Chapter 2. Symptoms of micronutrient deficiencies in crops of the Asia-Pacific Region, and how to remedy these

DEFICIENCY SYMPTOMS

Since most micronutrients are relatively immobile in the plant, they are not readily transferred from older leaves to younger ones. Therefore, the concentration of the nutrient tends to be lowest in younger leaves. It is in these younger leaves where the symptoms of deficiency are usually most pronounced.

Boron deficiency

Boron deficiency is widespread in many Asian countries, including the Philippines, Thailand, Korea, Malaysia, Japan, and Taiwan ROC. It is more common in volcanic soils and calcareous soils, or in soils derived from igneous rocks. It is not often found in soils derived from sedimentary rocks such as sandstone and shale.

In annual crops, the symptoms of boron deficiency vary from one species to another. Black gram deficient in boron does not show any visible symptoms in the seed, but the yield may fall by as much as 50%. In peanut or soybean, boron deficiency often results in an empty space within the seed, known as "hollow heart". A common result of boron deficiency in all crops is an interruption in flowering and fruiting (Plate 1). Yields are poor, and the fruit or grain is deformed or discolored.

Plate 1. Typical symptoms of boron deficiency in papaya

In the last few years, the production of orchard fruits has been a growing industry all over the Asian and Pacific region. Boron deficiency is common in orchards. In apples, this produces the symptom of corking in the fruit. Affected trees show die-back of shoots, or the leaf tips may be distorted into a rosette shape.

The problem of boron deficiency can be easily solved by applying boron. Usually boron is applied in the form of borax, a white crystalline salt. The quantities needed for the crop are very small. As little as 0.5 to 5 g borax/tree can correct the disorder in papaya in Taiwan (Chang 1999).

Farmers must be careful not to apply too much, or trees may suffer from boron toxicity. If growers of perennial crops such as fruit trees keep applying boron every year, there is a danger that boron will build up in the soil and poison the plant. A typical symptom of boron toxicity is that the leaves curve backwards. Chlorosis of the leaves, and yellow leaf veins, are common. Fruit from apple trees suffering from boron toxicity may become brown inside during storage.

Copper deficiency

The soils in which copper (Cu) deficiency occurs are usually organic soils, calcareous soils or sandy soils. Many plants have a low copper requirement, and this is probably the reason why copper deficiencies are fairly rare. In addition, 53-62% of copper uptake in some legumes is because of uptake by the mycorrhizae. For example, peanut plants depend on mycorrhizae for adequate copper uptake in highly leached clay soils in Thailand, to which no fertilizer had been applied.

In using plant analysis to diagnose copper deficiency, it is the concentration of copper in the youngest leaves which is important. In the case of peanut, there is a close relationship between copper concentration in the shoot tips, and vegetative growth and peanut yield. The critical copper concentration in the shoot tips ranges from 1 to 1.5 mg/kg (dry weight). The critical level of copper in soybean is about 2.0mg /kg (dry weight).

Plate 2. Typical symptoms of copper deficiency in tomato

Copper deficiency affects the formation of grains, seeds and fruit much more than if affects vegetable growth. The main reason for the poor development of seeds and fruits is because a high percentage of the pollen from copper-deficient plants is not viable. The critical deficiency level of copper in vegetable parts is generally in the range of 3-5 mg/kg. Stunted growth, distortion of young leaves, and/or "summer dieback" in trees are typical symptoms of copper deficiency (Chang 1999) (Plate 2).

High application rates of phosphate fertilizer may increase copper deficiency (Tiaranan *et al.* 1985). Peanut crops which were given a complete fertilizer treatment had copper concentrations in their leaves which were below the critical level, even when copper fertilizer was applied to the soil (Bell *et al.* 1990). (Tiaranan *et al.* 1985).

Iron deficiency

Iron (Fe) deficiency is common in leached tropical soils, particularly in calcareous soils derived from limestone and in poorly drained soils. Legumes are particularly sensitive. The main symptom of iron deficiency is chlorosis or yellowing between the veins of new leaves (Chang 1999) (Plate 3 and Plate 4).

Plate 3. Typical symptoms of iron deficiency of peanut

Plate 4. Iron deficiency of starfruit

Iron deficiency limits legume production on black calcareous soils in several Asian countries, including Thailand and Taiwan. Most of these black calcareous soils are considered quite fertile. However, the presence of calcium carbonate and an alkaline pH may cause iron deficiency in legume crops, especially if the soil pH is higher than 7.5.

Corn and sorghum are not very sensitive to iron deficiency in calcareous soils. As little as 6-8 mg iron/kg soil provides sufficient iron for either crop. Peanut, on the other hand, showed chlorotic symptoms in calcareous soils when the iron content ranged from 5 to 10 mg/kg (DTPA extractable) in Thailand, or from 10 to 15 mg/kg (0.1 M HCl extractable) in Taiwan. The numbers of both pods, and kernels per pod, were increased by adding 50 kg iron/ha.

The total iron concentration in plants does not correlate well with plant growth response to applied iron. The o-phenanthroline extraction method can be used to diagnose iron deficiency in peanut, soybean and mungbean (Osotsapar 1999). In the case of both soybean and mungbean, the concentration of extractable iron in the youngest fully expanded leaves had a negative correlation with the degree of iron chlorosis.

Iron is required for several key enzymes in legumes. For this reason, all legumes have a high iron requirement. Iron deficiency severely depresses nodule mass, hemoglobin content and crop yield (Chiu 1990, Tang *et al.* 1992).

Iron fertilizer may be applied to the soil, or as a foliar application. Foliar applications have proved very successful in treating iron deficiency of peanut.

Zinc deficiency

Sometimes zinc (Zn) may be present in the soil, but not available to plants. A high soil pH, or a calcareous soil means that zinc is less soluble. Crops under these soil conditions may suffer from zinc deficiency. This tends to result in stunted growth, while young leaves are smaller than normal. Corn and rice plants growing in zinc-deficient soils in Taiwan had small, brown spots on their leaves, and plant growth was poor (Plate 5 and Plate 6). Fruit trees deficient in zinc may have a growth at the end of their 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" (Chang 1999).

Plate 5. Zinc deficiency of corn

Plate 6. Zinc deficiency of rice

Both the solubility of zinc in soils, and the uptake of zinc by plants, fall rapidly as the soil pH increases. High levels of phosphorus in soils have been known to make zinc deficiency worse in a number of crops (Forth and Ellis 1997, Chang 1999). Repeated applications of phosphate fertilizer to rice-growing soils may induce zinc deficiency and reduce rice yields (Chang 1999). Therefore, in addition to normal NPK fertilizer, the application of zinc fertilizer at a rate of not less than 6.25 kg Zn/ha is recommended on sandy loam soils for rice production in Thailand. This tends to increase the weight of filled grains, reduces the percentage of empty grains, and increase the ratio of grain to straw.

Two different types of zinc fertilizer had different effects on phosphorus uptake in rice grown on sandy loam soils in Thailand. Zinc sulfate reduced phosphorus uptake and the phosphorus content of the rice shoots, while Zn-EDTA increased it (Nammuang and Ingkapradit 1986).

Manganese deficiency

Manganese (Mn) deficiency is common in leached tropical soils, particularly in calcareous soils derived from limestone. Legumes are particularly sensitive. The main symptom of manganese deficiency is chlorosis or yellowing between the veins of new leaves (Plate 7).

Manganese deficiency limits legume production on black calcareous soils in Asian countries. Most of these black calcareous soils are considered quite fertile, but the presence of calcium carbonate and an alkaline pH may cause manganese deficiency in legume crops.

Corn and sorghum are not sensitive to manganese deficiency in calcareous soils. As little as 6-8 mg Mn/kg soil provides sufficient manganese for both crops. Peanut, on the other hand, showed chlorotic symptoms in calcareous soils. The numbers of both pods, and kernels per pod, were increased by adding 50 kg Mn/ha.

Chlorotic peanut plants with severe manganese deficiency failed to form nodules until foliar applications of manganese were given. A number of treatments, including the application of 200 kg/ha of manganese sulfate, were tested in 1983 in Taiwan (Lin 1990). The application of 3 mt/ha of silicate slag gave the best response. There was a yield increase of abut 8%, and a residual effect of a 19% yield increase (Lin 1990).

Plate 7. Typical symptoms of manganese deficiency of soybean

Molybdenum Deficiency

Molybdenum (Mo) concentrations in leaves and nodules showed a correlation with the shoot dry weight and nitrogen content in several legume crops, including 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 the critical values for leaves. However, nodules are more difficult to sample than leaves. In green gram, critical values vary according to the age of the leaf. This means that it is essential to sample the youngest fully expanded leaf blade. In contrast, in black gram plants the critical values in different leaves were very similar. In the case of peanut, the relationship between seed dry matter and concentrations of molybdenum in the leaf was most reliable at the pod filling stage (Bell *et al.* 1990).

Often the symptoms of molybdenum deficiency are similar to those of ordinary nitrogen deficiency. In the case of legumes, a shortage of molybdenum affects the nitrogen-fixing activities of soil microorganisms, so that the plants are, in fact, N-deficient. "Yellow-spot" of citrus, "blue-chaff" of oats, and "whiptail" of cauliflower are some examples. Depending on the kind of crop, critical deficiency levels of molybdenum range from 0.1 to 1 mg/kg (Chang 1999).

Molybdenum deficiency of peanut has been observed in the acidic soils of many Asian countries, including Thailand, Japan, Korea, Philippines, and Taiwan. Symptoms of molybdenum deficiency resemble those of nitrogen deficiency, that is, overall chlorosis, stunted growth, and low yield (Plate 8 and Plate 9).

DIAGNOSIS OF MICRONUTRIENT DEFICIENCIES

This description of symptoms shows that it is difficult to diagnose a micronutrient deficiency from the visible symptoms alone. In fact, sometimes there may be no symptom at all except a reduction in yield. This type of latent or hidden deficiency may be suspected if crops do not respond to applied fertilizer (Chang 1999, Osotsapar 1999). All nutrients must be present in optimum quantities for the best yields. If one nutrient is lacking, it negates the value of all the others. To make diagnosis even more difficult, crops often suffer from multiple micronutrient deficiencies, not just one. Moreover, the symptoms of micronutrient deficiencies often mimic those of diseases, especially virus diseases.

Farmers need laboratory tests to be sure of a diagnosis, and these are expensive. However, farms in a region with the same kind of soil tend to share the same plant nutrient problems.

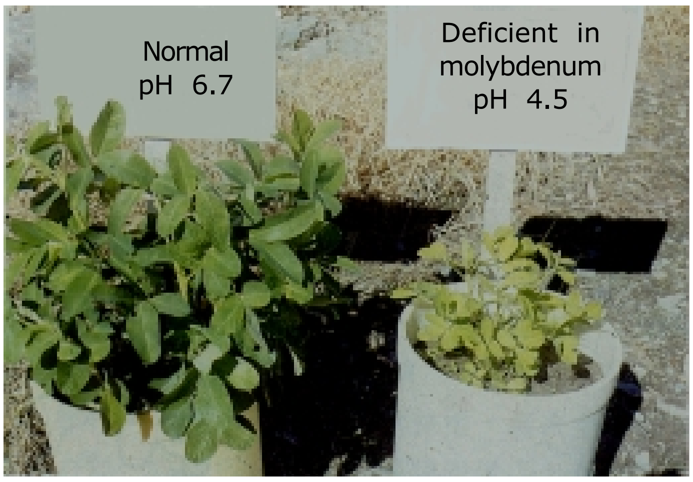

Plate 8

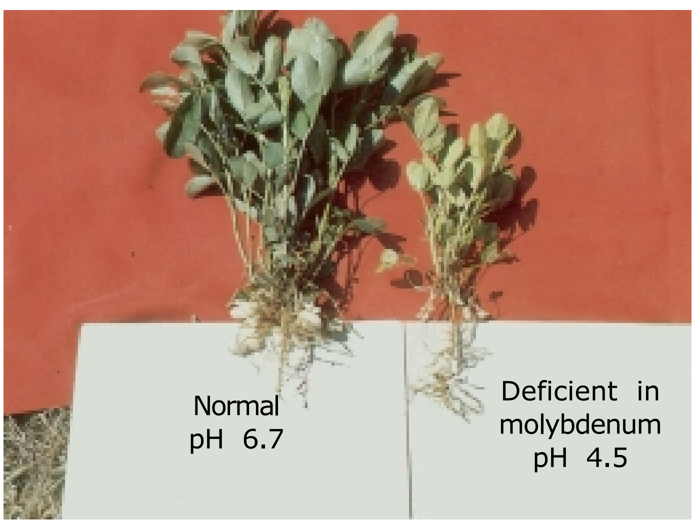

Plate 9

Plate 8 and Plate 9. Molybdenum deficiency of peanut (right) grown in strongly acid soil (pH 4.5)

There is no need to test on a farm-by-farm basis, although this is ideal if farmers can afford it.

How can farmers protect their crops from micronutrient deficiencies? Certainly, they should never apply a good dressing of assorted micronutrients “just in case”. Toxicity problems from a surplus of micronutrients in the soil can be even more damaging than a deficit, and can be more difficult to correct.

Farmers should apply only the nutrient needed, in the quantity needed by the crop. Application rates for micronutrients are very low. A typical boron application, for example, is one kilogram per hectare. Critical levels in leaves of most micronutrients are only 10-20 mg/kg. However, a lack of this very small amount is likely to cause serious damage to the plant. For this reason, if there are micronutrient deficiencies, it is important that they are diagnosed and treated without delay.

In short-term crops such as vegetables, by the time symptoms are marked enough to diagnose deficiency, it may be too late to save most of the crop. In the case of perennial crops such as fruit trees, once corrective measures are applied, the farmer may still lose his harvest. However, he will usually be able to save the crop.

HOW TO CORRECT MICRONUTRIENT DEFICIENCIES

Boron

The amount of boron needed to correct a deficiency is fairly small. In a soil in Thailand with a boron level of only 0.12 mg/kg of hot water soluble boron (HWS-B), the application of 4 kg/ha borax was enough to prevent deficiency in early crops of black gram grown during the rainy season. However, if the boron-deficient fields were cropped continuously, the residual effect of this small application was short-lived. By the third successive crop, it could no longer prevent boron deficiency. If higher borax rates of 10-20 kg/ha were applied, the residual effect lasted for ten crops (Rerksasem 1989).

Boron deficiency in peanut of Thailand is widespread in sandy, highly weathered soils (Ultisols). Their surface soil contains only 0.08 mg/kg boron (HWS-B). The application of boron at a rate of 0.25-0.5 kg/ha significantly increased the number of both pods and seeds, and also the weight per plant of pods and seeds. It also increased the incidence of large seeds which were more than 0.7 cm in diameter. Applications of 0.5 kg/ha boron also reduced the incidence of hollow heart in large seeds due to boron deficiency. However, the incidence of hollow heart in small seeds did not fall until boron applications reached 1 kg/ha, and even then was as much as 9-11% (Keerati-Kasikorn *et al.* 1987).

Foliar applications may sometimes be more effective than applying boron to the soil. Two foliar sprays of borax of only 50 g/ha each, applied at the strategic times of flower development and pod set, were as effective in correcting boron deficiency in black gram in the Philippines as a higher rate applied to the soil (Rerkasem and Boonkerd 1989).

In Taiwan, the leaves of sugar beet suffering from boron deficiency contain about 20 mg/kg boron. This can be compared to the level of 40-65 mg/kg boron found in normal sugarbeet plants.

The critical level of boron (HWS-B) for papaya was found to be 0.28 mg/kg for soils classified as black soils (derived from igneous rocks and rich in organic matter) and 0.15 mg/kg for other soil groups (Ho 1999). The different boron requirements of crops growing in different soils may be due to the higher organic matter content of the black soils.

In papaya, typical symptoms of boron deficiency are a bumpy skin surface and the secretion of latex. In studies of boron deficiency in papaya in Taiwan, samples were taken from the 10th leaf blade (without petiole), counted from the 1st leaf (the most recently matured leaf, with a leaf blade which has only just fully developed, and which has a brownish petiole). Standard sampling of this kind can give an accurate picture of variations in the boron content of different orchards. The boron content of the 10th leaf blade of papaya trees with deformed fruit was always lower than 20 mg/kg. In contrast, the boron content of leaves from normal trees was generally 25-155 mg/kg (Ho 1999).

Boron deficiency symptoms may sometimes appear for the first time when crops are suffering from water deficit. Crops growing in dry soil are less effective at taking up boron. When boron deficiency symptoms of citrus in Taiwan were observed in a drought year, the boron content was less than 10 mg/kg in the fruit peel and leaves. However, the boron content in the same orchard when precipitation was abundant was 20 mg/kg in leaves and 14 mg/kg in peel, and no boron deficiency symptoms were observed. In an orchard where fruit had deficiency symptoms, the soil HWS-B content was 0.15 mg/kg in the surface soil (0-15 cm), and 0.10 mg/kg in the subsoil (15-30 cm) (Ho 1999).

Applying boric acid to the soil in Taiwan at a rate of 40-120 g per tree (the citrus trees were about 10 years old) was effective in correcting the boron deficiency problem. This was followed by soil application at a rate of 40-50 g of boric acid per tree every four years, to prevent a recurrence (Ho 1999). Toxicity symptoms have occasionally been observed from excessive applications of boron. Leaves with symptoms have a boron concentration of more than 150 mg/kg. Levels as high as 200-650 mg/kg have been observed.

In Taiwan, a foliar spray of 0.3% boric acid solution was also effective. However, a considerable amount of boron accumulated in the soil when trees were sprayed each year. For this reason, it is recommended that a foliar spray should not be applied every year.

A water-soluble boron content of 1-1.5 mg/kg in the soil is regarded as the critical level for pineapple in Taiwan. The soil boron level should be checked after the first good rain. Soil application of borax, at a rate of 12-14 kg/ha, will correct any boron deficiency. The boron is mixed with a basal dressing of fertilizer (Ho 1999). Borosilicate glass (sold in small fragments), which usually contains 3-6% boron, seems to be a suitable source of boron, especially in sandy soils and under high rainfall conditions, because of its slow-release nature.

For ratoon crops of pineapple in Taiwan, it is recommended that farmers spray a 0.3% borax solution two or three times after harvesting the first crop. This should be done before the floral differentiation of the ratoon crop in autumn and winter, i.e. late August to early November.

Copper

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 important. The critical copper concentration in the shoot tips usually ranges from 1 to 1.5 mg/kg (dry weight), depending on the crop. The critical value for the diagnosis of copper deficiency in soybean in Thailand is slightly higher, at 2.0 mg Cu/kg (dry matter) (Osotsapar 1999).

Higher rates of phosphate fertilizer application may increase the incidence of copper deficiency (Tiaranan *et al.* 1985). For example, complete fertilizer treatment of peanut in Thailand depressed copper concentrations in the leaves. Copper levels were below the critical value even when copper fertilizer was applied to the soil (Bell *et al.* 1990).

Iron and manganese

Foliar applications of inorganic salts or chelated compounds are widely used to treat iron-deficient crops. Ratararat *et al.* (1990) suggested that five foliar applications of 0.5 iron sulfate ($FeSO_4$) (or manganese sulfate: $MnSO_4$) solution at 10, 20, 30, 40 and 50 days after emergence was the most effective way of alleviating iron (or manganese) chlorosis, and substantially improved yields of peanut in Thailand.

Mungbean crops in Thailand sometimes show chlorotic symptoms when they grow in calcareous soils. Plants given a foliar spray with a nutrient solution which combined 0.5% iron, zinc and manganese recovered from the chlorosis, and produced greater numbers of pods (Unkasem and Tawonsok 1988).

A major problem with foliar applications is the poor translocation of applied iron within the plant. That is, the applied iron does not readily move from the parts of the plant which it contacts into other parts of the plant. Rates of translocation vary according to the type of crop, but are always less than 50% of the iron applied to a given leaf or leaflet. In the field, growers may need to apply foliar sprays of iron more than once, sometimes at ten-day intervals, to provide adequate iron for the developing canopy. This is because iron translocation from previously treated areas is insufficient (Chen and Barak 1982).

The application of manure or compost is another way of solving the problem of chlorosis due to iron deficiency. Field experiments showed increased yield in peanut after the application of organic humus or chicken manure (Suwanarat and Suwanarit 1986).

Molybdenum and nitrate

Nitrate is one of the most serious contaminants in the world, second only to pesticides. It is a potential human health threat, especially to enfants, causing the condition known as “blue baby syndrome”. Long-term consumption of high levels of nitrate in food is suspended of causing cancer. Nitrate can also cause other problems. A high level of nitrate in pineapple in Thailand is a serious quality problem for canneries, since excess nitrate (>25 mg/kg) causes the tin to deteriorate (Luksanavinol *et al.* 1997). The major cause of nitrate accumulation in fruit is reduced efficiency in nitrate reduction, which is carried out by nitrate reductase (NR) enzymes. Several nutrient elements (molybdenum, magnesium, manganese, iron etc.) must be present for these enzymes to function. Thus, one result of molybdenum deficiency may be excess nitrate in plants.

In Thailand, the level of nitrate in pineapple fruit should not exceed 25 mg/kg. Chongpraditnun *et al.* (1997) compared different fertilizer treatments, and suggested that the foliar application of molybdenum at a rate of 11.7 mg/plant could improve fruit quality by preventing or reducing the accumulation of nitrate in pineapple fruits, without affecting the sweetness or yield of the fruit.

Foliar applications of molybdenum fertilizer in Thailand were not the only way to increase the molybdenum content of the leaves. It could also be increased by the application of manganese and magnesium, especially the former. Chongpraditnun *et al.* (1997) suggested that the foliar application of manganese might help the molybdenum taken up by the leaves to translocate into the phloem (sap) and spread to all parts of the plant.

Zinc

High levels of phosphorus in the soil can sometimes increase the symptoms of zinc (Zn) deficiency (Foth and Ellis 1997). Thus, repeated applications of phosphate fertilizer to paddy soils may bring about zinc deficiency and reduce rice yields. In some pot experiments in Thailand, it was found that zinc applications did not affect the general growth and yield of rice plants. However, they did reduce the phosphorus content in shoots at both the heading and the harvesting stages.

In Thailand, the effect of zinc applications in decreasing phosphorus concentrations in rice shoots was greater in sandy loam soils than in clay loam soils. Therefore, in addition to normal NPK fertilizer, the application of zinc fertilizer at a rate of not less than 6.25 kg Zn/ha is recommended on sandy loam soils.

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 (Zn SO_4) or Zn EDTA) increased grain and straw yield on sandy loam soils of Thailand (Osotsapar 1999). They also reduced the percentage of unfilled grains. The two different types of zinc fertilizer had different effects on phosphorus uptake in rice. Zinc sulfate reduced phosphorus uptake and the phosphorus content of the rice shoot, while Zn-EDTA increased it (Nammuang and Ingkapradit 1986).

In Taiwan, the average zinc content of zinc-deficient rice is about 18 mg Zn/kg (ranging from 14 to 24 mg/kg). The average zinc content of healthy plants is 48 mg/kg (ranging from 23 to 88 mg/kg) (Chan 1999). During the 1970s, farmers were recommended to apply 30 to 50 kg/ha of zinc oxide to soils with a low level of low available zinc. For sugarcane in Taiwan, 25 kg/ha of zinc oxide was recommended. Sugarcane given this zinc treatment increased the cane yield by 14%, and the sugar yield by 8%. The results also indicated that the critical concentration in sugarcane for zinc deficiency is 20-25 mg/kg.