^{-1}) are uneconomical as compared to three foliar srpays of 0.5-1.0% $MnSO_4$. H_2O solution (7.5-15.0 kg Mn ha^{-1}). The slightly lower wheat yield in case of broadcast application of Mn is most likely related to its rapid conversion to higher oxides due to greater contact of applied Mn to reactive soil constituents (**Sadana et al., 1991)**. Thus, Mn applied to foliage of wheat is more efficient and economical as compared to its soil application mainly because foliar applied Mn by passes the immobilizing reactions that occur within the soil.

A variety of boron containing fertilizers has been tested for their efficiency and effectiveness for managing B deficiency in field and horticultural crops in India. Significant increase in the yield of wheat was reported due to addition of 20 kg borax ha^{-1} on silty loam acid soils of North Bengal; as high as 1890 kg ha^{-1} additional grain yield was recorded over control **(Mitra and Jana, 1991)**. Among the modes of application, half of the amount of B applied to soil and the remaining half sprayed on the foliage led to higher response as compared to individual applications (either to soil or foliage). Superiority of combining soil and foliar application was ascribed to more uniform availability of B throughout growing period of crop. In a study laid out on a leaching probe acid soil (Inceptisol), 20 kg sodium tetraborate per hectare applied directly to soybean proved superior in increasing yield to two foliar sprays. Not only that, but residual effect of soil application in increasing yield of following wheat also excelled that obtained with two fresh foliar sprays of boron **(Katyal et al., 2004**).

Response of Fababean to different levels of boron application (0, 1.0, 2.0 kg B ha^{-1}) was studied in alluvial soils at Bichpuri, Agra, Uttar Pradesh **(Ali et al., 2013).** Maximum grain and straw yield were obtained at 1.0 kg B ha^{-1}. The mean increase in grain and straw yield due to application of 1.0 kg B ha^{-1} over no boron application was from 4.14 to 4.41 and 4.19 to 4.47 t ha^{-1}, respectively. At higher dose of B (2.0 kg ha^{-1}), a slight reduction in grain and straw yield was recorded over 1.0 kg B ha^{-1} level. The increase in yield may be because of photosynthetic activity of the plant due to B application. Application of 1.0 to 2.0 kg B ha^{-1} initially gave higher response but indiscriminate use of B at more than 2.0 kg ha^{-1} may cause B toxicity in plants and cause deleterious effect of growth and yield of several crops.

Response of oilseed, pulse and vegetable crops to Mo application were observed in acidic soils of Jharkhand, Orissa and Karnataka **(Sarkar and Singh, 2003**). Soil application of 0.6 to 1.5 kg Mo ha^{-1} as ammonium molybdate to groundnut, soybean and cauliflower on a red sandy loam soils of Jharkhand was beneficial and gave response of 19.5, 25.8 and 32.5%, respectively. Greengram and soybean responded well to Mo application as seed treatment in acidic red loam soils of Orissa and yield response was 39.9 and 26%, respectively.

Future Challenges in Micronutrient Research in India:-

- Micronutrient fertilization programmes for nutrients other than Zn and B has not picked up at all. Even in case of Zn where its inclusion in fertilization schedule for cropping systems is more or less established, some aspects need to be immediately probed.
- Delineation and reassessment of micronutrient status in soils should strictly be carried out based on geographical positioning system (GPS) and state-wise and district-wise micronutrient fertility maps should be prepared using geographical information system (GIS) software especially in uncovered areas.
- Development of integrated micronutrient management technology, using available organic materials, in important crop sequences is vital for increasing micronutrient use efficiency. Inclusion of inoculation of vesicular arbuscular mycorrhizal (VAM) fungi in the integrated nutrient supply systems has potential of mitigating deficiencies on not-so-severely deficient soils.
- Monitoring micronutrient deficiencies in different cropping systems in various agro-ecological regions is essential for forecasting potential micronutrient problems.
- Case studies have shown that sewage and industrial effluents and sludges have enriched the soils with heavy metals including micronutrients. Monitoring of both micronutrient and toxic metal concentrations in the edible parts of crops grown on such soils will have important practical significance from animal and human health points of view. Wherever possible, integrated packages including application of these wastes as a component of balanced fertilization should be developed.
- Since importance of micronutrients is increasing beyond soil and plant system and nutritional security of the people of country is becoming a crucial concern, some systematic studies on micronutrient in soil-plant-animal-human continuum need to be conducted to find out effect of micronutrients deficiencies in soils, on animal and human health.
- Micronutrients research on fruits and vegetable crops is scattered and scanty; however, there is ample scope for micronutrients use in these crops for enhancing quality and yield. Intensive micronutrient research in fruits and vegetable need to be carried out.

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