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Implication of Micronutrients in Agriculture and Health with Special Reference to Iron and Zinc

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Abstract

The green revolution fulfilled the food demand of crowded millions. From the time of green revolution to till date high yielding and fertilizer responsive varieties have evolved to increase the production per unit area. To improve the productivity only major nutrients are concentrated almost in all crops. Though the importance of micronutrient realized during past decades in most of the crops but it is not effectively materialized in general crop cultivation practices. The micronutrient deficiencies in soil are not only hamper crop productivity but also deteriorating the produce quality. World health organization (WHO) has estimated that over 3 billion people in the globe suffer from the micronutrient malnutrition and about 2 billion people of these have iron deficiency. Iron is one of the 16 essential elements needed for plant growth. Iron is used for the synthesis of chlorophyll and is essential for the function of chloroplasts. Zinc is involved in membrane integrity, enzyme activation, and gene expression. Rice, sorghum and corn are Zn sensitive and sorghum, sugarcane, groundnut, soyabean, beans, grapes, vegetables and citrus are highly Fe sensitive crops. To overcome these problems foliar spray is being recommended but it is not crop specific or soil specific recommendation. Keeping these problems in the view, recently development of micronutrient efficient genotypes, creating awareness of micronutrient dose, crop specific micronutrient uptake and accumulation are vital to improve productivity and to address human health problems. In this paper we discussed the importance of iron and zinc in agriculture and their role in crop plants and ways to improve the crop productivity as well as human health.

Keywords:
Iron deficiency, Micronutrients, Malnutrition, Zinc deficiency.

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INTRODUCTION

Plants are the immense example of autotroph mechanism. Photosynthesis is a source of energy for virtually all of the organisms on the earth. Survival and reproduction of plants require water, air, light and relatively considerable amounts of nutrients called essential nutrients to carry out photosynthesis and thus produce energy (Wiedenhoeft, 2006). The breakfast you ate today, whether bread, cereal, or cornflakes, was derived from crop plants and also a major raw materials for livelihood of either rich or poor people. To get the benefit from the crop plant we have to protect them from various kind of stress, especially nutrient stress (deficiency). Plant can not synthesis required nutrient, so it extracted from soil medium and loaded into the plant parts and which is to be finally entered in to the food chain. Majority of the people in the semi-arid tropics (SAT) depends on subsistence agriculture for their livelihood. The productivity in these areas is low as compared to those in irrigated agriculture because SAT regions characterized by shortage of water and low soil fertility. Hence the soils in SAT are often referred to as thirsty and hungry soils. As on today, comparatively more rainfed (60%) area under cultivation, however in future such poor soils would be brought under cultivation due to population pressure (Rego *et al.,* 2005). Therefore, we need to create massive awareness and develop model strategy to get the maximum benefits of micronutrients on crop yield and quality and that can be readily accepted by farmers and consumers.

Micronutrient deficiencies in soil not only limit the crop production but it also has negative effects on human nutrition and health. The WHO has estimated that over 3 billion people in the world suffer from micronutrient malnutrition and that about 2 billion people of these have a Fe deficiency (WHO, 2002; Long *et al.,* 2004). In Asia about 35% of children between 0-5 years of age suffer from Fe and Zn deficiency. It affects large segment of population mostly women, infants and children in resource poor families in the country (Singh *et al.,* 2009). Prevalence of anaemia in pregnant women is highest (87.5%) in India. Agriculture is a vital tool of ameliorating micronutrient malnutrition as it is a primary source of all the micronutrients. Agriculture can contribute by numerous way to increasing micronutrients output in stable food crops to meet human needs such approaches include agronomic practices like cultivation of high micronutrient dense seed or variety selection, advanced fertilization and organic matter amendment practices. Micronutrient biofortification in plant system has been considered to be one of the alternative new approaches that may able to minimize micronutrient malnutrition on a large scale (Bouis, 2003). Since, there is a gap between the Micronutrient concentration in plants and those required by human. It is a very complex process to establish the critical levels of micronutrients in plants that are ultimately required for human health.

What is a micronutrient and what for it is?

The drive for higher agricultural production without balanced use of fertilizers created problems of soil fertility exhaustion and plant nutrient imbalances not only of major, but also of secondary and micronutrients (Patel and Singh, 2009). Micronutrients are the essential elements required by plants in relatively low concentrations (Prasad *et al.,* 2006). Micronutrients form a coherent group, including eight core elements: iron (Fe), sodium (Na), chlorine (Cl), boron (B), manganese (Mn), zinc (Zn), copper (Cu), and molybdenum (Mo). Some scientists consider silicon (Si) as a micronutrient. Though it not known to be essential, it is accumulated by plants and used in the plant body at a fairly high concentration. Cobalt (Co) is an essential micronutrient for plant species that form root nodules. Additionally, nickel (Ni) is a micronutrient that, virtually never limiting or deficient in the natural world. In biological system, the micronutrients are needed in low enough concentrations but no way are micro in their role, rather they play major role in enhancing efficiency of macronutrients there by it helps in the physiological processes of growth and development (Shukla *et al.,* 2009).

Significance of micronutrient in agriculture

About four billion people will be added onto the present population by 2050 (Khoshgoftarmanesh *et al.,* 2010). This increase of population further intensified the demand for agricultural food production and to meet this demand, production should increase on the existing land (Cakmak, 2002). Green Revolution on one hand increased crop production per unit area and on other hand it also has resulted in greater depletion of soil phytoavailable micronutrients as less attention has been paid to micronutrients fertilization (Khoshgoftarmanesh *et al.,* 2010). Impact of micronutrient deficiency in crop production is well documented as loss of yield (Shukla *et al.,* 2009). Thus micronutrient deficiency has become a limiting factor for crop productivity in many parts of the world (Singh *et al.,* 2009). Unless increased supply of micronutrient during crop growth as with that of crop removal at every harvest, the deficiency may emerge and limits crop productivity (Shukla *et al.,* 2009). In severe deficiency conditions, the yield loss could reach as high as 100% due to omission of micronutrients in cropping system (Katyal 1985). Now yield loss due to omission of Zn fertilization schedule was about 10 % in India (Shukla, *et al.,* 2009). Improvement in zinc fertility in four decades has helped in enriching seed with higher concentration of Zn in paddy, wheat and maize from 12 to 29, 14 to 72, 28 to 47 mg kg-1 seed respectively and concentration of Fe, Mn, B, and S also increased in seeds and stover with micronutrient fertilization (Singh *et al.,* 2009).

Furthermore, many stable food crops in developing countries can not provide sufficient micronutrient content to meet the demands of their citizens, especially low-income families (Parthasarathy Rao *et al.,* 2006). The most commonly deficient elements in the diet of humans are Fe and Zn (Franca and Ferrari, 2002). Physiologically accumulated micronutrients in plant parts are more bioavailable to humans (Storksdieck and Hurrell 2007). To increase the accumulation of micronutrients in plants biofortification is a good sustainable option. However, the effectiveness of food fortification depends on soil properties, genotypes, agricultural management practices and climatic factors (Schulin *et al.,* 2009). Soil productivity is decreasing globally due to enhanced soil degradation in the form of erosion, nutrient depletion, water scarcity, acidity, salinisation, depletion of organic matter and poor drainage. As indicated in Table 1, nearly 40% of the agricultural land has been affected by soil degradation, particularly in Sub-Saharan Africa and Central America (Scherr, 1999). Enhanced soil degradation along with slowdown in cereal production contributes to food insecurity in developing countries (Cakmak, 2002).

Table 1: Global estimates of soil degradation in agricultural land (Scherr 1999)

Regions	Agricultural land (m.ha)		
	Total	Degraded	Percent
Africa	187	121	65
Asia	536	206	38
South America	142	64	45
Central America	38	28	74
North America	236	63	26
Europe	287	72	25
Oceania	49	8	16
World	1475	562	38

Therefore, balanced micronutrient fertilization to the cultivable soil is most important and thereby to seeds and feeds is very much desired to reduce malnutrition in animals and humans (Singh *et al.,* 2009).

Is micronutrient deficiency will cause food and nutritional insecurity?

If we were to assume that all land currently in agriculture would continue to be as productive as it currently is, with no loss of land devoted to agriculture, we could, from a purely nutritional standpoint, feed the world (Wiedenhoeft, 2006). In the late 1950's around a billion people about one-third of the world's population were estimated to go hungry every day. In response to this alarming picture, scientists, policymakers, farmers, and concerned individuals initiated a concerted push to boost agricultural productivity particularly in developing countries where large portion of world hungry people resides. While massive gains in improving the availability of and access to food were achieved in China, India, and many other developing countries as a result of these successes, far less has been achieved in improving the quality of food. The land serves as storage for water and nutrients required for plants and other living organisms. Thus demand for food, nutrition and other human requirements depends upon the preservation and improvement of the soil productivity. But over the decades cultivable land resources are shrinking by populated industrial world. For instance in India, increasing population has reduced the availability of land over the decades. The per capita availability of land has declined from 0.89 hectare in 1951 to 0.37 hectare in 1991 and is projected to slide down to 0.20 hectare in 2035 (Govt. of India, 2010). Therefore it needs improvement in terms of its production per unit area to meet the food security challenge.

Rainfed agriculture is characterized by low levels of productivity, erratic rainfall and low input usage makes crop production unstable from year to year. More than 200 million of the rural poor live in the rainfed regions and they are far from the levers of political power and beyond the range of vision of the media. Except when war or a natural calamity briefly focuses global attention and sympathy, little is said and less is done to put an end to the suffering of a ‘continent of the hungry’. The green revolution bypassed the more nutritious orphan food grains like pulses, which are the major source of proteins in vegetarian Indian diets, as well as millets like sorghum (jowar), pearl millet (bajra), finger millet (ragi) and many other smaller millets which were the staple for many populations living in dryland areas (Bamji, 2007) and this made the situation worst for the people living in dry land areas compared to other places where green revolution has made the people suffice enough to meet their agricultural food demands. The countries that succeeded in reducing hunger were characterized not only rapid economic growth but specifically by rapid growth in their agricultural and allied sectors. They also exhibited slower population growth and higher ranking in the UNDP’s Human Development Index (FAO, 2003). On the other hand dry land areas have shown less economic growth and agricultural production with high population growth. Less agricultural production are majorly caused by nutrient deficient soils (infertile) which reduces the food security. Micronutrient deficient soil decreases the nutrition quality of food produced from this soil which increases nutritional insecurity of the regions. Therefore the dry land areas are the “hot spot” as nutrient deficient lands have high potential to degrade further with changing climate.

Food and nutrition security can be achieved, if adequate food (quantity, quality, safety, socio-cultural acceptability) is available and accessible for satisfactorily usage by all individuals at all times to live a healthy life. Since, micronutrient deficiency occurs in cultivable land, the application of fertilizers needs to be continued for better production. Though, India is the third largest producer and consumer of fertilizers in the world after China and USA, but the fertilization well adopted in certain states it need to be followed all over the country irrespective of the crop cultivation (Govt. of India 2010). Hence, by understanding the proper plant nutrition uptake, rhizosphere mechanisms, and their bioavailability through agronomic and breeding approach, we can identify the future avenues of research that may help to alleviate nutritional insecurity problems.

Geographical distribution of low Fe and Zn soil

Zinc deficiency recognized as one of the widest spread plant nutrient disorders in the world (Brennan *et al.,* 1993), zinc and iron deficiency spread both in tropical and temperate regions (Sillanppa and Vlek, 1985). This problem exists even in developed countries like Australia and USA (Kubota and Alloway, 1972; Welch *et al.,* 1991). Asia is a most well documented areas for Zn deficient, particularly arid and semi arid region of India (Nayyar *et al.,* 1990) in paddy fields of Pakistan (Rasid and Rafique, 1998),

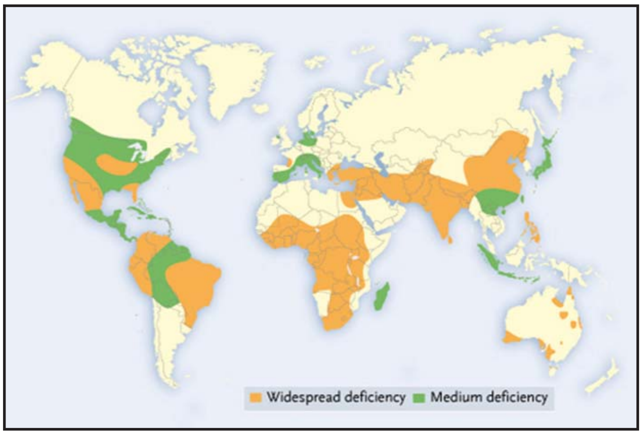

Figure 1: Geographical distribution of low Zn soil section in the world (adapted form Alloway, 2008).

poorly drained calcareous soils of china (Sillanppa, 1982). The total and available micronutrient contents in Indian soils were reported in detail at end of 20th century. The total Fe content of soil ranged from 13000 to 80000 ppm with average of 33000 ppm, and the Zn content ranged from 20 to 97 ppm with an average of 55 ppm (Rattan *et al.,* 1999). The availability of the trace element was very little, Fe availability ranged from 3.40 to 68.1ppm (average of 20.5 ppm) similarly Zn ranged from 0.12 to 2.80 ppm with a mean of 0.54 ppm (Rattan *et al.,* 1999).

In India, analysis of 2.52 lakhs surface soil samples collected from different parts of the country revealed the predominance of zinc deficiency in divergent soils. Of these samples 49, 12, 4, 3, 33 and 41 percent soils are tested to be deficient in available zinc (Zn<1.0ppm), iron (Fe<6.3ppm calcareous soil and <3.6ppm non calcareous soil) manganese (Mn), copper (Cu) , boron (B) and sulphur (S), respectively (Singh 2009). Calcareous soils of Bihar, Vertisols and Inceptisols of Andhra Pradesh, Tamil Nadu and Madhya Pradesh and Aridisols of Haryana showed extensive deficiency of zinc resulting low crop yields (Singh and Abrol, 1986). Zinc deficiency map of different states of India developed by Indian Institute of Soil Science, Bhopal and the states which showing severe deficiency were depicted in Figure 2. In general, depletion of soil macronutrients would take only a few years if there were no replacement whereas, for the micronutrients, depletion may take hundreds or even thousands of years. In fact, depletion may never occur at all, owing to various inadvertent additions and other soil forming processes (Graham and Welch, 2000). However the massiveness of Zn deficiency in Indian soils well documented and confirms that half of the Indian agricultural land is suffering from Zn deficiency (Rattan *et al.,* 2009). Zinc deficiency is the most widespread in the four IGP (Indo-Gangetic Plains) countries viz. Bangladesh, India, Nepal, and Pakistan. Some areas in Punjab, India revealed a marked decrease in the extent of zinc deficiency but there has been an increase in the deficiency of iron and manganese.

The extent of iron deficiency is approximately a fifth that of zinc deficiency and is largely influenced by the vast areas under alkaline to calcareous soil tracts. Iron deficiency is only second in importance after zinc deficiency in Punjab and Haryana in India. Manganese deficiency is in localized sites where rice-wheat crop rotation is practiced in coarse-textured soils. Copper deficiency is not widespread in the IGP, but deficiency based on plant analysis is higher than soil analysis. The critical limits used for soil copper or plant copper need to be re-calibrated. The incidence of boron deficiency was highest in the acid soils of West Bengal followed by the calcareous soils of Bihar (Nayyar, 2001). Long term field experiment results indicated that rate of depletion of micronutrients under continuous cropping in soil was in the order of Zn >Fe>Mn>Cu (Patel and Singh, 2009).

Diagnosis of micronutrients deficiencies in soil and plant samples

Soil samples can be taken at any time of the year but care is needed to ensure that a representative sample has been taken over the full area of the field. It is also important to avoid contamination of the soil samples by contact with metal equipment. The soil tests most widely used around the world include AB-DTPA (Soltanpour and Workman, 1977) and DTPA (Lindsay and Norvell, 1978). These are multielement soil tests for alkaline soils and effective as conventional micronutrient tests for Cu, Fe, Zn and Mn (Imtiaz *et al.,* 2006). The GPS provides accurate positioning of the sample points, so that accurate geo-referenced maps of nutrient levels can be made with geographic information systems (GIS), and related to other data sets such as yield maps, soil survey, and remote sensing imagery. Even if GPS is unavailable, sample points should be referenced.

Plant micronutrients were analyzed using standard wet digestion and dry ashing method. Full recovery of micronutrient (Zn and Fe) in high-silica containing plant tissues (like wheat, barley, rice, sugarcane etc.) is not possible by dry ashing procedure. Therefore, this kind of plant materials should be wet-digested using Di acid (HNO_3-$HClO_4$) or Tri acid (H_2SO_4-HNO_3-$HClO_4$) mixture. Many other elements (like P, K, Ca, Mg, Na) can also be determined in the same digest.

Table 2: Sufficiency range of Fe and Zn concentrations in critical stages of different crops

Crops	Fe(ppm)	Zn(ppm)	Stage	Parts to be sampled
Rice	100-150	25-50	Seedling or heading stage	Fully expanded middle leaves
Wheat	50-250	20-60	Seedling or heading stage	Fully expanded middle leaves
Oats	50-200	20-50	Seedling or heading stage	Fully expanded middle leaves
Barley	50-250	20-50	Seedling or heading stage	Fully expanded middle leaves
Maize	40-400	25-50	Tasseling or Silking	Ear leaf
Sorghum	50-500	25-50	-	-
Millets	50-250	15-70	-	-
Pulses	50-250	20-40	Seedling stage	Entire above ground plant parts
Soybean	100-250	20-60	-	-
Groundnut	50-250	10-50	Blossom stage	Fully expanded top leaves
Sunflower	50-250	20-50	Blossom stage	Fully expanded top leaves
Sugarcane	100-1000	10-20	Grand growth stage (up to 4 months)	Fourth fully opened leaves from the top
Cotton	50-250	20-50	First bloom or square forming	Youngest fully expanded leaves in the main stem

During plant sample collection time of sampling and sample section (top leave/ bottom leave) are important factor to be considered to enhance the accuracy of the results (Table 2).

The critical micronutrient values for both soils and field crops have not been extensively field tested; field validation will be of immense help to researchers and extension specialists. An eco-regional soil and plant micronutrient status-analysis in India and synthesis of this information using geographic positioning system (GPS) and geographic information system (GIS) will facilitate delineating regions of specific deficiencies. This will help to formulate on-farm diagnostic and adaptive research, spreading of awareness amongst farmers, and extrapolating results to similar regions within India where intervention programs on micronutrients can be undertaken (Nayyar *et al.,* 2001).

Crop species and micronutrient deficiency

Although minerals are abundant in most soil, iron and zinc are the most common nutrients limiting plant growth in the world (Guerinot, 2001; Rattan *et al.,* 2009). Sorghum, sugarcane, groundnut, soyabean, beans, grapes, vegetables and citrus are highly iron sensitive crops where as millets, sugar beet and potatoes are less sensitive crops. Cereals exude phytosiderophores, which mobilise Fe and other essential nutrients of low availability. These organic acids solubilize micronutrients by competing for cation binding sites. Zinc deficiencies affect the physiology of plants and can cause many problems within the plant. Visual symptoms of zinc deficiency in plants are leaf mottling, interveinal chlorosis, and reduced plant growth. Zinc is involved in membrane integrity, enzyme activation, and gene expression (Kim *et al.,* 2002). Despite the importance of zinc as a micronutrient for plant growth, there have been relatively few studies of the mechanism of zinc uptake (Reid *et al.,* 1995). Soil analysis of major soil series in India clearly indicated that Zn is the most limiting micronutrient (Rego *et al.,* 2005). Zn deficiency is common in a wide range of soil types, including high pH calcareous soils, sandy soils and high phosphorous-containing fertilized soils (Marschner, 1995).

Zn available to plants is present in the soil solution or is adsorbed to the roots in a labile form. Many soil factors affect the availability of Zn to plants. These include the total Zn content, pH, organic matter content, calcium carbonate content, redox conditions, microbial activity in the rhizosphere, soil moisture status and concentration of other micronutrients and macro-elements (Alloway, 2004). In total, about 30% of the soils in the world are affected by Zn deficiency (Sillanpaa 1990). Plant tolerance to micronutrient-deficient soils, termed micronutrient use efficiency, is a genetic trait that characterizes the adaptation of a genotype to micronutrient-deficient soils compared to the average cultivar of the species (Graham, 1984). Within crop species, individual varieties can often vary considerably in their response to Zn deficiency (Hacisalihoglu

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[1] *Grain yield efficiency index (Fageria, 2001) = (Yield at low Zn level/Experimental mean yield at low Zn) / (Yield at high Zn level / Experimental mean yield at high Zn).*

and Kochian, 2003). Growing Zn-efficient plants on Zn-deficient soils represents a strategy of “tailoring the plant to fit the soil” in contrast with the alternative strategy of “tailoring the soil to fit the plant” (Ruel and Bouis, 1998), and will be a more environmental friendly and sustainable approach.

Crop species markedly differ in their ability to adapt to Zn deficient soils (Graham, 1984). Among the some cereal species such as, rice, sorghum and corn are classified as Zn sensitive, whereas, barley, wheat and rye are classified as less sensitive (Clark, 1990). Grain yield efficiency index [1] was used to classify genotypes into efficient and inefficient groups. This index is useful in separating high yielding, stable and Zn efficient genotypes from low yielding, unstable and Zn inefficient ones. Genotypes with grain efficiency index higher than one are considered Zn-efficient.

Influence of soil factors on Fe and Zn availability

The soil characteristics are essential to determining the availability of micronutrients to plants, and therefore the crop yield potential and crop quality. Soil factors affecting the crops production are organic matter content, pH, texture, structure, cation exchange capacity (CEC), slope and topography, soil temperature, depth of root zone and soil management factors such as tillage and drainage (Tisdale *et al.,* 1993). Many of these soil factors have potential for manipulation by farmers in order to improve crop yields. For instance, Gypsum ($CaSO_4$) and elemental S are used to decrease the pH of alkaline soils as well as to amend sodic and saline-sodic soils. Application of acid producing amendments on alkaline and calcareous soils could decrease soil pH and consequently increase plant-available Fe and Zn (Singh *et al.,* 1989). The trace element zinc (Zn) and iron are essential to the normal growth of plant. Only a small proportion of the total trace elements in soil are available. The mobility and availability of trace elements is controlled by chemical and biochemical processes including precipitation-dissolution, adsorption- desorption, complexation-dissolution and redox processes (Hursthouse, 2001). Most metallic micronutrients, including iron and zinc, are relatively insoluble in soils. This insolubility is especially marked in soils where pH is greater than 5, as in many areas with low rainfall. Under these conditions, micronutrient cations react with hydroxyl ions, precipitating hydrous metal oxides. In order to hold these cations in solution, they must bond with an organic ligand, or chelating agent, which donates electrons to the cation (Salisbury and Ross, 1992). Iron is a transition metal, and is ubiquitous in biological systems (EVP, 2003). Total iron concentrations in most soils are more than sufficient to supply plants, but actual availability is controlled by soil factors that govern iron solubility (Steyn and Herselman, 2005). Iron deficiency in crops, characterised by interveinal chlorosis, is a worldwide problem in calcareous soils. It is often treated by the addition of a commercial chelator. Although iron is more available at pH 5.5, the problem also exists that, in acidic soils, soluble aluminium is abundant, which restricts iron absorption by plants (Salisbury and Ross 1992). In aqueous solution, iron exists in two oxidation states: the ferrous (Fe^{2+}) and ferric (Fe^{3+}) forms. Of these two forms, Fe^{2+} is more soluble, and thus more easily absorbed by plant roots. However, in well-aerated soils, Fe^{2+} is oxidised to Fe^{3+}, which precipitates. Ligands, synthesised either by soil microbes or by plant roots, form chelates with iron which prevent precipitation. The ability of plants to produce ligands is thought to be a defence mechanism against iron deficiency; there are two recognised strategies for iron requisition by plants (Charlson and Shoemaker, 2006; Cakmak, 2002). Most plants acquire Fe^{2+} from soil after reduction of Fe^{3+} using the strategy I mechanism which involves the release of phenol-like ligands. Grasses, including cereals, employ the strategy II mechanism, which involves the synthesis, secretion and uptake of phytosiderophores that chelate Fe^{3+} from soil (Charlson and Shoemaker, 2006). By growing plants with greater chelating ability, iron uptake in calcareous soils can be improved without the need for the application of artificial chelators.

As for iron, zinc deficiency is common throughout the world, particularly in soils with high pH, and is thought to be the most widespread micronutrient deficiency in cereals (Ruel and Bouis, 1998). It is a worldwide nutritional constraint for crop production, especially in calcareous soils. Fifty percent of soils used for cereal production contain low levels of plant available zinc (Graham and Welch, 1996), therefore reducing grain yield and nutritional value for human or animal food. Deficiency of zinc causes decreased growth of leaves and stem internodes, and results in interveinal chlorosis, which often occurs in maize, sorghum and beans (Salisbury and Ross, 1992). Unlike iron, zinc does not need to be reduced before transport. It is absorbed as divalent Zn^{2+}. It is thought that plants which extrude phytosiderophores in response to iron deficiency may also use this chelation strategy in order to obtain zinc from the soil (Welch, 1995). Several zinc-efficient cultivars exist, which are thought to have increased ability to obtain the limiting nutrient rather than increased tolerance to lower levels (Grotz and Guerinot, 2006). Distinct differences occur within and among various cereal species in terms of susceptibility to zinc soil deficiency, which is closely related to the total amount of zinc per shoot. When zinc fertilizer is applied to the soil growing various species and hybrids, rye in particular has shown a remarkable increase in zinc content in the shoots. This is explained as a genotypic difference, and has important implications for the place of zinc fertilizer application, which would be valuable for the yield of grain in rye but not so for certain varieties of wheat (Cakmak *et al.,* 1997).

Plant factors influences for Fe and Zn uptake

There are three ways in which nutrient ions in soil reach the root surface. These are interception, whereby ions attached to root hair surfaces (e.g. H^+) may exchange with ions held on the surface of clays and organic matter in soils due to intimate contact; mass flow, where nutrients are transported in the flow of water to the root resulting from transpirational water uptake by the plant; and diffusion, involving ions moving from areas of high concentration to those of low concentration. Upon reaching the root surface, ions are moved into the plant root by passive and active uptake. Generally, ions in the soil solution enter the roots through passive diffusion and ion exchange. They are then actively taken up into cells against an electrochemical gradient by ion carrier complexes (Tisdale *et al.,* 1993). Once micronutrient divalent metals are absorbed into plants, they are kept soluble partly by chelation with cellular ligands; organic acids, are important for the transport for example, iron and zinc through the xylem (Shah and Nongkynrih, 2007). Ultimately, much of the iron and zinc is bound to proteins, where they catalyse the electron transport processes of photosynthesis and respiration, and increase the catalytic activity of enzymes (Briat *et al.,* 2007).

Iron and Zinc Uptake

Iron and zinc are usually present in soil in adequate to excess amounts, but deficiency is caused by their presence in an unavailable form rather than by their lack, and a plant can improve its iron and zinc uptake by using strategies solubilize the iron and zinc present in the soil (Rengel, 2001). For the most part, plants acquire micronutrients by absorbing them from the soil solution; therefore, the availability of micronutrients to plants is closely related to the solubility of the forms in which they appear (Aquaah, 2002). Several environmental factors can affect the solubility of micronutrients. Leached, acid, sandy soils, organic soils, soils that have supported intensive cropping, soils with high pH, and eroded soils all tend to be low in available iron and zinc (Brady and Weil, 2002). Uptake efficiency of soil-grown plants may consist of increased capacity to solubilize non-available nutrient forms into forms that are available to the plant, and/or increased capacity to transport nutrients across the plasma membrane. However, it appears that increased conversion capacity is of greater importance for efficient uptake, especially for nutrients that are transported to roots by diffusion (Rengel, 2001).

Utility of resources for increased crop yield in mineral deficient soils

Mineral nutrients have played an important role in enhancing crop production since the beginning of the green revolution. According to Borlaug and Dowswell (1993), nearly half of the increased crop yields during the 20th century were due to application of chemical fertilizer. The increase in crop production has been mainly resulted from the application of N-P-K fertilizers (Brady and Weil, 2002). In contrast, alleviation of micronutrient deficiencies to improve crop yields is difficult due to large temporal and spatial variation in phytoavailability of soil micronutrients (Brennan and Bolland 2006; Shaver *et al.,* 2007). The easiest and most straightforward practice to correct micronutrient deficiency is to apply micronutrient fertilizers.

In India, there are 686 Soil Testing Laboratories. These include 560 static and 126 mobile laboratories maintained by either state governments or state agricultural university. During 2008-09, an amount of Rs.16.63 crore has been released under National Project on Management of Soil Health and Fertility" (NPMSF) for 42 new Static Soil Testing Laboratories (STLs), 44 Mobile Soil Testing Laboratories (MSTLs), strengthening of existing soil testing laboratories and fertilizers quality control laboratories (FQCLs) in 16 States (Govt. of India, 2010). Kisan Call Centres have been functioning since 21st January, 2004 and working in different locations covering almost all the States of the country where farmers can get information to improve soil health and fertility for higher productivity.

Role of micronutrient (use) efficient cultivars in deficiency soils

The utilization efficiency of applied fertilizers under field conditions is poor. This results in loss of a costly input and accentuates the environmental degradation. Therefore, the development of cultivars with improved mineral use efficiency is an important contribution to sustainable production system. Nutrient use efficiency is defined as the ability of a genotype to realize better grain yields under low soil nutrient conditions in comparison with other genotypes.

Genetic variability and plant ability to absorb, translocate, distribute, accumulate and use mineral elements are important in adapting plants to specific environments. It is well documented that genotypes (cultivars, parental lines and hybrids) within species differ extensively in their ability to take up and use mineral elements. Taking advantage of these differences, selection or improving plants for greater adaptation or to have greater efficiency to take up and use mineral elements is becoming more important. Though variability in plant species for mineral use efficiency has been recognized for a long time, but only recently have these differences been considered conscientiously to adapt plants to fit soil mineral nutrient stress conditions or to improve efficiency of nutrient uptake and use. The research in this area will hopefully help to reduce input use and enhance plant productivity with more efficient plants.

Exploiting the genetic variation in crop plants for micronutrient density is one of the most powerful tools to change the nutrient balance of a given diet on a large scale (Graham and Welch, 2000). Crop genotypes with root traits permitting increased nutrient acquisition would increase yields in low fertility soils but have uncertain effects on soil fertility in the long term because of competing effects on nutrient removal vs. the soil conserving effects of greater crop biomass. The Indian soils have been under intensive cultivation for hundreds of years and the deficiencies of various micronutrients are not surprising (Rego *et al.,* 2005). Reduction of micronutrient deficiency can be alleviated simply by balanced application of micronutrient. However, it is not always successful and sustainable solution due to agronomic and economic factors such as reduced availability of micronutrient element owing to topsoil drying, subsoil constraints, disease interactions, and cost of fertilizer in developing countries.

Though several agronomical techniques have been developed and practiced to increase plant mineral content, attempts to explore breeding strategies and genetic principles are scanty. Currently, numbers of breeding programs are ongoing to develop new cereal genotypes with high genetical ability to absorb Zn and Fe from the soil and accumulate in grain at desired levels for human nutrition. The critical value of Zn content in pearl millet plant 16.7 ppm, where as soil had only 0.56 ppm of available Zn. This low value clearly have made, pearl millet a relatively resistant crop to Zn deficiency and it can grow successfully when crop like maize and other cereals

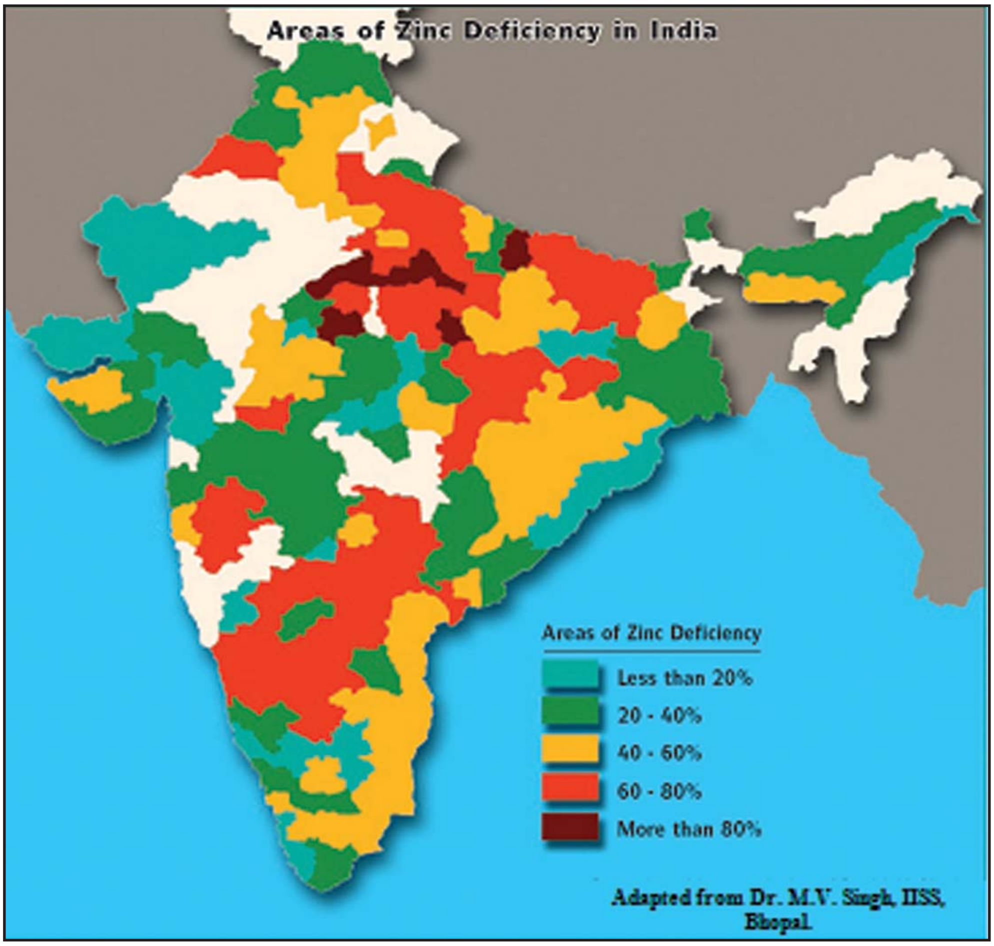

Figure 2: Geographical distribution of Zn deficient soils in different states ofIndia.

may adversely affected by Zn stress (Gupta *et al.,* 1981). The differential zinc efficiency (ZE) has been reported in several crop species including common bean (*Phaseolus vulgaris* L.) (Ambler and Brown 1969; Singh and Westermann 2002) and wheat (Cakmak *et al.,* 1997; 1998; Rengel and Romheld 2000). Moraghan and Grafton (1999) compared the growth and seed-Zn accumulation of four bean cultivars. They reported that seed-Zn content could be used as an important indicator for selecting Zn-efficient bean genotypes. In studies on wheat cultivars, it was found that shoot-Zn concentrations are not a reliable parameter for screening genotypes for ZE, but genotypic differences in Zn translocation capacity from older into younger organs may be an important factor in the expression of high ZE (Torun *et al.,* 2000).

In green plants there is often a good correlation between the level of Fe supply and the chlorophyll content, plants well supplied with Fe being high in chlorophyll (Jacobson and Oertli, 1956; Dekock *et al.,* 1960). Zinc Efficiency was found to be positively correlated with the activity of the Zn-requiring enzyme Cu / Zn SOD for wheat (Cakmak *et al.,* 1997; Hacisalihoglu *et al.,* 2003) and black gram (Pandey *et al.,* 2002). No correlation was noticed between 59Fe uptake and Fe stress tolerance mechanisms (Kannan 1980).

Agronomic management measures to reduce Fe and Zn deficiency

An application of 5 kg zinc ha-1 to alluvial red and lateritic soils and 10 kg zinc ha-1 in swell-shrink soils or application of 12.5t /ha FYM and enriched Zn (200kg cowdung+25 kg $ZnSO_4$ incubate it for 45 days). Seed costing of pulses with $ZnSO_4$ @20g/kg and foliar spray of 0.5% $ZnSO_4$ twice at 15 days interval was found optimum in ameliorating zinc deficiency. Soil application of FYM 12.5 t /ha and $FeSO_4$ 25 kg/ha as basal dose all the crops except sugarcane

(100kg/ha). Foliar spray of 0.5% $FeSO_4$ twice at 15 days interval was found optimum in ameliorating iron deficiency.

Future directions

- Iron and zinc deficiency in soil and crop plants has been recognized as a worldwide nutritional constraint. Hence, large number of controlled experiments must be conducted to screen and evaluate dry land soils and crop genotypes for iron and zinc use efficiency.
- The screening method used for iron and zinc use efficiency should be simple and does not require much plant analysis. So that it becomes cost effective breeding strategies.
- Field design for nutrient use efficiency and its evaluation trials should be universally proved. Development of appropriate statistical package for analysis the complex data obtained form such genetical studies.
- Still, a close interaction between the soil scientist and breeders is lacking which sometimes becomes a limiting factor and progress becomes sluggish.

CONCLUSIONS

Zinc and iron deficiency leads to crop yield losses and human health problem. Importance of micronutrient in agriculture systems have been realized middle of 20th century but not intensively yet practiced in many crops. To improve zinc and iron in crop produces, focused research on, to evolve high micronutrient responsive variety, plant and soil diagnostic kits, soil and crop specific management studies to be carried out. Effective outreach to farmers to adopt recommendation will improve crop productivity, quality of crop produce and improve the Fe and Zn availability to human and animals.

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