

Chapter 9. Micronutrients: A summary

The seven micronutrients, including boron, copper, chlorine iron, manganese, molybdenum, and zinc, are no less important to plant growth than are the macronutrients in the soils. Micronutrients are required in very small quantities of only a few mg/kg in plant tissues, being one or more orders of magnitude lower than for the macronutrients.

Micronutrients play many complex roles in plant nutrition and plant production. While most of the micronutrients participate in the functioning of a number of enzyme systems, there is considerable variation in the specific functions of the various micronutrients in plant and microbial growth processes. For example, copper, iron, and molybdenum are capable of acting as electron carriers in the enzyme systems that bring about oxidation-reduction reactions in plants. Such reactions are essential steps in photosynthesis and many other metabolic processes. Zinc and manganese function in many plant enzyme systems as bridges to connect the enzyme with the substrate upon which it is meant to act.

BORON

Boron (B) deficiency is widespread in many countries, including the Philippines, Thailand, Korea, Malaysia, Japan, and Taiwan ROC. It is more common in volcanic soils, acidic soils derived from igneous rocks and in calcareous soils.

In annual crops, the symptoms vary from one species to another. Boron deficiency may not show any visible symptoms in the seed, but the yield may fall by as much as 50%. In peanut, soybean, papaya, and citrus, boron deficiency often results in an empty space within the seed known as “hollow heart”, “woody fruit”, or “stone fruit”. A common result of boron deficiency in all crops is an interruption in flowering and fruiting. Yields are poor, and the fruit or grain is deformed or discolored on the surface.

In soils with a level of hot-water-soluble (HWS) boron of 0.15 mg/kg, the application of 5-10 kg/ha of borax was enough to prevent deficiency for all kinds of soils. In continuous cropping, the residual effect of this small application was short-lived.

COPPER

The soils in which copper (Cu) deficiency occurs are usually organic soils, calcareous soils or sandy soils. The low requirement of many plants for copper is probably the reason why copper deficiencies are fairly uncommon. Copper deficiencies are seldom seen in the crops of Asian countries.

In using plant analysis to diagnose copper deficiency, we should be aware that the concentration of copper in the oldest leaves is misleading as an indicator of the total copper status of the plant. It is the copper concentration in the shoot tips which is related to vegetative growth and yield. The critical copper concentration in the shoot tips of peanut ranged from 1 to 1.5 mg/kg (dry weight). The critical value for the diagnosis of copper deficiency in soybean is 2.0 mg Cu/kg (dry matter). A foliar spray of 0.1% copper sulfate solution mixed with lime is strongly recommended to remedy Cu deficiency in crops.

IRON

Iron (Fe) deficiency is common in leached tropical soils of Asian countries, particularly in calcareous soils derived from limestone. Legumes are particularly sensitive. The main symptom of iron deficiency is chlorosis or yellowing between the veins of new leaves. Iron deficiency limits legume production on black calcareous soils in all Asian countries. Most of these black calcareous soils are considered quite fertile, but the presence of calcium carbonate and the alkaline pH may cause Fe deficiency in legume crops.

Foliar applications of inorganic salts or chelated compounds are widely used to treat iron-

deficient legume crops. Foliar sprays of 0.5% iron sulfate solution applied once every 10 days until the Fe deficiency had improved gave substantially higher yields of peanut.

MANGANESE

Manganese (Mn) deficiency is common in leached tropical soils, particularly in calcareous soils derived from limestone. Legumes are again particularly sensitive. The main symptom of Mn deficiency is chlorosis or yellowing between the veins of new leaves. Mn deficiency also limits legume production on black calcareous soils in Asian countries.

Foliar applications of 0.5% manganese sulfate solution are often recommended, applied once every ten days until the manganese deficiency has improved.

MOLYBDENUM

Molybdenum (Mo) concentrations in leaves and nodules show a significant correlation with the shoot dry weight and nitrogen content in peanut, soybean, green gram and black gram. The results can be used to establish critical concentrations for the diagnosis of molybdenum deficiency. The critical values for nodules are much higher than those for leaves. In the case of peanut, the relationship between seed dry matter and leaf Mo concentrations were most reliable at the pod filling stage.

Often the most obvious symptoms of Mo deficiency are similar to those of uncomplicated nitrogen deficiency. In the case of legumes, depending on nitrogen fixing activities of soil microorganisms, the plants may in fact be nitrogen-deficient. Examples of Mo deficiency are “yellow-spot” of citrus, “blue-chaff” of oats, and “whiptail” of cauliflower. Depending on the crop species, the critical deficiency levels of Mo vary from 0.1 to 1 mg/kg.

Foliar applications of molybdenum fertilizer are not the only way to increase the molybdenum content of the leaves. It also can also be increased by the application of manganese and magnesium, especially the former. Research results also suggest that the foliar application of manganese might help molybdenum uptake translocation, by reducing the adsorption of molybdenum to the surface, cell wall or cell membrane of leaves. This might increase the movement of molybdenum into the phloem.

ZINC

A calcareous soil means that zinc (Zn) is less soluble, so that crops may suffer from zinc deficiency. This tends to result in stunted growth and small leaves. Crops growing in zinc-deficient soils often show small brown spots, and root development is poor, especially in rice, corn and citrus. Fruit trees deficient in zinc may have a growth at the end of shoot tips which looks rather like a rosette. Citrus trees often show chlorosis between the veins of the leaves, a condition sometimes known as “mottle-leaf”.

Zinc that is available for plant uptake is present as Zn^{2+} in the soil solution, or as exchangeable zinc on cation-exchange sites, organically complex zinc in solution or organically complex zinc in soil solids. Zinc extracted from the soil solution is generally in the range 0.05 - 0.25 mg/L. The critical concentration of zinc in soils extracted with ammonium acetate appears to be in the range 0.1-2 mg/kg. The lowest values probably occur in soil where zinc deficiency is found in plants.

Heavy applications of phosphate fertilizer (200 mg P_2O_5 /kg soil) combined with 10 mg Zn/kg soil (in the form of zinc sulfate or ZnEDTA) increased grain and straw yield of rice on sandy loam soils. They also reduced the percentage of unfilled grains. In Taiwan, 30 to 50 kg/ha of zinc oxide is recommended for rice production on soils with low available zinc status. For sugarcane in Taiwan, 25 kg/ha of zinc oxide is recommended, and increases the cane yield by 14% and sugar yield by 8%, compared to fields which did not receive zinc oxide applications.

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Report on International Workshop MICRONUTRIENTS IN CROP PRODUCTION

Held at National Taiwan University, Taipei, Taiwan ROC, November 8-13, 1999

Countries participating: Japan, Korea, Malaysia, Philippines, Taiwan ROC, Thailand

INTRODUCTION

In traditional Asian agriculture, soil productivity depended mainly on the natural fertility of the soil. Micronutrient deficiencies were relatively uncommon. Over the last three decades, however, farmers all over the Asian and Pacific region have adopted the use of chemical fertilizers and high-yielding varieties. Today in most countries it is chemical fertilizers which are supplying most of the macronutrients needed by crops. Farmers seldom apply micronutrients, even though intensive modern agriculture has a depleting effect. Yields are higher than those of the past, while early maturing varieties make it possible for rice farmers to increase the number of crops grown in the course of a year. Micronutrients are being continuously removed in high yields of harvested produce, without being replaced. The result is widespread micronutrient deficiencies.

Micronutrients may be minor in terms of the amounts needed by the crop, but they can be major in terms of their impact on crop growth. As one workshop participant pointed out, in order to maximize yields, all nutrients must be optimized. If one nutrient is lacking, it negates the value of the others. The response of crops to supplementation, in cases where deficiency exists, can be very marked.

Deficiency is shown in various kinds of physiological damage, all of which affect the quality and quantity of produce. There may also be latent deficiency, in which there are no visible symptoms but the crop does not respond as expected to applied fertilizer.

The Workshop had four main aims: To assess the current status of micronutrients in crop production in the region; to develop recommendations for extension purposes; to identify research gaps and the need for future work; and to discuss other relevant issues in micronutrient usage.

MICRONUTRIENT DEFICIENCIES

Critical levels of micronutrients which are sufficient to allow good growth of plant tissues vary, but are generally small. Areas where crops suffer from with boron deficiency, for example, have a boron content (ppm or mg/kg of soil) of less than 0.15 (topsoil) or 0.10 (subsoil). Critical levels in reference leaves are usually in the range 10-20 ppm for most crops. However, a lack of this very small amount of boron or some other micronutrient in the crop is likely to cause serious physiological damage, thus retarding plant growth and reducing the crop yield substantially.

The symptoms of deficiency vary according to the nutrient and type of crop. In Thailand, boron deficiency in black gram, a legume crop very sensitive to boron, causes a 40-50% drop in yield but no visible symptoms in the seed. In peanut or soybean, boron deficiency often induces an internal empty space known as 'hollow heart'. Legumes sown in boron deficient soil have a poor rate of germination. More seed must be sown, and seedlings are stunted. In apples grown in Korea, boron deficiency causes internal corking, while shoot tips form a rosette shape. Papaya with boron deficiency have lumpy fruit. In general, a common consequence of boron deficiency in all crops is an interruption in flowering and fruiting, so that yields are poor and the fruit or grain is deformed or discolored.

Zinc deficiency tends to result in stunted growth and small leaves. Fruit trees deficient in zinc often have a rosette-like growth at the end of shoot tips, while citrus typically shows interveinal chlorosis ("mottle-leaf"). Rice grown in zinc-deficient soils in Taiwan showed small brown

spots, which appeared a few weeks after transplanting. Root development was poor, and yields were low. Deficiencies of manganese, magnesium and copper show similar variation in different crops. In the case of iron deficiency, a universal symptom in all crops is the chlorosis of young leaves.

Critical levels vary, not only from one crop species to another, but even in different varieties of the same crop species. One participant recommended that critical levels of micronutrients should be established every time a new crop variety is bred and extended to farmers.

Early detection is also important. Otherwise the plant cells may be irreparably damaged and the yield reduced, even if the deficiency is corrected at a later stage of growth. In short-term crops such as vegetables, usually by the time deficiency is detected, the damage to plant cells is already done. It is too late to save the crop, although countermeasures will save subsequent crops. In the case of perennial crops such as fruit trees, corrective measures can be applied. The farmer may lose a harvest, but will usually be able to save the crop.

CURRENT STATUS OF MICRONUTRIENTS IN THE REGION

Field surveys have shown that boron deficiency is widespread in the countries represented at the Workshop (Philippines, Thailand, Korea, Malaysia, Taiwan, Japan). It was noticeable that no boron deficiency occurred in the intensively cropped vegetable farms of the Cameron highlands in Malaysia, where farms are fertilized with heavy applications of chicken manure.

The micronutrient content of soils is largely related to the parent material. Boron deficiency, for example, is more common in volcanic soils or soils derived from igneous rocks, than in soils derived from sedimentary rocks such as limestone. Apart from boron, volcanic soils are usually fairly rich in micronutrients. In Japan, a volcanic island chain, severe micronutrient deficiencies are rare except for boron, and manganese which is easily leached. Typically, tropical soils are acidic and highly leached. Micronutrient deficiencies in tropical countries are common, and often severe.

COUNTERMEASURES TO CORRECT MICRONUTRIENT DEFICIENCIES

Corrective measures once a micronutrient deficiency has been diagnosed are usually simple and cheap. The missing nutrient is applied as a fertilizer, either to the soil or as a foliar spray. Only a small amount is needed. Farmers in Japan are getting good results from boron in the form of slow-release fertilizers. Iron deficiency may be difficult to correct, and there has been some success in selecting rhizobium which are effective in soil with a low iron content, and inoculating either soil or young seedlings with them.

Sometimes deficiencies are corrected by amending the soil conditions which cause them. In the case of iron deficiency of peanut in Taiwan, foliar applications of ferrous sulfate were effective, but the best remedy was to apply sulfur well before planting, in order to lower the pH. Tests of rice with brown spot disease in Taiwan showed low available manganese, silica and potassium. Silicate slag was the best amendment for this condition.

In the Philippines, where field surveys showed widespread boron and zinc deficiency, there was a clear response to applications of boron, zinc sulfate and chicken manure. During the Final Discussion, participants commented that the improved yields brought about by composted chicken or cattle manure may be partly because of the improvement to soil properties, but may also reflect the correction of latent micronutrient deficiencies. It was suggested that chicken manure could be seen as an effective micronutrient fertilizer, although analysis is needed to determine its total nutrient value.

One point discussed at the workshop was whether chicken manure should be recommended as a remedy for micronutrient deficiencies. It was decided that this would depend on the costs and returns, and also the availability of organic fertilizers. In some countries, chicken manure is the best solution. In other countries, foliar fertilizers are cheaper and more effective.

Another important topic of discussion was whether micronutrients should be premixed into compound fertilizers. For some crops, it was felt that this would be beneficial. For example, coconut have a high chloride requirement, and it was suggested that compound fertilizers for coconut in the Philippines should contain chloride, and also zinc, sulfur and boron. In this situation, where three million hectares are planted in a single perennial crop, smallholders would benefit from premixed fertilizers which included micronutrients.

In other situations, premixing of micronutrients would be likely to lead to toxicity problems. There is also the economic aspect. Fertilizer companies manufacture fertilizer in bulk, in order to make a profit. If they have to produce a wide range of premixed fertilizers with different micronutrient levels for different crops, the cost of fertilizer would rise. Smallholders buying fertilizer would have to pay extra for micronutrients they might not need.

It was pointed out at the workshop that management of plant residues, together with and good soil and water conservation, is part of good nutrient management. Most micronutrients are lost as the result of erosion and leaching.

PROBLEMS IN MICRONUTRIENT USE

There are two main problems, diagnosis of existing deficiencies, and toxicity brought about by over-correction when a deficiency has been identified.

Diagnosis of micronutrient deficiencies

It is not easy to diagnose micronutrient deficiencies from the visible symptoms. Symptoms vary in different soils and with different crops. Moreover, the symptoms of a micronutrient deficiency are very similar to those of virus diseases. Experience is needed to distinguish the two. Often in fact they cannot be distinguished on the basis of the symptoms themselves, but only according to the pattern of symptom development. Virus symptoms tend to begin at one spot and then spread through the field, while deficiency symptoms tend to be spread over the whole field.

A further problem is that many crops are suffering from multiple micronutrient deficiencies, rather than a lack of only one element. Multi-nutrient deficiencies are very difficult to diagnose. Often too, micronutrient deficiencies are combined with virus infection. One participant suggested that micronutrient deficiencies may weaken perennial crops and make them more susceptible to virus infection.

Laboratory testing for micronutrients, whether of soil or plant tissues, is a more reliable indicator than visible symptoms. Laboratory tests can also identify deficiency states which do not produce visible symptoms, but inhibit fertilizer response and depress yields. However, testing for micronutrients is expensive, and most small-scale farmers cannot afford it.

A high level of a particular micronutrient in an agricultural soil does not mean there is enough for the crop. Sometimes a nutrient may be present in adequate quantities, but soil conditions mean that it is not available to plants. The condition most affecting availability is the soil pH. Calcareous or alkaline soils have poor availability of iron, magnesium, copper and zinc. In soils with a low pH, molybdenum is less available to plants, while on soils with a high pH boron is less available. Iron deficiencies can also be induced by an excess of magnesium, copper or nickel.

As well as a high pH, boron availability also decreases if soils are coarse in texture, or if soils are dry. One example was given at the Workshop from Nagasaki Prefecture in Japan of carrots which developed a rough, blackened skin as a result of boron deficiency after two years of relatively low rainfall. Carrots have a relatively high boron requirement, and those in Nagasaki were unable to absorb enough boron because the soil was too dry. Similarly, the lumpy fruit typical of boron deficiency in papaya are more common on latosols and old slate soils in Taiwan if young trees are planted in dry soil over the summer.

Production of horticultural crops in Asian countries with a cold winter is often carried out in

greenhouses. Greenhouse soils generally receive heavy fertilizer applications. There is a common problem of salt accumulation, particularly phosphate. This reduces the availability of micronutrients such as iron, manganese, copper, zinc and boron, which are converted to an insoluble form.

One paper presented at the workshop described how conditions in contaminated soils can be manipulated to make heavy metals less available to plants. Most industrialized countries have areas where the soil has been contaminated by industry. In Taiwan, scientists are studying the treatment with manganese oxide of soils contaminated with cadmium and lead, in order to convert the contaminants to less available forms.

Micronutrient toxicity

Most micronutrient deficiencies are easily corrected by the application of small quantities of fertilizer. Molybdenum deficiency in legume crops in Thailand, for example, was corrected by application rates of only 0.25kg/ha. In cases of boron deficiency, borax is usually applied at a rate of just over one kilogram per hectare.

However, once a deficiency has been diagnosed, farmers tend to apply the needed nutrient repeatedly each year, often at higher than recommended rates. The aim is to protect the crop from future deficiencies. The result may be toxicity problems which may do even more damage than the original deficiency. In Korea, some apple orchards are suffering from boron deficiency, while others are suffering from excess applied boron. In general, boron levels in Korea are not so high as to cause toxicity problems, but some orchards do show the characteristic symptoms of chlorotic leaves, leaves arched backwards, and necrosis of the shoot epidermis of scions above the graft. Fruit are smaller and have a shorter storage life, often developing internal browning after harvest. Manganese toxicity is also seen, especially in soils with a high calcium content. The main symptom in apple trees is necrosis of the bark. Boron toxicity has been found in rice in the Philippines, where the main symptom is brown necrotic spots on the leaf tip and margins. The boron in this case seems to originate in geothermal springs rather than applied boron fertilizer.

It was suggested at the Workshop that toxicity problems may be even more serious than micronutrient deficiencies. A state of deficiencies can be corrected quickly. Toxicity may take a long time to correct. It may take years for an excess nutrient to be slowly leached from the soil.

FUTURE RESEARCH NEEDS

During the final discussion, participants identified important topics for future research. These were as follows:

- The physiological effects of micronutrient deficiencies, including their effect on the flowering and fruiting of perennial fruit trees;
- Low-cost diagnostic techniques that can be used in the field by extension staff or farmers;
- Sampling strategies for both soils (soil testing) and crops (leaf analysis);
- Improved laboratory methods of analysis. In particular, it was suggested that the hot-water method of boron extraction can give variable results. A new method was presented at the workshop which uses synthetic resins.
- Movement of micronutrients in soil and groundwater;
- Micronutrient requirements of tropical fruit crops such as durian and lychee.

CONCLUSION

Micronutrient problems are a serious constraint to productivity in the Asian and Pacific region, and are tending to become more serious year by year. Most farmers now depend on mineral fertilizers

as a nutrient source, and are tending to apply macronutrients in fertilizer, but not micronutrients. High-yielding varieties are removing large quantities of trace elements in the harvest which are not being replaced.

Furthermore, micronutrient deficiencies are difficult to diagnose. Symptoms vary from crop to crop, and overlap with the symptoms of virus disease, while laboratory tests are expensive. Latent deficiencies have no visible symptoms at all, but crops will not respond well to fertilizer treatments and yields will be suppressed until the deficiency state is corrected. Although deficiencies are usually easily corrected by a small application of the missing nutrient, the window of opportunity between levels needed to correct a micronutrient deficiency, on the one hand, and levels which produce toxic symptoms in plants, is a small one.

A question of concern to the Center was the extent to which information about micronutrients is reaching farmers, and whether research data is being packaged and extended in a practical form to extension staff in the region. Most countries have developed fertilizer recommendations for macronutrients, but micronutrients have not been studied as thoroughly, while recommendations are highly location specific depending on the crop, the soil type and the soil pH.

Recommendations from the Workshop

1. FFTC should publish a handbook on micronutrients (deficiencies, toxicity and corrective measures)
2. Premixing of micronutrients in NPK fertilizers should be done with care, to avoid micronutrient toxicity
3. Application of micronutrients should not cause environmental damage to soil, crops or people.
4. Further review of research gaps is needed.

PAPERS PRESENTED

1. Micro-nutrients in crop production in Taiwan
- Su-San Chang, Council of Agriculture, Taiwan ROC
2. Field and research experiences on micronutrient fertilization in selected crops in the Philippines.
- Severino S. Magat, Philippine Coconut Authority and M. R. Recel, Tropical Research and Technology Center, Inc., Philippines
3. Micronutrient content and uptake by vegetable crops in Malaysia
- Purushothaman Vimala, H. Salbiah and T. Zaharah, Malaysia Agricultural Research & Development Institute (MARDI)
4. Micro-nutrients in crop production in Thailand
- Yongyuth Osotsapar, Kasetsart University
5. Distribution characteristics of micronutrients in soils and vegetable plants in Korea
- Yang-Ho Park, National Institute of Agricultural Science & Technology, RDA
6. Relationship between trace metal concentration, metal fractionation and bioavailability of trace elements in soils of Taiwan
- Zueng-Sang Chen, National Taiwan University
7. General aspects of fruit trees with respect to micronutrients in Korea
- Hee-Seung Park, National Horticultural Research Institute, RDA
8. Boron deficiency of crops in Taiwan
- Sheng-Bin Ho, National Taiwan University
9. Hidden boron deficiency in southern Japan
- Hisao Oda, National Institute of Agro-Environmental Sciences
10. Micro-nutrient status of some Philippines soils
- Diosdado A. Carandang, University of the Philippines at Los Banos
11. Background levels of micro-nutrients in soils of Japan
- Makoto Nakai, National Institute of Agro-Environmental Sciences

APPENDIX

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