

MICRONUTRIENTS IN CROP PRODUCTION IN THAILAND

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ABSTRACT

Boron deficiency in legumes was observed in the north and northeastern regions of Thailand. On average, the concentration of boron in deficient seeds, was $10.6 \pm 5.8\mu\text{g}$ boron/g, while the level in seeds with adequate boron was 16.4 ± 2.7 . 'Hollow heart' symptoms of boron deficiency in peanut were found in soils with a hot-water-soluble boron (HWS-B) level of less than 0.14 mg boron/kg soil. Borax at 4 kg/ha was sufficient to prevent boron deficiency in sandy soils of the northern region.

Several soil series in Thailand contained a limited amount of molybdenum available to plants. Application at a rate of 0.5 kg Mo/ha corrected the deficiency in legumes in the north-eastern region.

Iron deficiency limited legume production in calcareous soils. This is because it reduced nodule development by the roots. There was also decreased leghaemoglobin concentration, bacteroid content and acetelene reduction activity in peanut nodules. Foliar application of 0.5% FeSO_4 solution at 10, 20, 30 to and 50 days after emergence was the most effective way of correcting iron chlorosis.

Copper deficiency was not a serious problem, although high phosphate fertilizer applications tend to induce a deficiency of this element.

The application of phosphate fertilizer also induced zinc deficiency in rice grown in sandy loam soils containing limited available zinc.

INTRODUCTION

Soils in Thailand are classified into seventeen great soil groups, eleven of which are widespread. The major soil-forming parent materials in Thailand are low in weatherable minerals, which makes micronutrient deficiencies fairly likely. In northeastern Thailand, the soils have weathered from coarse-grained sediments high in quartz, which were already highly weathered when they were deposited. Consequently, the soils in this area are sandy, with a low content of weatherable minerals and low levels of plant nutrients (Peterson 1983). Some of the same siliceous sedimentary parent materials of the northeast also occur in the northern Thailand, which suggests that the same micronutrient deficiencies might occur. In the central highlands,

limestone formations are prevalent, giving rise to black calcareous soils in which iron deficiency is common (Monchareon 1980). Rapid leaching of acid sandy soils tends to produce a deficiency of tightly held nutrients such as zinc, copper or boron. Therefore, problem soils such as acid alkaline or sandy soils may be deficient in one or more micronutrient elements (Singer and Munns 1992).

The most comprehensive study of micronutrient deficiencies in Thailand was carried out by Australian and Thai scientists with the support of the Australian Center for International Agricultural Research (ACIAR). Scientists from several Thai and Australian universities and the Thai Department of Agriculture worked together to determine the extent and severity of micronutrient deficiencies in the production of four food legume

Keywords: available nutrients, critical concentration, foliar fertilization, micronutrients, Thailand

crops: black gram, green gram, peanut and soybean, in four regions of Thailand (north, northeast, central and southeast). This project aimed at developing procedures for the diagnosis and correction of micronutrient deficiencies on farms. The contribution from this group of researchers provided the standards to identify micronutrient problems in these four crops on four major problem soils (Grey podzolic, Low humic gley, Rendzina and Reddish-Brown lateritic soils) in Thailand.

The objective of this Bulletin is to describe micronutrient deficiency problems in different crops in Thailand, and the appropriate methods of correcting these.

BORON

The total boron concentration in soil varies according to its parent material and degree of weathering. Sandy soils tend to be low in boron, while clay and soils with a high organic matter content tend to have fairly high levels of boron. Soil boron may be divided into soil solution boron, adsorbed boron and mineral boron. When the pH of the soil is in the range 5 to 8, boron usually occurs as the undissociated acid H_3BO_3 . When boron is added to soil, some of it is adsorbed on the solid phase of soil, while some remains in solution. The adsorption of boron varies with the type of clay mineral and the presence of iron and aluminum oxides. The oxide coating of clay is more important than the type of clay in determining the amount of adsorption (Barber 1995).

Occurrence and Severity of Boron Deficiency in Crops

Northern Region

A survey of peanuts in northern Thailand used the symptom of hollow heart as an indicator. Widespread boron deficiency was found, especially in the far north. The effect of boron deficiency on green gram, soybean, peanut and black gram, Thailand's four most important grain legumes, included reduction of seed yield and lowering of seed quality. Seed from plants suffering from boron deficiency tend to show poor germination and/or poor seedling establishment. In the case of soybean and peanut, low boron levels in the seed are associated with physical damage which may lead to other quality problems (Rerkasem 1989).

Hollow heart was found in peanut kernels

from 50% of the sites, and was rated as moderate to severe (>5% of kernels affected) in 40% of the sites surveyed. The severity of hollow heart was closely related to the boron content of peanut kernels. There was no hollow heart in kernels with a boron concentration greater than 13 $\mu\text{g/g}$. Below this level, the percentage of kernels with hollow heart increased sharply with lower levels of boron in the kernel (Netsangtip *et al.* 1985).

Boron deficiency commonly occurs in crops during periods of drought. This is possibly because reduced water flow to the roots also reduces the supply of boron to the root. The reduced level of water in the soil also causes a proportionate decrease in the rate of boron diffusion to the root (Barber 1995).

Northeastern Region

Boron deficiency in legumes was also observed in the northeast. Keerati-Kasikorn *et al.* (1987) conducted a field survey to assess the extent and severity of boron deficiency of peanut in Khon Kaen province, and found that in the dry season, 28% of 458 crops studied were boron deficient. Half of the boron deficient crops during the dry season had seeds with hollow heart, whereas in the wet season, 30% of seeds had this symptom. Ninety-five percent of normal seeds had a boron content higher than 12 $\mu\text{g B/g}$, whereas 70% of the seeds with hollow heart had a lower boron content than this. The average boron content of normal peanuts was 16.4 ± 2.7 , while the level in seeds with hollow heart was $10.6 \pm 5.8 \mu\text{g B/g}$ (Table 1 and Table 2).

Available Boron in Soils, and Effect on Legume Growth

The most common way of measuring the boron content of soil is to extract it with boiling water. Levels of hot-water-soluble boron (HWS-B) in different soils in northern and northeastern Thailand show a close correlation with the incidence of hollow heart in peanut. The disorder was higher in soils with low levels of clay and organic matter. Hollow heart symptoms were found in peanut on soils with HWS-B values below 0.14 mg B/kg. No symptoms of hollow heart was observed in peanut grown in Pakchong soils (0.25 mg B/kg). The high boron content in peanut leaves at 60 days (71-76 $\mu\text{g B/g}$) indicated that Pakchong soils provided sufficient boron for this crop (Ratanarat *et al.* 1987).

The critical HWS-B for seed yield and seed quality of peanut, green gram, soybean and black

Table 1. Boron concentrations of peanut seed (1985 wet season survey).

Seed	Mean B concentration ($\mu\text{g B/g}$) \pm SD	Range of B concentration ($\mu\text{g B/g}$)
Without hollow heart	16.4 \pm 2.7	8.6 - 22.6
With hollow heart	10.6 \pm 5.8	3.5 - 35.2

Source: Keerati-Kasikorn *et al.* 1987

Table 2. Distribution of peanut with different boron concentrations

Boron content ($\mu\text{g B/g}$)	% seed sample	
	Without hollow heart	With hollow heart
0 - 4	0	3
4.1 - 8	0	34
8.1 - 12	5	34
12.1 - 16	42	15
16.1 - 20	47	7
>20	6	7

Source: Keerati-Kasikorn *et al.* 1987

gram (Table 3) indicated that soybean is less sensitive to boron deficiency than the other three crops (Bell *et al.* 1990). Black gram has been found to be especially sensitive to B deficiency. A reduction in seed yield of 40-50% as the result of boron deficiency was common in soils with HWS-B 0.12-0.14 mg B/kg (Rerkasem *et al.* 1988).

Early growth of green gram and black gram plants growing in soils with a low boron content was depressed because of the large percentage of abnormal seedlings. In soils with 0.08 mg B/kg, the incidence of abnormal seedlings in green gram cv. Uthong decreased linearly as seed boron rose to 10 mg B/kg. Abnormal seedlings of black gram cv. Regur decreased as seed boron rose to 14 mg B/kg. Beyond these levels, there was virtually no abnormality. Increasing the boron content of the soil to 0.36 mg B/kg eliminated any abnormal seedlings, regardless of the seed boron content (Rerkasem 1990).

Critical Boron Concentrations in Legume Leaves

The critical available level of boron in legume leaves was studied. Noppakoonwong (1991) suggested that 12-18 mg B kg⁻¹ dry weight in the youngest fully expanded leaf blade (YFEL), and the

minimum boron requirement for unrestricted leaf blade elongation (LBE), may be used as a critical range for diagnosis of boron deficiency in black gram (*Vigna mungo*) from the vegetative to the reproductive stage. The minimum boron requirement for unrestricted LBE is the concentration of B in an expanded leaf blade associated with 10% depression in its elongation rate.

The result of field experiments on a Typic Tropaqualf with a silty loam texture revealed that the critical boron concentration for black gram in the first mature leaf was 13-17 mg B kg⁻¹ dry weight (Noppakoonwong *et al.* 1997).

Varied Response of Legume Cultivars to Boron

A comparative study on the susceptibility to boron deficiency of various soybean cultivars, as well as peanut (cv Tainan) and black gram (cv Regur) on a Typic Tropaqualf in Northern Thailand showed a range of variation related to the genotype. Without added boron, soils with boron deficiency depressed seed yield by 60% in soybean cv NW1 compared with 30% in cv SJ5, 40% in cv 7016, 45% in peanut and 93% in black gram. Boron deficiency also induced a localized depression on the internal surface of one or both cotyledons of some soybean

Table 3. Critical hot-water-soluble boron values (mg HWS-B/kg soil) in the 0-10 and 0-25 cm layer of soils for the prognosis of seed quality in peanut, green gram, soybean (cv. SJ4 and NW1) and black gram

Soil depth (cm)	Peanut	Green gram	Soybean		Black gram
			cv. SJ4	cv. NW1	
Seed diameter					
0 - 10	0.13	0.14	0.09 - 0.10	0.09	0.10 - 0.18
0 - 25	0.13	0.12	0.08	0.09 - 0.11	0.08 - 0.13
% defective seed ^a					
0 - 10	0.16	0.17 - 0.18	b	0.11 - 0.12	b

^a Seed defects defined as follows: Peanut - hollow heart; Green gram - lesions in the seed coat; Soybean dimples, hollow heart and withered seeds

^b No defects observed in cv.SJ4 soybean or black gram

Source: Bell *et al.* 1990

seeds, resembling the symptom of “hollow heart” in peanut seeds. It induced 50% hollow heart in peanut, 17% in soybean cv NW1, 5% in SJ5 and 1% in 7016, while black gram seeds had no symptoms. The addition of boron reduced or eliminated the symptoms (Rerkasem *et al.* 1993).

Black gram sown in the cool season, which is relatively dry, was more sensitive to boron deficiency than black gram planted in the hot, rainy season. Black gram is generally more sensitive than green gram. Peanut is relatively tolerant in terms of grain yield, but is sensitive if the incidence of hollow heart is used as a criterion (Rerkasem 1989). Boron deficiency depressed seed yield of black gram by an average of 70%, compared to an average yield depression of only 21% in green gram (Table 4). Wheat and sunflower were also more sensitive to boron deficiency than green gram (Rerkasem 1990).

Soybean is generally the most tolerant, since it was not affected by boron deficiency at the same level which reduced seed yield of green gram and black gram, and caused a significant percentage of hollow heart in peanut. However, some soybean genotypes, e.g. NW1, are more sensitive to boron deficiency than others (Rerkasem 1989).

Boron Fertilizer Application for Legumes

For the correction of boron deficiency in legumes, boron fertilizers can be applied to soil or as a foliar spray.

Soil Application

In a soil with a level of HWS-B of 0.12 mg/kg, the application of 4 kg/ha borax was enough to prevent deficiency in early wet-season black gram. In continuous cropping, the residual affect of this small application was short lived. By the third successive crop, it could no longer prevent boron deficiency. Higher borax rates of 10-20 kg/ha ran out after 10 crops (Rerkasem 1989).

Boron deficiency in peanut was widespread in sandy (Paleustult) soils containing 0.08mg B/kg (HWS-B) in surface soil. The application of 0.25-0.50 kg B/ha significantly increased pod and seed number, and the weight per plant of pods and seeds. It increased the incidence of large seeds (>0.7 cm diameter). The incidence of hollow heart in large and small seeds due to boron deficiency was minimized with boron applications at 0.5 and 1 kg B/ha, respectively. Nevertheless, the incidence of hollow heart in small seeds was still as high as 9-11% (Keerati-Kasikorn *et al.* 1987).

Foliar Application

Two foliar applications of borax, each at a very low rate of 50 g/ha, at the strategic times of flower development and pod set, were as effective in correcting boron deficiency in black gram as a higher rate applied to the soil (Rerkasem 1989).

Table 4. Comparison of boron response in green gram (*Vigna radiata* cv. Uthong) and black gram (*Vigna mungo* cv. Regur)

Boron treatment (borax kg/ha)	% of maximum potential yield*	
	Black gram	Green gram
0	30	49
4	76	94
8	91	95
16	88	96
32	100	88
Maximum yield (kg/ha)	3283	2783

* Average over three growing seasons
Source: Rerkasem 1990

Response of Other Crops to Boron

Wheat

The total planted area of wheat in Thailand is small. Sterility of this crop has sometimes been observed. Boron deficiency in wheat, which causes grainset failure, is associated with symptoms of poorly developed pollen and anthers. Fertility of both the male and the female part of the wheat flower appears to be affected by boron deficiency. Cross pollination of boron deficient female flowers with pollen from plants with adequate boron resulted in only 28% grain set, compared with 94% from manual crossing of B-sufficient pollen on female flowers which also had sufficient B (Rerkasem *et al.* 1993). When wheat has a low boron supply, flower development and seed and grain production are much more depressed than vegetative growth. This may be the result of one or more of the following:

- Boron requirements for reproductive development are greater than for vegetative development;
- The supply of boron to reproductive tissue is more easily interrupted; *or*
- The supply of boron to the reproductive tissue is insufficient to meet demand because of rapid growth of reproductive organs, and their limited ability to transpire water (Rerkasem 1995).

Papaya

Papaya growing in acid sandy soils in northeast Thailand usually have a low yield of poor-quality

fruit, due to micronutrient deficiencies, especially of boron. Ratananukul *et al.* (1998) conducted field experiments on response of papaya grown in sandy soil to different rates of boron fertilizer. The addition of borax at a rate of 10-40 g per plant improved fruit quality, in terms of appearance and shape, and tended to increase fruit yield per plant.

Cantaloupe

Cantaloupe grown in sandy soil in the northern region generally has a low yield. Fruit deteriorate after only a few days' storage, due to a deficiency of calcium and boron. A weekly foliar spray of calcium and boron, beginning when flowers appear at nodes 14 and 15 and continued until harvest, markedly increased fruit quality and yield. Not only was average fruit weight increased, but also the storage life. Fruit of plants given this foliar treatment had significantly higher flesh density and total soluble solids (TSS), had a better texture and taste, and showed reduced weight loss after six days' storage at room temperature (Passornsiri *et al.* 1996).

Garlic

Boron deficiency in garlic was also observed in the northern region, and caused a marked reduction in yields. Jermisiri *et al.* (1995) reported that applying borax to garlic increased the yield by 24-40%. The addition of other micronutrients as well as borax tended to improve bulb quality.

MOLYBDENUM

Molybdenum occurs in soil in the following forms:

- The water-soluble forms present in the soil solution;
- Adsorbed by soil colloids;
- Held in the crystal lattice of minerals, *and*
- Present in organic matter.

Forms most available for plant use are the soluble forms in the soil solution, and Mo adsorbed by soil colloids. Highly weathered acid soils are more likely to be deficient in molybdenum. On the other hand, soils derived from granitic rocks, shales, slates or argillaceous schists tend to have a high Mo content (Gupta and Lipsett 1981).

Iron oxides found in acid soils carry a positive charge, and can react with MoO_4^{2-} . A soil high in free iron oxide sorbed the largest quantities of MoO_4^{2-} from the aqueous solution, while Mo adsorption in mineral soils increased with free iron oxide content. Aluminum oxides are also capable of removing Mo from aqueous solutions, but their effectiveness is less than that of iron oxides under the same conditions (Barber 1995).

Extractable and Adsorbed Molybdenum

Soils in Thailand have variable pH and variable levels of clay and iron oxide. These factors tend to affect the level of soil molybdenum. Crops growing in acidic (pH 4.7-5.2) sandy soils, which are typical of the Northeast, usually respond to applied molybdenum. To diagnose deficiency status, the NH_4^+ -oxalate extraction procedure appeared to be satisfactory, whereas the Mo sorption procedure was not. A level of ammonium oxalate extractable Mo of <0.074 mg/kg soil was considered too low for seed production of black gram, while >0.050 mgMo/kg in soil was sufficient to prevent nitrogen deficiency in peanut. Generally, peanut in an Ustoxic Paleustult with 0.36 mg/kg extractable Mo absorbed sufficient Mo for normal growth (Bell *et al.* 1990).

Diagnosis of Mo Deficiency by Plant Analysis

Molybdenum concentrations in leaves and nodules showed a 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 (Table 5). The critical

values for nodules are much higher than those for leaves. However, nodules are more difficult to sample than leaves. In green gram, critical values vary according to the age of the leaf. The 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 (Table 6). In the case of peanut, the relationship between seed dry matter and leaf Mo concentrations stage were most reliable at the pod filling stage (Bell *et al.* 1990).

Molybdenum Requirements of Legumes

Pongsakul *et al.* (1987) studied the molybdenum requirements of peanut grown in Ustoxic Paleustults and Typic Paleustults soils. They revealed that molybdenum concentrations in nodules and young fully expanded leaves dropped considerably between 30 days after planting and 60 days. Molybdenum applications increased levels of both molybdenum and nitrogen in leaves and shoots in both types of soil. It was noted that the application of 0.5 kg Mo/ha in soil with a low molybdenum sorption capacity caused luxury consumption of Mo by plants, while normal molybdenum levels were observed in leaves of peanut grown in soil with a higher molybdenum sorption capacity.

Applications of molybdenum at a rate of 0.25 and 0.50 kg/ha corrected Mo deficiency in wet-season crops in northeast Thailand. In a dry-season crop grown in paddy fields, the lower rate was not sufficient to raise leaf Mo to adequate levels. This suggests that surface placement may not be appropriate for the dry season. On heavy clay soils, even the higher application rate was insufficient to maintain adequate Mo levels in leaves late in the cropping season (Bell *et al.* 1990).

Molybdenum and Nitrate Content of Pineapple

A high level of nitrate in pineapple 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.

Other factors related to nitrate accumulation are the application of excess nitrogen, (particularly when applied at the red bud stage), high nitrate

Table 5. Classification of molybdenum status of peanut and soybean crops based on analysis of youngest fully expanded leaves collected from farmers' fields in northern Thailand

Classification	Concentration (g/kg dry weight)	
	Peanut	Soybean
Severely deficient	<20	<15
Deficient	20 - 50	15 - 20
Marginally adequate	51 - 130	21 - 100
Adequate	131 - 1000	101 - 1000
High	> 1000	> 1000

Source: Pongsakul *et al.* 1987

Table 6. Critical Mo concentrations in youngest fully expanded leaf and nodules for diagnosis of deficiency in four crops

Plant part	Growth stage	Mo concentration (g Mo/kg dry weight)			
		Peanut	Soybean	Green gram	Black gram
YFEL	R1-2	130	17 - 23	90 - 130	35
Nodules	R1-2	7000	2000	3900 - 4300	7000
YFEL	R5-6	-*	20	-	-
Nodules	R5-6	-	2000	-	-

YFEL: Youngest fully expanded leaf

* not determined

Source: Bell *et al.* 1990

uptake after rain, high nitrogen levels in the form of ammonium form, and low light intensity. In Thailand, the acceptable 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 were not the only way to increase the molybdenum content of the leaves. It also increased with the application of manganese and magnesium, especially the former. Chongpraditnun *et al.* (1997) suggested 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.

IRON

Many agricultural crops in Thailand suffer from iron deficiency. Crops sensitive to iron deficiency include beans, citrus, peanut and soybean. Deficiencies are usually recognized by chlorotic, or yellowish, intervein areas in new leaves. They are typically found in sensitive crops grown in calcareous soil (Vacharotayan 1987).

Characteristics of Black Calcareous Soils

Calcareous soil is sometimes classified as any soil containing sufficient calcium carbonate (often with magnesium carbonate) to effervesce visibly when treated with cold 1 N hydrochloric acid (Brady 1990). Black calcareous soils (Typic Calcicustolls) are formed from highly calcareous materials, mainly marls and weathered fragments of hard limestone.

They occur mainly in limestone areas around Thailand's Central Plain. Such soils have a black to very dark brown surface layer, merging at varying depths (usually less than 50 cm) into the subsoil, which contains 50% or more calcium carbonate. Free lime is usually found throughout the profile. These soils are fairly fertile, producing good upland crops (corn, sorghum, cotton, etc.). Where the calcareous subsoil is near the surface, crops may fail because of the lack of various micronutrients (Dudal 1963).

The problems of calcareous soil are similar to those arising from over-liming. Deficiencies of available iron, manganese, copper or zinc may be induced. Phosphate availability may fall, because of the formation of complex and insoluble calcium phosphates. Finally, the uptake and utilization of boron may be hindered (Brady 1990).

The central highlands of Thailand are made up mainly of limestone formations, giving rise to black calcareous soils in which iron deficiency is common. This iron deficiency results from the low availability of Fe in such soils, which typically contain 3.5-11.5% CaCO₃ and have a pH of 7.5-8.2. Organic matter levels are relatively high, compared with those of other upland soils in central Thailand. Out of 20 calcareous soils examined, eight contained DTPA extractable iron levels of less than 4 mg/kg. DTPA extractable Fe comprised only a small proportion (0.2%) of total iron in soil, and decreased with depth. This is in contrast to total iron content, which increased with soil depth (Parkpian *et al.* 1987).

Iron Deficiency in Legumes

Iron deficiency limits legume production on black calcareous soils in Thailand. Most of the black calcareous soils are considered quite fertile, but the presence of CaCO₃ and the alkaline pH may cause Fe deficiency in legume crops.

Corn and sorghum are not sensitive to Fe deficiency in calcareous soils. As little as 6-8 mg Fe/kg soil provides sufficient Fe for both crops. Peanut (cv. SK 38), on the other hand, showed chlorotic symptoms in calcareous soils containing (DTPA extractable) iron ranging from 5 to 9 mg/kg. The number of both pods, and kernels per pod, were increased by adding 50 kg iron/ha.

Since total Fe concentrations in plants do not correlate well with plant growth response to Fe, Parkpian *et al.* (1986) used the o-phenanthroline method to diagnose Fe deficiency in peanut, soybean and mungbean. They reported that the concentration

of extractable Fe in the youngest fully expanded leaves of these crops was inversely related to the degree of Fe chlorosis in bean leaves (Table 7).

Iron Deficiency and Symbiotic N Fixation in Peanut

Iron is required for several key enzymes of the nitrogenase complex in legumes, as well as for the electron carrier ferredoxin. Legumes also have a high iron requirement for the heme component of hemoglobin and nodule formation. Iron deficiency severely depresses nodule mass, leghemoglobin content, the number of bacteroids and nitrogenase activity (Tang *et al.* 1992).

Chlorotic peanut with severe iron deficiency failed to form nodules until foliar iron applications were given. In order to identify the stage of nodule biosynthesis most sensitive to iron, Parkpian and Boonkerd (1989) conducted two glasshouse experiments on two groundnut cultivars in black calcareous soils. The results suggest that Fe deficiency specifically limited nodule development in groundnut. However, *Bradyrhizobium* populations in the soil and rhizosphere were not limited in calcareous soils with Fe deficiency. In addition, root infection by *Bradyrhizobium* was not restricted. Plants sprayed with iron produced greater numbers of excisable nodules and carried a greater nodule mass than untreated plants. Five days after iron application, nodules on sprayed plants contained 200 times more bacteroids per unit weight, and a 14 times higher concentration of leghaemoglobin. Iron deficiency also delayed the activity of nitrogenase enzymes in both cultivars.

Correction of Iron Deficiency

Foliar Applications

Foliar applications of inorganic salts or chelated compounds is widely used to treat iron-deficient crops in Thailand. Ratararat *et al.* (1990) suggested that five foliar applications of 0.5% FeSO₄ solution at 10, 20, 30, 40 and 50 days after emergence was the most effective way of alleviating iron chlorosis, and substantially improved yields of peanut.

Mungbean cultivars sometimes show chlorotic symptoms when grown 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

Table 7. Effect iron sulfate foliar spray¹⁾ on iron concentration²⁾ (mg/kg fresh matter) and degree of chlorosis in peanut

Treatment	Extractable iron ³⁾	Iron chlorosis score ⁴⁾
Control	5.5 cd	4 a
3 sprays FeSO ₄	7.4 c	3 b
5 sprays FeSO ₄	9.5 b	2.4 bc
9 sprays FeSO ₄	75.5 a ⁴⁾	2.4 bc

1) 0.5% FeSO₄

2) Iron extractable by Orphananthroline

3) Young fully expanded leaf sampled at Day 30

4) Chlorosis score on young fully expanded leaves, using 0-4 point rating scale where 0 = No chlorosis

5) Leaves sampled 6 hours after foliar spray

Source: Parkpean *et al.* 1986

Means in a column with the same letters are not significantly different at $p = 0.05$

Pods (Unkasem and Tawonsok 1988).

A major problem with foliar applications is the poor translocation of applied iron within the plant. Rates of translocation are species dependent, but did not exceed 50% of the iron applied to a given leaf or leaflet. In the field, respraying is often required, sometimes at ten-day intervals, to provide adequate iron for the developing canopy, since Fe translocation from previously treated areas is insufficient (Chen and Barak 1982).

Organic Fertilizer

The application of manure or compost is an alternative 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). Manure not only contained iron (18-24 mg Fe/kg by DTPA extraction) and other micronutrients, but also had an infrared spectrum similar to that of fulvic acids, and had strong adsorption due to carboxylic and phenolic groups. The complexing between these groups and iron seems to be the mechanism by which iron nutrition is improved by the application of manure (Welkie and Miller 1993).

Genetic Selection of Cultivars

Screening varieties for iron efficiency can be done in two steps. First comes a quick screening procedure, in which seedlings are grown in a modified Hoagland and Arnon No 1 solution

containing 0.2 ppm Fe as FeHEDTA. After six days, plants are graded for chlorosis. Secondly, promising cultivars are tested in the field to measure their yield potential (Chen and Barak 1982).

Many tests have been carried out in Thailand to compare growth and yield performance of various peanut cultivars. Robut 33-1 is considered the most efficient in iron absorption from calcareous soils. It shows relatively few iron deficiency symptoms, especially when grown with an appropriate rhizobium strain 92 such as NC 92.

The study of iron acquisition systems in graminaceous plants (Grasses) has made much progress in recent years. It has become increasingly clear that grasses retain an inherent iron acquisition system termed Strategy II. In this system, phytosiderophores of the MA family serve as an indispensable chemical tool for both iron extraction from soils and subsequent transport of extracted iron into the roots. Recently, it has become clear that a wide range of iron-efficient cotyledonous plants equip their roots with a special iron acquisition system, in which enzymatic reduction of Fe (II) to the ferrous state is obligatory. This system is now generally called Strategy I. It is believed to occur in most families of angiosperms except the Gramineae (Takagi 1993). When we compare the iron efficiency of various cultivars in calcareous soils, we should consider such mechanisms.

COPPER

The soils in which copper 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. In addition, 53 - 62% of copper uptake in some legumes is due to uptake by mycorrhizal hyphae (Barber 1995). Peanut plants depend on vesicular arbuscular mycorrhizae (VAM) for adequate Cu uptake in unfertilized Oxic Paleustults in Thailand (Bell *et al.* 1990).

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 shows a close relationship with vegetative growth and peanut yield. The critical copper concentration in the shoot tips 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).

Complete fertilizer treatment of peanut depressed copper concentrations in the leaves below the critical value even when copper fertilizer was applied to the soil (Bell *et al.* 1990). Higher rates of phosphate fertilizer application may increase the incidence of this problem (Tiaranan *et al.* 1985).

ZINC

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 zinc exchangeable with ammonium 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 (Barber 1995).

The solubility of zinc in soils, and the uptake by plants, both fall rapidly as the soil pH increases. Of the various kinds of inorganic zinc in the soil solution, Zn^{2+} is the most common where the pH is less than 7.7 while $Zn(OH)^+$ is predominant where the pH is between 7.7 and 9.1 (Foth and Ellis 1997). However, under these latter soil conditions, some efficient crops do show any zinc deficiency symptoms. Intalab and Sodthisong (1979) reported that mungbean (Utong 1 cultivar) in calcareous soil did not show any positive yield response to soil applications of zinc fertilizer (0-37.5 kg $ZnSO_4$ ha⁻¹). Soil chemical analysis after mungbean harvest indicated that the available zinc in control plots was about 1 mg Zn kg⁻¹. Soil chemical analysis after the mungbean harvest indicated that the available zinc

in control plots was about 1 mg Zn kg⁻¹. This experiment indicates that Utong 1 mungbean is a Zn-efficient crop.

High levels of phosphorus in soils have been known to intensify Zn deficiency in a number of crops (Forth and Ellis 1997). Repeated applications of phosphate fertilizer in paddy soils may induce Zn deficiency and reduce rice yield. To clarify this problem, Nammuang and Suphakumnerd (1984) carried out pot experiments to study the effect of zinc applications on RD 7 rice grown in sandy loam (Aeric Paleaquults) and clay loam (Aeric Trophaquults) soils. The result indicated that Zn applications had no effect on the general growth and yield of rice plants. However, increasing the application rates of Zn-chelate (from 0 to 3.5 mg Zn kg⁻¹ soil) tended to decrease the phosphorus content in shoots at both the heading and the harvesting stages. However, this did not influence the Fe and Mn concentrations in the rice shoot. The effect of Zn applications in decreasing phosphorus concentrations in rice shoots was greater in sandy loam than in clay loam soils. Zinc chelate at a rate of 3.5 and 2.7 mg Zn kg⁻¹ soil in sandy loam and clay loam soils, respectively, tended to increase the weight of filled grain, reduce the percentage of unfilled grain, and reduce the ratio of straw to filled grain. 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 these 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 Zn SO_4 or Zn EDTA) increased grain and straw yield on sandy loam soils. They also decreased the percentage of unfilled grain. The two different types of zinc fertilizer had different effects on P uptake in rice. Zinc sulfate reduced P uptake and the P content of the rice shoot, while Zn-EDTA increased it (Nammuang and Ingkapradit 1986).

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