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Factors Responsible for Micronutrients Availability in Soil-Plant System

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SUMMARY

In India, the depletion of soil micronutrient is a cause for concern. Most soils in India are generally poor in fertility as they have consistently been depleted of their nutrient resources due to continuous cultivation. The micronutrient deficiencies of zinc, iron, manganese and boron are widespread and are associated with specific soils or soil cropping systems. This has resulted in the soil becoming a poor food crop producer. The states severely affected include Punjab, Haryana, Bihar, Uttar Pradesh, Madhya Pradesh, Gujarat, Tamil Nadu and Andhra Pradesh. In most of these states micronutrient deficiencies are widespread. The national thrust has been on maximization of food production to feed its expanding population. This has resulted in the depletion of micronutrient reserves. Modern agriculture, which relies heavily on intensive cultivation and use of fertilizers, has depleted the micronutrient reserves of the soil. Unless immediate steps are taken to replenish the micronutrient reserves, the soil will lose all its fertility. The improper or imbalanced use of fertilizers has worsened the problem at many places. The increasing use of fertilizers generally devoid of micronutrients has brought about the problem related to micronutrient deficiencies by depleting the resources in the soil. Although fertilizers are essential for increasing production, they should be used very judiciously. A few important factors which affect the soil micronutrient status are extensive cultivation of fertilizer-responsive high-yielding varieties on marginal soil.

INTRODUCTION

By the term 'micronutrient availability' we mean the total micronutrient forms in soils, which are available for plants (i.e., all the soluble forms that can be taken up by plants). Availability depends on solubility in soils, i.e., the solubility of micronutrients in soils determines their availability for plants (thus their uptake) and their downward mobility. Understanding the factors controlling trace element solubility allows the selection of soil amendments that promote or reduce their availability and of course the selection of the suitable plant species (those that are optimal for the desired goal of managing trace element influx in the soil-plant system). There are many soil factors influencing micronutrient solubility and availability for plants. Micronutrients are most apt to limit crop growth under the following conditions: a) highly leached acid sandy soils, b) muck soils, c) soils very high in pH and d) soils that have been very intensively cropped and heavily fertilized with macronutrients only. Strongly leached acid sandy soils are low in micronutrients for the same reasons they are deficient in most of the macronutrients. Their parent materials were originally deficient in the elements and acid leaching has removed much of the small quantity of micronutrients originally present. The micronutrient contents of organic soils are dependent upon the extent of the washing or leaching of these elements into the bog area as the deposits were formed. Intensive cropping of muck soils and their ability to bind certain elements, notably copper, also accentuate trace element deficiencies.

Factors Affecting Availability of Micronutrient in Soil

The availability of micronutrients to plants depends on several factors such as Soil pH, Oxidation state, Organic Matter, Chelates, Arbuscular mycorrhizal fungi, Inorganic reactions,other factors etc. It is also not possible to select the most important soil factors influencing micronutrient availability to plants, because all factors are equally important and their importance can vary between elements. However, certain soil factors have the same general effects on the availability of all of them.

Soil pH: The micronutrient cations are most soluble and available under acid conditions. In very acid soils there is abundance of the ions of Fe, Mn, Zn, and Cu. In fact, under these conditions the concentrations of one or more of these elements is often sufficiently high to be toxic to common plants. As the pH is increased, the ionic forms of the micronutrient cations are changed first to the hydroxyl ions of the elements and finally to the insoluble hydroxides. All of the hydroxides of the trace element cations are insoluble, some more so than others. The exact pH at which precipitation occurs varies from element to element an even between oxidation states of a given element. At low pH, most of the B compounds are soluble and remain available to plants as boric acid (Deb et al. 2009). Moreover, availability of B is less in acid soils as compared to alkaline soils (higher pH). In acid soils, Mo availability is a serious problem as it gets fixed with Fe and Al compounds as well as on silicates, thus unavailable for plant use (Choudhary and Suri 2013).

Oxidation State: The degree of oxidation or reduction in soil is indicated by the redox potential measurement. In soils, reducing conditions are brought by anaerobic conditions as a result of waterlogging, while oxidised conditions are normally found in well-drained aerobic soils (Dass et al. 2015). The reduced states of Fe, Mn and Cu are more soluble than higher oxidation states at normal soil pH range. Generally, high pH favours oxidation, whereas acid conditions are more conducive to reduction (Brady 2002; Deb et al. 2009). At neutral soil conditions, oxidised states of micronutrient cations are generally less soluble than at reduced states. At low pH and poor aeration, micronutrient cations are somewhat more available at restricted drainage; thus, flooded soils generally show higher availabilities than well aerated ones (Dass et al. 2015). At high pH range, well-drained, aerated, calcareous soils are sometimes deficient in available Fe, Zn or Mn that exists in oxidised state, even though adequate quantities of these elements are present in soil; therefore, plant suffers from micronutrient deficiency (Brady 2002; Deb et al. 2009).

Organic Matter: Soil organic matter (SOM) has been related to increased, decreased and no effects on micronutrients availability to crop plants (Tisdale et al. 1985). Soils that receive regular additions of organic residues or manures rarely show micronutrient deficiencies as excessive application of P fertilizer in overly manured soils, leading to Zn deficiency (Das 2011; Kumar et al. 2014). Soils rich in organic matter content accumulate higher amount of heavy metals in sorption complex and are released slowly in soil solution as compared to mineral soils, which is attributable to high affinity of soil organic compounds to heavy metals. Further, extremely high organic matter content in soil (muck or peat) also induces micronutrient deficiencies due to strong natural chelation i.e. combination of a micronutrient with an organic molecule, which makes some of the micronutrients unavailable, especially copper, manganese and zinc.

Chelates: Microorganisms in the rhizosphere continuously produce chelating agents during the decay of plant and animal residues that have ability to transform solid phase micronutrient cations into soluble metal complexes and thereby increase the availability of insoluble micronutrients to plants (Deb et al. 2009). Natural organic chelates in soils are products of microbial activity and degradation of soil OM and plant residues. Many natural organic chelates have not been identified; however, compounds such as citric and oxalic acids formed during decomposition and exuded by roots have chelating properties. Artificial chelates are widely used in micronutrient fertilizer applications.

Arbuscular Mycorrhizal Fungi: Arbuscular mycorrhizal fungi (AMF) is known to induce many favourable changes in the crop rhizosphere by way of exudation/secretion of organic acids/chelating agents (Kumar et al. 2014), which lead to efficient solubilisation and mobilisation of plant nutrients from organic and inorganic complexes (Choudhary and Suri 2013). Further, AMF greatly influence the absorption of micronutrients through extended rhizospheric exploratory area due to hyphal network (Harrier and Watson 2003). Thus, AMF has the ability to increase micronutrient availability to crop plants. Like AMF, there are a number of microbes in rhizosphere that play an important role in micronutrient regulation.

Inorganic Reactions: Micronutrients interact with silicate clay in two ways. First they may be involved in cation exchange reactions much like those of Ca an H. Second they may be more tightly bound or fixed to certain silicate clays, especially of the 2:1 type. Zinc, manganese, Co and Fe are found as integral elements in these clays. Depending on the conditions, they may be released from the clays or fixed by them. The fixation may be serious in the case of Co and sometimes Zn since these two elements are present in soil in such small amounts. The application of large quantities of phosphate fertilizers can adversely affect the supply of some of the micronutrients. The uptake of both iron and Zn may be reduced in the presence of excess phosphates. From a practical standpoint, phosphate fertilizers should be used in only those quantities that are required for good plant growth. Lime induced chlorosis (Fe deficiency) in fruit trees is encouraged by the presence of the bicarbonate ion. The chlorosis apparently results from iron deficiency in soils with high pH. In some way the bicarbonate ion interferes with iron metabolism.

Other Factors: Application of irrigation water contains varying levels of micronutrients as well as other nutrients. When land is levelled to accommodate irrigation, micronutrient deficiencies, particularly Zn, often occur because the available Zn is removed with the surface soil (organic matter). Fixation of micronutrients by soil clays may cause serious problems for Zn and Cu and is less significant for Fe and Mn because of their high total content in soils (Deb et al. 2009). The general soil conditions that influenced micronutrient availability and acquisition by plants are given in Table 13.7. Nutrient acquisition by plant is a dynamic process in which nutrients are continuously replenished in soil solution from soil solid phase followed by transportation to roots for absorption by plants (Choudhary and Suri 2013). In soil system, nutrients move to plant roots by mass flow, diffusion and root interception. More than 90–95 % of B, Cu and Zn and considerable quantity of Fe (65 %) are supplied to plants by mass flow. Considerable quantities of Mn, B and Fe (>20 %) move by diffusion, whereas root interception plays a significant role in B, Zn and Mn absorption. In recent years, increased anthropogenic activities such as burning fossil fuels, application of sewage and industrial sludge, use of amendments (fertilisers, manures, lime), application of pesticides and deposition of atmospheric particles induce addition of toxic trace elements like Cd, Cr, Ni, Pb, Cu, Zn, As, Co and Mn (including some essential micronutrients) in soil–plant system. Excessive levels of trace elements may pose phytotoxicities to crop plants. Liming of acid soils reduces N availability due to lime-induced B fixation by freshly precipitated Al and Fe hydrous oxides; overliming further induces B deficiency in crops. Liming of acid soils increases the availability of native Mo (Deb et al. 2009; Kumar 2012).

CONCLUSION

The micronutrient deficiencies in agriculture are limiting the crop production worldwide, and these deficiencies will likely to increase in the future. Micronutrients are not only important for better crop productivity but also essential for sustaining human and animal health. A sharp increase in micronutrient uptake and yield of crops by alleviating soil conditions through proper management practices, liming and applying micronutrients directly in soil or as foliar application. Moreover, exploitation of soil microbes such as micronutrient solubilisers and AM fungi has proven as boon in micronutrient uptake and improving soil quality. Maintenance of optimum soil organic matter status and balanced fertilization or soil test-based fertilizer application also lead to eliminate micronutrient deficiency and improve soil and plant health.

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