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Cover photo: Staff from the Thai Department of Agriculture applying fertilizer to peanuts grown on a boron deficient soil in Khon Kaen province, northeastern Thailand (Photo: R. Bell).

Mineral Nutrition of Food Legumes in Thailand
with Particular Reference to Micronutrients

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Copper

Preface

THIS report outlines the findings of ACIAR Projects 8329 (Micronutrient requirements for biological nitrogen fixation and growth of legumes—March 1984 to June 1986), and 8603 (Boron and other micronutrients for food legume production — July 1986 to December 1989). ACIAR Project 8329 developed from a joint Thailand/ACIAR Planning and Coordination Workshop held in Bangkok from 10–12 October 1983 which was organised at the request of Thai scientists seeking collaboration with Australian scientists on food legume improvement (Persley 1985).

Project 8329 brought together scientists from:

Murdoch University, Perth, Western Australia;
Chiang Mai University, Chiang Mai, Thailand;
Khon Kaen University, Khon Kaen, Thailand;
Thai Department of Agriculture, Bangkok; and
Universiti Pertanian Malaysia.

The objectives of ACIAR Project 8329 were to:

- develop standards for the diagnosis of micronutrient deficiencies in peanut (*Arachis hypogaea* L.) and soybean (*Glycine max* L. Merr.);
- use these standards to identify micronutrient limitations to soybean and peanut production on four major problem soils (Grey podzolic, Low humic gley, Rendzina, and Reddish-brown lateritic soils) in Thailand; and
- determine the relation of symbiotic associations and environmental conditions to deficiency diagnosis.

In February 1986, a panel chaired by Dr Eric Craswell of ACIAR reviewed Project 8329 and recommended that the research objectives be redefined to focus on boron (B) deficiency in food legumes in Thailand. The objectives of the new Project 8603 — Boron and other micronutrients for food legume production — were to:

- determine the extent and severity of B deficiency for food legume crops [peanut, black gram (*Vigna mungo* L. Hepper), green gram (*Vigna radiata* L. Wilczek), and soybean] in Thai soils;
- develop procedures for the diagnosis, prediction and correction of B deficiency in farmers' crops; and
- explore the role of other micronutrient deficiencies in crop production and develop standards for their diagnosis.

Abstract

THE aims of the study were to determine the extent and severity of micronutrient deficiencies for the production of the food legume crops, black gram, green gram, peanut and soybean, in four regions of Thailand (north, northeast, central and southeast), and to develop procedures for their diagnosis, prediction and correction in farmers' crops. The importance of macronutrient deficiencies in legume crop production was also explored and procedures for their diagnosis developed. The study has shown that a high proportion of legume crops in Thailand suffer from one or more deficiencies of the micronutrients boron (B) and molybdenum (Mo) and the macronutrients phosphorus (P), potassium (K), sulfur (S), and nitrogen (N).

Nearly 30% of some 4000 farmers' peanut crops sampled in 50 provinces in Thailand were B deficient with hollow heart disorder. The deficiency was important in all regions but most common in the north and northeast. Whilst most samples were from wet season crops on upland soils, B deficiency was also common in the dry season peanut crops grown on lowland soils.

In northeastern, southeastern and central Thailand, deficiencies of P, N, S, and K were diagnosed by leaf analysis in 71, 43, 35, and 24% of farmers' wet and dry season peanut crops, respectively. Since most of the farmers' peanut crops sampled suffered one or more other deficiencies, correction of these deficiencies would intensify the expression of B deficiency. In northern Thailand, P and K deficiencies were diagnosed by leaf analysis in 43 and 13% of farmers' soybean crops, respectively, in the dry season.

Response of legumes to B varied with plant species and cultivars and with time of planting. Cultivars of soybean, peanut, black gram and green gram varied markedly in their performance on low B soils. Neither of the recommended cultivars of green gram was sensitive to B deficiency on low B soils. But some of the currently recommended cultivars of soybean and peanut were sensitive to B deficiency on low B soils although others were not. Further selection of cultivars which are tolerant of low B soils would assist farmers in the management of B deficiency especially in peanut and black gram.

Plant analysis successfully diagnosed B deficiency in leaves and seeds in legumes. For prediction of B deficiency in farmers' legume crops, reliable soil and plant analysis standards were established and tested in the field.

For hollow heart in peanut, low rates of B fertilizer (0.6–1.2 kg B/ha) corrected B deficiency. Even lower rates overcame the depressing effects of B deficiency on seed dry matter yield in peanut, black gram and green gram. In black gram, strategically timed foliar applications during early reproductive growth corrected B deficiency.

Applications of boric acid and borax to the soil had poor residual value especially on sandy soils. On a sandy Oxic Paleustult in Khon Kaen province, initial applications of 0.25, 0.5, and 2 kg B/ha were required to correct B deficiency in black gram in the first, second, and third crops after application, respectively.

Low levels of B in seed were shown to seriously impair seed quality by depressing seed germination of black gram and soybean, and early growth of soybean, black gram and green gram. In soybean, the effects persisted through to final seed yield which was depressed by up to 700 kg/ha. Low B in peanut seed also accelerated loss of viability during storage.

Critical nutrient concentrations were defined for the diagnosis of Mo deficiency in peanut, black gram, green gram and soybean. These values were used to interpret leaf analysis of over 600 samples collected from farmers' crops. The

data suggest that Mo deficiency may be depressing seed production in 17% of farmers' peanut crops in northeastern, central and southeastern Thailand: it may be depressing N fixation in a further 28% of the crops. In black gram, seed production was more sensitive to Mo deficiency than in peanut. At four sites in northeastern Thailand, black gram seed production was depressed by 10–35%.

Iron deficiency strongly depressed seed yield in peanut cv. Tainan 9 grown on the alkaline Typic Calciustolls of the central highlands of Thailand. Typic Calciustolls are important soils in the central highlands but are of limited importance elsewhere. Iron deficiency was not observed on any other soil. Cultivars of peanut and black gram varied in sensitivity to Fe deficiency on the Typic Calciustolls suggesting the selection of cultivars which tolerate low Fe soils would be a good long term option for increasing legume production. Iron deficiency specifically limited nodule development in peanut but strains of bradyrhizobia varied in their capacity to develop an effective symbiosis with peanut suffering Fe deficiency.

Copper (Cu) deficiency was diagnosed from leaf analysis in only 1% of 636 farmers' peanut crops. However, experiments on the Oxic Paleustults in northeastern Thailand suggested that a much larger proportion of crops would develop Cu deficiency if fertilized with P-fertilizer. In peanut, P-fertilizer appeared to induce Cu deficiency by depressing the levels of vesicular–arbuscular mycorrhiza (VAM) in roots. Further studies are needed to demonstrate conclusively that VAM are important in Cu uptake by peanut on Oxic Paleustults in northeastern Thailand and to determine its role and that of P-fertilizer use in the Cu nutrition of other crops.

CHAPTER 1

Background

FOOD legumes, though secondary to rice, are important crops in Asian farming systems (McWilliam and Dillon 1987). By contrast with the large gains made in yields of rice and wheat in the past two decades in Asia, those of the food legumes are generally low and have remained fairly stagnant during the same period (Craswell et al. 1987). That a large yield gap (1–5 t/ha) exists between yields from experimental plots and those in farmers' crops suggests that yields of the food legumes can be markedly increased by removing constraints such as drought, pests, diseases, and mineral disorders. Success in alleviating constraints for food legume production requires reliable procedures for their diagnosis and prognosis. This study has concerned the diagnosis and prognosis of micronutrient disorders in food legumes in Thailand. However, the principles are valid for other crops and other regions.

Food Legumes in Thailand

Soybean, green gram, black gram and peanut are important upland crops in Thailand, ranking in terms of their farm value behind cassava, maize and sugar cane (Table 1.1). For all the legumes, northern Thailand is the main production region. In northeastern Thailand, only peanut is grown extensively (Office of Agricultural Economics 1987).

Soybean is grown for domestic consumption both as processed food for humans and as a component of animal feeds. Domestic production is actively encouraged because production is still far short of local demand (Wonghanchao and Nabangchang 1987). Seventy five percent of the soybean is grown as rainfed crops in upland soils (Benjasil and Arworth 1985; Na Lampang 1985) either at the beginning of the wet season or towards the end of the wet season when it follows corn or the first soybean crop (Kaosa-ard et al. 1987). The remaining 25% is grown mainly in the upper north under irrigation as a dry season crop in paddy soils following rice.

Green gram and black gram are grown in the same three seasons as soybean and often as an alternative crop to soybean (Na Lampang 1985). Green gram is less suited to dry season cropping in northern Thailand on account of its greater sensitivity to cold temperatures. In other areas, it may be favoured over soybean because of its earlier maturity.

Table 1.1 Estimated value and production, area harvested, and yield of the principal agricultural crops in Thailand, 1986

Commodity	Estimated value million Baht[a]	Estimated production million tonnes	Area harvested '000ha	Yield (kg/ha)
Rice	45 530	18.9	9 194	2 050
Maize	6 894	4.31	1 815	2 375
Cassava	18 580	19.6	1 371	14 270
Sugar Cane	7 163	24.5	520	47 000
Mungbean[b]	1 773	0.301	493	612
Soybean	2 192	0.356	282	1 263
Peanut	844	0.169	125	1 356

[a] Aust $1.00 = 20 Baht
[b] Includes green and black gram.
Source: Office of Agricultural Economics 1987.

Most of the peanut is planted either in the early wet season under rainfed conditions or in the dry season after rice either with irrigation or using the residual moisture in the paddy field (Na Lampang 1985).

Soil and Climatic Constraints for Food Legume Production

Soils and land use

The Kingdom of Thailand is classified into six physiographic regions: the northern and western continental mountains, northeastern plateau, southeastern coast, central highlands, central plain, and peninsula (Moorman and Rojanasoonthon 1968). The latter two regions will not be considered further as very little of the present research was conducted there (Fig. 1.1).

Northern and Western Continental Mountains. Much of the region is mountainous but the valleys of the major rivers, and numerous smaller ones, have been largely cleared and are now extensively cultivated for rice, soybean, tobacco, peanut, and horticultural crops (Chulasai et al. 1985). The soils of the valleys can be divided into two major classes, lowland and upland. Lowland soils of the alluvial plains and lower terraces are cultivated for rice in the wet season and irrigated crops in the dry season; the upland soils of the higher terraces are sown to field crops in the wet season. Typical bedrocks of the region are conglomerates, sandstones, and greywacke which are interbedded with shales and limestone (FAO–UNESCO 1979).

Northeastern Plateau. The northeastern plateau comprises three terrace levels plus the alluvial flood plain (Moorman et al. 1964). Soil properties are closely related to the landform. For the most part, the alluvial soils and low terrace soils are planted to rice on account of their poor drainage (Chiangprai 1987). The middle terrace is most extensive and was the main area of interest for the present study because of its cultivation for field crops including cassava, sugar cane, kenaf, and peanut. The high terrace occupies a relatively small area but is cultivated for field crops also. The bedrock of the northeastern plateau consists largely of sandstone, siltstone, shale and conglomerates of the Triassic and Jurassic age (Pendelton 1962).

Southeastern Coast. The southeastern coast is a region largely of upland soils on old marine and river terraces derived from acid igneous rocks, quartzite and phyllite, granite and gneiss (Tongchuta 1973). The soils tend to be sandy as is common elsewhere in Thailand. The upland soils have been extensively cleared for cassava, sugarcane and peanut, and in the higher rainfall areas to the east, rubber and fruit trees.

Central Highlands. The central highland region has a complex physiography, but only the features of the middle portion are relevant to this study. The landscape of the middle portion is dominated by an extensive low undulating peneplain interrupted by steep limestone ridges and buttes (Chiangprai 1987). The dominant geological formations of the region are the marls which give rise to alkaline clay soils (Calciustolls) and shales which give rise to moderately acid clay soils (Oxic Paleustults): both groups of soils are quite unlike the majority of upland soils in Thailand on account of their heavy texture. Upland crops grown extensively in this region include corn, cotton, green gram, black gram, sorghum, peanut, sesame and soybean.

Climate

The climate of Thailand apart from the peninsula is monsoonal with distinct wet and dry seasons (van den Eelaart 1973). The wet season begins about May and ends quite abruptly in October: August and September are the months of heaviest and most reliable rainfall (Table 1.2). Mean annual rainfall is about 1100–1400 mm throughout the study area (Chiangprai 1987: see Table 1.2), but varies substantially from year to year. It can also vary within one season over short distances because it falls in thunderstorms (van den Eelaart 1973). At Chiang Mai, for example, annual rainfall between 1973 and 1986 varied from 784 to 1560 mm (Chulasai et al. 1985). Slightly more than 50% of northeast Thailand experiences < 80 rainy days per year (i.e. days with >10 mm rain) (Chaiwanakupt 1985). The uneven distribution, short duration and variable quantity of rain from year to year are serious limiting factors for upland crop production (Chiangprai 1987). The short growing season determines the types of cropping systems, and in particular has led to an emphasis on early maturity in legume breeding programs (Na Lampang 1985). These factors are exacerbated by the fact that most upland soils in Thailand have relatively low available water-holding capacity (van den Eelaart 1973).

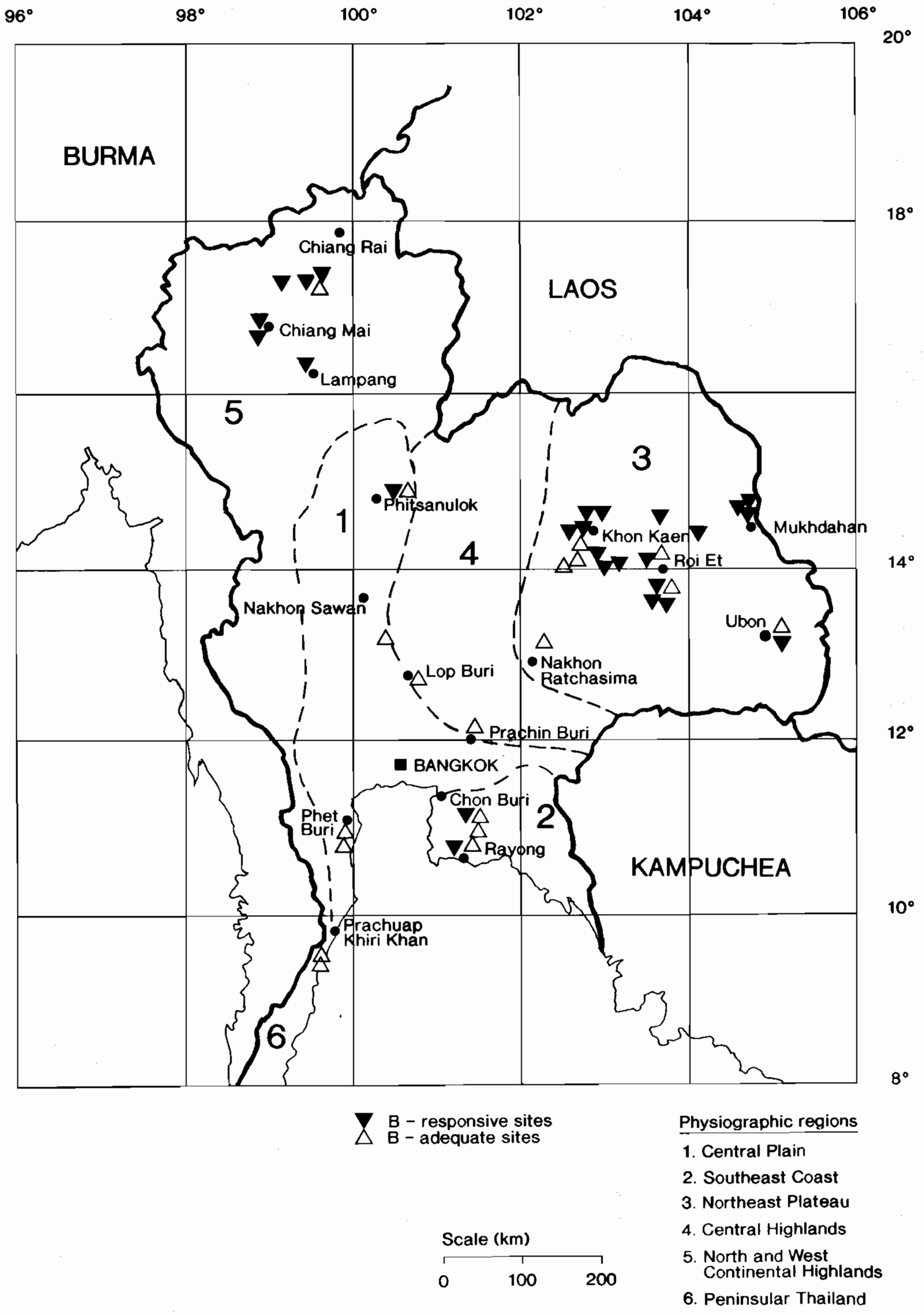

Fig. 1.1 Map of Thailand showing its physiographic regions and the location of field experiments.

Table 1.2 Mean monthly precipitation (mm) at selected stations in northern, northeastern, central and southeastern Thailand.

Station[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Chiang Mai	12	7	19	50	166	146	180	241	255	130	35	19	1260
Khon Kaen	7	15	34	63	172	181	157	188	277	86	14	3	1197
Lop Buri	9	18	51	72	165	143	166	172	277	154	37	7	1271
Chon Buri	13	25	38	78	162	119	162	166	298	216	60	8	1345

[a] See Fig. 1.1 for the location of stations.
Source: data from Meteorological Department (1982) for the period 1951–1980.

During the wet season, mean maximum and minimum temperatures are generally 30°–35°C, and 20°–25°C, respectively (Table 1.3). Northern Thailand experiences a distinct cool season from November to February when minimum temperatures are below 20°C and may on occasions drop to below 5°C. In the cool season, these temperatures limit production of green gram and other cold sensitive tropical species. To a lesser extent soybean (Na Lampang 1985) is also affected.

Micronutrient Research in Thailand

Previous studies in Thailand have occasionally shown responses by field crops and pastures to micronutrient fertilizers but the extent and severity of these deficiencies in upland soils has not been studied systematically (Keerati-Kasikorn 1984, 1985). The most comprehensive study of the micronutrient status of Thai soils was that of Sillanpaa (1982) who reported that the levels of boron (B) in Thai soils were low compared to the average for soils collected from 29 countries around the world.

Many of the samples collected in Thailand had hot water soluble (HWS) B levels considered to be marginal or deficient for plant growth. By contrast, the levels of iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), and molybdenum (Mo) in Thai soils were close to their international average values. For Zn, Fe, and Cu, some of the soil samples from Thailand contained levels which were regarded as marginal or deficient for plant growth but in general, deficiencies of micronutrients apart from B were not considered likely to be a major problem in Thailand.

Sillanpaa's samples consisted mostly of neutral to alkaline soils with heavy texture collected from the central region. He sampled few acidic and sandy textured soils which are characteristic of northern, northeastern and southeastern Thailand (Table 1.4). Hence the studies outlined here were the first systematic examination of micronutrient deficiencies for food legume crops in northern, central, southeastern and northeastern Thailand.

Other evidence also suggested that micronutrient deficiencies might limit crop production in Thailand. The major soil-forming parent materi-

Table 1.3 Monthly mean maximum and minimum temperatures (°C) of synoptic stations at Chiang Mai, Khon Kaen, Lop Buri and Chanta Buri.

Station		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Chiang Mai	max	29.8	32.7	35.2	36.6	34.8	32.9	31.9	31.4	32.0	32.1	30.9	29.3	32.4
	min	13.2	14.1	17.5	21.4	23.3	23.6	23.4	23.2	22.9	21.6	18.7	14.9	19.8
Khon Kaen	max	30.3	32.8	35.3	36.5	34.9	33.1	32.6	32.0	31.6	31.4	30.9	29.8	32.4
	min	15.7	18.7	21.9	24.1	24.6	24.6	24.1	24.0	23.6	22.2	19.3	16.1	21.7
Lop Buri	max	32.5	34.5	36.2	37.0	35.3	33.6	32.7	32.3	31.7	31.6	31.4	31.3	33.3
	min	19.0	21.9	23.8	24.8	24.8	24.3	24.0	24.1	24.0	23.5	21.4	19.2	22.8
Chanta-Buri	max	31.3	32.1	33.2	34.1	33.3	32.5	31.9	31.6	31.2	31.3	31.1	31.0	32.0
	min	20.1	22.4	24.2	25.4	25.4	25.5	25.0	24.9	24.4	23.8	22.1	20.3	23.6

Source: data from Meteorological Department (1977) for the period 1951–1975.

Table 1.4 Physical and chemical properties of soils (0–10 or 0–15 cm) at selected sites on which field and pot experiments were conducted in the present study.

	Soil series					
	Khorat	Satuk	San Sai	Pak Chong	Map Bon	Takli
Location	Taphra, Khon Kaen	Samjarn, Khon Kaen	Chiang Mai Univ, Chiang Mai	Koktoom Lop Buri	Khao Hin Son, Chachoengsao	Takfa, Nakon Sawan
Soil taxonomy	Oxic Paleustult	Oxic Paleustult	Typic Ochraqualf	Oxic Paleustult	Typic Paleustult	Typic Calciustoll
National	Grey podzolic	Red-yellow podzolic	Low humic gley	Reddish-brown lateritic	Red-yellow podzolic	Rendzina
Texture	Loamy sand	Sand	Silty clay loam	Clay loam	[a]	Clay
% clay	4	0	26	33	8	47
% sand	82	85	16	40	[a]	27
Soil pH (1:1 H_2O)	6.1	5.9	6.0	5.0	4.8	7.9
Exchangeable cations (mg/kg)						
Ca	280	160	641	625	[a]	33 000
Mg	50	21	48	180	[a]	400
K	40	70	148	169	[a]	600
Avail P (mg/kg)	7	17	7	10	[a]	47
Organic C (%)	0.3	0.4	1.5	2.3	1.3	2.9
HWSB (mg/kg)	0.13	0.08	0.10	0.26	0.18	a

[a] not determined

als in Thailand, for example, are low in weatherable minerals suggesting that micronutrient deficiencies are likely. In northeastern Thailand, the soils have weathered from coarse grained sediments high in quartz which had already been highly weathered when they were deposited (Petersen 1983). Consequently, the soils of northeastern Thailand are sandy, with low contents of weatherable minerals and low levels of plant nutrients. Shelton et al. (1979) conducted simple omission design pot trials with 12 typical soils of the low, middle and high terraces in northeastern Thailand and found deficiencies of Cu, Mo, and B in 33, 25, and 25% of the soils, respectively. In ten of the soils, there were multi-element deficiencies, including one extremely sandy soil which was deficient in phosphorus (P), potassium (K), sulfur (S), magnesium (Mg), Cu, Mo, and B. Surprisingly, in northeastern Thailand only occasional responses have been obtained in the field with B treatment (peanut: Chiosamut and Kritrattakanon 1970), and Mo treatment (soybean: Ratanarat et al. 1975) of food legume crops. Several other pot and field studies involving a wide range of soils failed to obtain any response of legume crops to micronutrient treatments (Suwanarit 1985; Kumarohita et al. 1976).

The reasons for the failure of field crops to respond to micronutrients despite the low fertility of the soils of northeastern Thailand and the prevalence of deficiencies in the omission pot trials of Shelton et al. (1979) have not been thoroughly examined. Keerati-Kasikorn (1985) suggested that there were often insufficient data collected about the micronutrient levels in soils and crops studied to determine why responses to micronutrient treatment were not obtained. Suwanarit (1985) suggested that studies with micronutrients such as B may fail to show crop yield responses to its application unless the rate chosen is close to optimum because the range between deficient and toxic supply is relatively narrow. Other possible causes for the lack of micronutrient responses on soils of northeastern Thailand include inadequate supply of other nutrients, contamination of macronutrient fertilizers with micronutrients (e.g. Ozanne et al. 1965) or high levels of micronutrients in seeds (e.g. Harris et al. 1965; Robson and Mead 1980).

In northern Thailand, fewer studies have been conducted on the response of field crops to micronutrients than in the northeast (Keerati-Kasikorn 1984). However, the siliceous sedimentary parent materials of the northeast also occur in northern Thailand suggesting that the same micronutrient deficiencies might occur. As a precaution against B deficiency, tobacco companies have for many years supplied to their contracted growers compound fertilizers containing B (Rerkasem et al. 1988). Occasional responses to B application in peanut have been reported in Chiang Mai, but the effects have been variable (Multiple Cropping Project, 1974). Subsequently, Rerkasem (1986) found that omitting B fertilizer depressed sunflower seed DM by 83–100% on a Tropaqualf at Chiang Mai. Loneragan in an unpublished report to the Australian International Development Assistance Bureau (AIDAB) in 1982 examined the reasons for declining yields on intensively cropped soils in the Chiang Mai valley and concluded from soil properties and plant symptoms that deficiencies of B and Zn were likely.

In the Central Highlands, limestone formations are prevalent, giving rise to black calcareous soils (fine-clayey, montmorillonitic Typic Calciustolls; Soil Survey Staff 1975) on which iron deficiency is common (Parkpian et al. 1988). Iron deficiency is the most extensively studied of the micronutrient deficiencies in Thailand but is largely restricted to the Central Highlands. Results of research on iron nutrition of field crops in Thailand were recently reviewed by Parkpian et al. (1988). Iron deficiency on the Typic Calciustolls of Thailand results from the low availability of Fe in the soil. Typically these soils contain 3.5–11.5% $CaCO_3$, and have pH values ranging from 7.5 to 8.2 (Table 1.4).

Previous research has been conducted mostly with peanut which is more sensitive to Fe deficiency than other field crops commonly grown on the Typic Calciustolls of Thailand. Soil amendments including elemental S, poultry manure and organic humus were tested for their efficacy in correcting Fe deficiency but found to be ineffective unless used at very high rates (Parkpian et al. 1988). Similarly, $FeSO_4$ only corrected Fe deficiency when applied at very high rates. More recent studies on correction of Fe deficiency have concentrated on the use of chelated forms of Fe fertilizer such as FeEDDHA, FeDTPA, and FeEDTA, all of which were effective at rates of 20–50 kg/ha.

CHAPTER 2

Methods for Assessing Micronutrient Deficiencies

IN this study, field experiments were used extensively to investigate micronutrient deficiencies for food legume production in Thai soils. However, because field responses vary from year to year, and results may be site-specific, the field experimental program was supplemented by using plant symptoms, plant and soil analysis, and to a lesser extent pot experiments, to diagnose and predict the occurrence of micronutrient deficiencies.

Field Experiments

For the diagnosis of micronutrient deficiencies in a crop, its response to the application of micronutrient fertilizers to the soil or foliage provides a relatively easy and positive test. If good experimental techniques are used, the only serious problem with this procedure is that of micronutrient contamination in basal fertilizers, insecticides, fungicides, irrigation water, or seed, or from the procedures used during the application of the micronutrient treatments themselves.

Precautions against micronutrient contamination

Micronutrient content in fertilizers

A survey of the levels of micronutrients in commercially available fertilizers was conducted by Bell et al. (unpublished data). They found variable concentrations of micronutrients in most fertilizers (Appendix 1) and particular fertilizer products had contamination levels up to the following concentrations: B, 683 mg/kg; Cu, 270 mg/kg; Mn, 1120 mg/kg; Mo, 80 mg/kg; and Zn, 4648 mg/kg.

Fertilizers with these levels of contamination would obscure identification of micronutrient deficiencies in crops. For example, triple superphosphate was unsuitable as a P fertilizer on account of the high B content in some batches and batches of gypsum from Chiang Mai contained large amounts of Zn making them also unsuitable for micronutrient experiments.

Lefroy et al. (pers. comm.) found that compound NPK products varied by up to 63% from their certified values for P_2O_5 and K_2O, and products with the same formulation contained widely variable concentrations of S and Ca. The magnitude of these variations made NPK formulations quite unsuitable basal fertilizers for trials on micronutrients especially on soils that have multi-element deficiencies.

For multi-element fertilizer trials, single salt fertilizers were used to avoid confounding nutrient treatments. Suitably pure single salt fertilizers used were as follows: $Ca(H_2PO_4)_2$ (bakers' grade calcium aerophos); K_2SO_4; KCl; urea; $(NH_4)_2SO_4$; $CaCO_3$; MgO and $Ca(OH)_2$. Each time a new batch of fertilizer was obtained it was first analysed chemically before being used in micronutrient experiments.

Seed micronutrient content

A survey of micronutrient levels in farmers' peanut and soybean seed in Thailand was conducted (Bell et al. unpublished data). In peanut and soybean seed, the range of concentrations were as follows:

	Peanut	Soybean
Mo	0.03–7.41 mg/kg	0.17–4.64 mg/kg
Cu	2.3–18.4 mg/kg	6.2–16.3 mg/kg
Co	0.11–0.29 mg/kg	0.23–0.79 mg/kg

For omission field trials and Mo rates trials, Mo levels in the seed used were 0.040–0.490 mg/kg for peanut, 0.30–0.850 mg/kg for soybean and 0.31 mg/kg for black gram.

Other precautions

Other precautions taken in the field experiments to prevent micronutrient contamination included: avoiding movement from plots treated with micronutrients to those without; avoiding the use of materials or implements which contain micronutrients such as galvanised iron (which contains Zn), copper or brass fittings (e.g. in spray units used for crop protection); avoiding crop protection chemicals which might contain micronutrients such as Cu-containing fungicides; and using distilled or de-ionised water to apply the chemicals and checking the levels of micronutrients in *Bradyrhizobium* peat cultures.

Experimental design

Omission trials

The omission fertilizer trial is often used to identify nutrient limitations and is particularly useful for the clarification of multi-element deficiencies (Loneragan 1970). It has the advantage of simplicity which facilitates both the conduct of the experiment and the interpretation of the results. In the omission trial, the effects of omitting single elements or groups of elements on crop yield are compared with a complete fertilizer treatment.

Rates of fertilizer applied in the complete fertilizer treatment were based in part on recommendations of the Thai Department of Agriculture for legumes (e.g. Tiaranan et al. 1985) and other field crops (Ho and Sittibusaya 1984) but in general, for previously unfertilized soils, they were increased to minimise the possibility that the rates were inadequate (Appendix 2). On the Khorat soil series, P toxicity symptoms developed on peanut soon after emergence from soil treated with 410 kg calcium aerophos/ha suggesting that the basal rate of P was excessive: with time the plants appeared to grow out of the toxicity. A second side-effect of the high rate of P used on the Khorat soil was the widespread appearance of Cu deficiency symptoms in all P-treated plots at two sites near Khon Kaen. In the omission trial on the Takli soil series, the rate of Fe fertilizer applied to the soil was inadequate to correct Fe deficiency (Ratanarat et al. 1987). Similarly, the rate of B fertilizer (1 kg boric acid/ha) used in the complete fertilizer treatment in the omission trial on the Ubon soil series (Appendix 2) was inadequate to prevent hollow heart symptoms in peanut (Keerati-Kasikorn et al. 1987). Clearly in these experiments the full extent of micronutrient deficiencies was not revealed. These cases also illustrate one of the drawbacks of conducting omission trials on a wide range of soils without the assistance of prior knowledge of the optimal fertilizer rates for the particular site.

The legumes were reliant on symbiotically fixed nitrogen. At planting, seeds or soils were inoculated with peat cultures of recommended *Bradyrhizobium* strains.

Other experimental designs

Following the initial omission experiments which identified extensive B deficiencies, experiments were conducted to determine the rates of B fertilizer required to correct deficiencies and to study the factors affecting crop responses to B deficiencies. Four to seven rates of B supply were applied ranging from 0 to 4.5 kg B/ha as borax or boric acid. Boron rate treatments were usually applied in combination with one or two other factors which might affect the incidence of B deficiency or the level of its severity, such as plant species or cultivar (Rerkasem et al. 1988), seed B concentration (Rerkasem et al. 1990), year of fertilizer application (Keerati-Kasikorn et al. 1990), or basal fertilizer supply (Ratarnarat et al. 1990a). Rates of basal nutrients applied were similar to those given in Appendix 2. Legume species and cultivars grown in the B rates experiments were as follows: peanut cvv. Tainan 9 and KK60-1 (the latter in 1988 only); soybean cvv. SJ5 and NW1; black gram cvv. Regur and Uthong 2; green gram cv. Uthong 1.

Simple on-farm field trials were carried out at 27 sites in the wet season during 1988 and at 10 sites in the following dry season. Soils were treated with or without B fertilizer (0, 0.625 kg B/ha as boric acid) on unfertilized and fertilized soil. Rates of nutrients applied in the fertilizer treatment (superphosphate, potassium sulfate, and $NaMoO_4.H_2O$) were as follows (in kg/ha): 25 P; 30 K; 23 S; 0.53 Mo. Gypsum was applied in rows, to peanuts, at pegging at the rate of 500 kg/ha in fertilized plots only. Acidic soils (pH (1:2 H_2O) < 5.0) were limed to pH 5.5.

Plant Symptoms

Plants suffering nutrient deficiencies often exhibit distinctive symptoms which can be used to diagnose the deficiency. They are particularly useful where, as in the case of B deficiency in peanut, they are distinctive and specific. In peanut, kernel development is so sensitive to low B in the soil that it develops a characteristic symptom known as 'hollow heart' (Harris and Gilman 1957) even on soils that contain adequate B for shoot and seed dry matter production. In this study, the hollow heart symptom has been used extensively to identify B deficiency in farmers' peanut crops in Thailand. Samples comprising 100–200 pods were collected at crop maturity from farmers' fields and the proportion of kernels with hollow heart symptoms recorded. Wherever possible the incidence of hollow heart was correlated with hot water soluble B levels in the soil at early pegging or maturity and with soil properties and topography. The diagnosis of B deficiency in peanut by hollow heart symptoms was such a simple procedure that 3930 samples were collected from farmers' peanut crops in 50 provinces of Thailand with the cooperation of the officers of the Thai Department of Agricultural Extension.

Descriptions and colour photographs of selected nutrient deficiency and toxicity symptoms have been published for soybean (Grundon 1987), peanut (Reid and York 1958; Porter et al. 1984), and green gram (Smith et al. 1983). In Chapter 3, additional symptom descriptions particularly for B are given to aid in the diagnosis of nutrient disorders in these legumes.

Plant Analysis

At the start of this project, very few reliable standards were available for the diagnosis of macronutrient or micronutrient deficiencies in black and green gram, peanut, and soybean (e.g. see Reuter 1986). Those standards which had been developed were principally applicable to the prognosis of nutrient deficiency (see Small and Ohlrogge 1973) rather than its diagnosis. Okhi and co-workers (Okhi 1977, 1978, 1982; Okhi et al. 1979) have developed critical concentrations for diagnosis of Zn and Mn deficiencies in soybean whereas, for peanut, Parker and Walker (1986) and Robson et al. (1977) have determined critical concentrations for Mn and Cu, respectively. The development of the remaining standards was a major objective of this study.

Diagnosis of deficiencies

To diagnose nutrient disorders, standards were developed to distinguish between plants with adequate and deficient nutrient supply. Such standards are usually referred to as critical nutrient concentrations (Ulrich 1952). For each nutrient, the critical nutrient concentration is usually defined as that concentration in a plant part which limits the plant's yield to 90% of its maximum yield (Ulrich and Hills 1967).

Critical concentrations were determined for the diagnosis of deficiencies of P, K, S, Zn, Cu and Mo in peanut and soybean, and of Mo in black and green gram plants, in a series of glasshouse experiments at Murdoch University and the University of Western Australia using soils deficient in each of the elements studied. Lancelin sand, a low fertility soil with multi-element deficiencies was used for studies on K (Bell et al. unpublished data; Brady 1986), Zn (Bell et al. 1990a), Cu (Mahmood et al. 1987), and Mo (McLay 1989). Badgingarra sand was used for S (Supakamnerd et al. 1990) and K (Bell et al. 1987b) studies. Bodallin soil, an acid loam was used for Mo studies on soybean (Chotechaungmanirat 1988) and black gram (Jongruaysap, unpublished data). The methodology for each of these studies was similar and is illustrated by the study of Bell et al. (1990a) on Zn deficiency diagnosis in peanut.

For most of these nutrients, shoot dry matter was used as the criterion for measuring nutrient response and hence for defining critical concentrations. For B deficiency, shoot dry matter responds very slowly, making it an unsatisfactory criterion for defining the critical concentration (Kirk and Loneragan 1988). An alternative procedure used to determine critical values for diagnosis of B deficiency was described in detail by Kirk and Loneragan (1988). Soybean was grown in non-renewed culture solution at two initial B concentrations chosen so that the lower concentration became deficient during the growing period while those growing in the higher B concentration remained healthy. As the low B plants grew into B deficiency, the length of expanding leaf blades and their B concentrations were determined daily. For each leaf, the relationship between leaf blade elongation rate and B concentration was determined. The critical concentration was established as the B concentration which corresponded with a 10% decrease in the rate of leaf blade elongation. The same procedure was used for defining the critical B concentration for B deficiency diagnosis in peanut (Kirk unpublished data), black gram (Kirk unpublished data; Netsangtip unpublished data), and green gram (Kirk unpublished data; Bell et al. unpublished data).

As with the field experiments, a number of essential precautions were taken to avoid micronutrient contamination in the soil preparation, fertilizer treatment, watering of plants, collection and processing of plant samples, and elemental determinations in plant samples in the laboratory.

For the glasshouse experiments, soils were collected in the field using thoroughly washed steel or stainless steel spades. Soils were stored in unused jute bags and mixed with stainless steel spades in areas specially reserved for micronutrient studies and from which possible sources of contamination were eliminated. The glasshouse was free of exposed galvanised iron, Cu or brass fittings or Zn-pigmented paints in its superstructure and internal fittings. Macronutrient fertilizer salts were purified to remove Zn, Cu, Mo, and B contamination before application (Eskew et al. 1984; Kirk and Loneragan 1988). Double deionised water was used for studies on Zn. For Cu and Mo, water was de-ionised for a third time by passing through a mixed bed ion exchange resin. For B studies, the double de-ionised water was passed through a column of a B-specific resin to remove B impurities.

In the laboratory, the procedures used for preparing and analysing elemental concentrations in plant samples are listed in Appendix 3 and described briefly by Plaskett (1987).

Plants were harvested in a clean room reserved for the purpose. For drying, the plant samples were wrapped in tissue paper and placed in seed envelopes or brown paper bags and dried in a stainless steel lined oven. Wherever possible whole oven-dried plant samples were digested directly to avoid further handling. For larger samples (>2 g DM), or for samples which had to be subdivided for multi-element analysis, the oven-dry samples were ground in a stainless steel mill.

All glassware used for digesting samples and making up solutions was thoroughly cleaned. In the case of B analyses, plastic ware (polyethylene) was used for making up solutions rather than glassware which may be a source of B contamination (Moraghan 1985). High purity chemicals and acids were used to make up solutions and to digest plant samples, respectively. Solutions were made up in triple de-ionised water or B-free water as appropriate.

As a check on the accuracy of the elemental determinations, each batch of digested samples included 2–3 standard reference plant samples with known elemental composition. Two blank samples were carried through the entire digestion, extraction, dilution and determination sequence for each batch of samples to monitor levels of background contamination.

Prognosis of nutrient deficiencies

The development of prognostic plant tests was carried out in the field using the same B rates experiments that were used to determine the minimum fertilizer B requirements of food legumes (Rerkasem et al. 1988; Predisripipat 1988; Keerati-Kasikorn et al. 1990; Ratanarat et al. 1990a). Leaf samples were collected at defined reproductive growth stages: the earliest samples were taken at early flowering for soybean (R1, Fehr et al. 1971) and grams, or early pegging stage for peanut (R2, Boote 1982). Wherever possible a second sample was collected at either pod set for the grams (R3) or pod filling (R5–6) for peanut and soybean. For each sample, at least 20 leaf blades were collected at random from treated plots taking care to avoid leaves damaged by pests or disease. Leaves from guard rows were also avoided. Youngest fully expanded leaf blades (YFEL) were sampled in all cases and for B or Cu studies the youngest folded leaf blade (YFL) also. The same precautions required for collecting and handling leaf samples in the glasshouse experiments were also adopted in the field.

Critical concentrations were determined for each plant part sampled and for each sampling time by relating its nutrient concentration to either seed DM or quality at maturity. In peanut, critical concentrations were determined primarily for prognosis of hollow heart incidence in seed whereas for the other legumes they were determined for the prognosis of seed DM.

Soil Analysis

In field studies (e.g. Keerati-Kasikorn et al. unpublished data; Ratanarat et al. 1990a) and in pot studies using large (20 kg) amounts of soil (Hiranburana et al. unpublished data), soil B levels were related to seed DM or quality to develop standards for the prediction of B deficiency by soil analysis. Soil samples were collected from plots at 0–10 cm and 10–25 cm depths. Boron in soils was extracted by boiling in water for ten minutes and determined colorimetrically by the curcumin method (Dible and Berger 1952).

Two procedures were tested to assess the B fertilizer requirements of soils by soil analysis. In the first, the amount of B required to raise the equilibrium B concentration in the supernatant solution to 0.1 µg/mL was determined (Sims and Bingham 1967). Because of the difficulty of measuring the low supernatant B concentrations with this method an alternative incubation procedure was tested. Increasing amounts of B fertilizer as boric acid were incubated in 50 g portions of soil moistened to field capacity. After 30 days, B in the soil samples was extracted by hot water as described above. The relationship between amounts of applied B and levels of HWS B were determined for each soil. The amount of B fertilizer required to raise HWS B levels in the soil to 0.3 mg B/kg was used as the estimated fertilizer B requirement for the soil.

Soil Mo was extracted by NH_4-oxalate (Reisenauer 1965) and determined spectrophotometrically (Purvis and Peterson 1956). Molybdenum sorption capacity of soils was determined as follows. Ten grams of soil was weighed into each of seven 100-mL bottles to which were added 100 ml of 0.01M $CaCl_2$ containing Mo at 0, 0.25, 0.5, 1.0, 2.0, 4.0 and 8.0 mg Mo/ kg as Na_2MoO_4. The bottles were shaken horizontally by a mechanical shaker for 24 hours at room temperature. The suspension was filtered and the filtrate analysed for Mo. Molybdenum which was not detected in the filtrate was considered to have been adsorbed.

CHAPTER 3

Results and Recommendations

Boron

THIS study has shown that in many upland and lowland soils of northeastern, northern and southeastern Thailand, B deficiency is widespread in peanut crops (Figs 1.1 and 3.1) and is a potentially serious problem to improved seed production and quality in all legume crops.

Response of legumes to boron

Seed production in peanut, black gram and green gram was more responsive to low soil B than was vegetative dry matter. Moreover, seed quality of peanut, black gram, green gram and soybean was even more sensitive to low B in soils than was seed DM. In peanut, the most characteristic indicator of B deficiency is the hollow heart symptom in seeds (Plate 3.1: see also Harris and Gilman 1957; Harris and Brolman 1966). Indeed, in one experiment, B deficiency induced hollow heart symptoms in 35% of peanut seeds without depressing seed DM (Rerkasem et al. 1988). In 29 B responsive field trials in Thailand, peanuts without B produced seed with an average of 32% hollow heart but only a 13% depression in DM (Table 3.1).

In soybean, black gram and green gram, the quality of seed for germination and early plant growth was more sensitive to low B in the soil than was seed DM (Rerkasem et al. 1990, unpublished data). In black gram, for example, low B supply during plant growth depressed subsequent germination and vigour of seed (Bell et al. 1989). Seed germination and vigour was depressed more strongly than growth of the parent plant and seed yield. Thus, black gram plants with no symptoms of B deficiency produced seed with a low percentage germination and a high percentage of abnormal seedlings (Plate 3.2).

In black gram, low B in seed depressed the percentage of hard seed in both pot (Bell et al. 1989) and field studies (Netsangtip et al. unpublished data). Hard seed is a desirable characteristic in gram seed because it increases resistance to weather damage which can occur when the fruits mature in wet and humid conditions (Lawn and Ahn 1985). Resistance to weather damage in green gram appears to be positively correlated to the levels of hard seed (Williams et al. 1984) and cooperative plant breeding research is underway in Thailand and Australia to increase the levels of hard seed in green gram varieties (Imrie et al. 1988). The present results suggest that green gram seed with low B may be more susceptible to weather damage and hence be of inferior quality for sprouting.

Low B concentrations in seeds increased the percentage of abnormal plants of black gram, green gram (Rerkasem et al. 1990), and soybean (Rerkasem et al. unpublished data) in the field. The abnormal plants exhibited a range of symptoms including missing epicotyls, aborted apical

Table 3.1 Summary of boron responses obtained in field experiments in Thailand with peanut cv. Tainan 9, soybean cvv. SJ5 and NW1, and black gram cvv. Uthong 2 and Regur.

Species	Non-responsive sites		Responsive sites[a]				
	No.	Mean seed DM (kg/ha)	No.	Seed DM (kg/ha)			% Seed defects[b]
				All	All–B	Nil	
Peanut	16	1200	29	1460	1270	1020[c]	32
Soybean	10	2170	1	1790	1220	-	23
Black gram	5	1510	4	1650	790	80[d]	0

[a] Responsive sites were those where omitting B caused a significant ($P = 0.05$) decrease in seed DM or increase in the % defective seeds.

[b] In All-B treatments, seed defects denote hollow heart in peanut, and soybean.

[c] Mean for 20 sites only.

[d] Mean for two sites only.

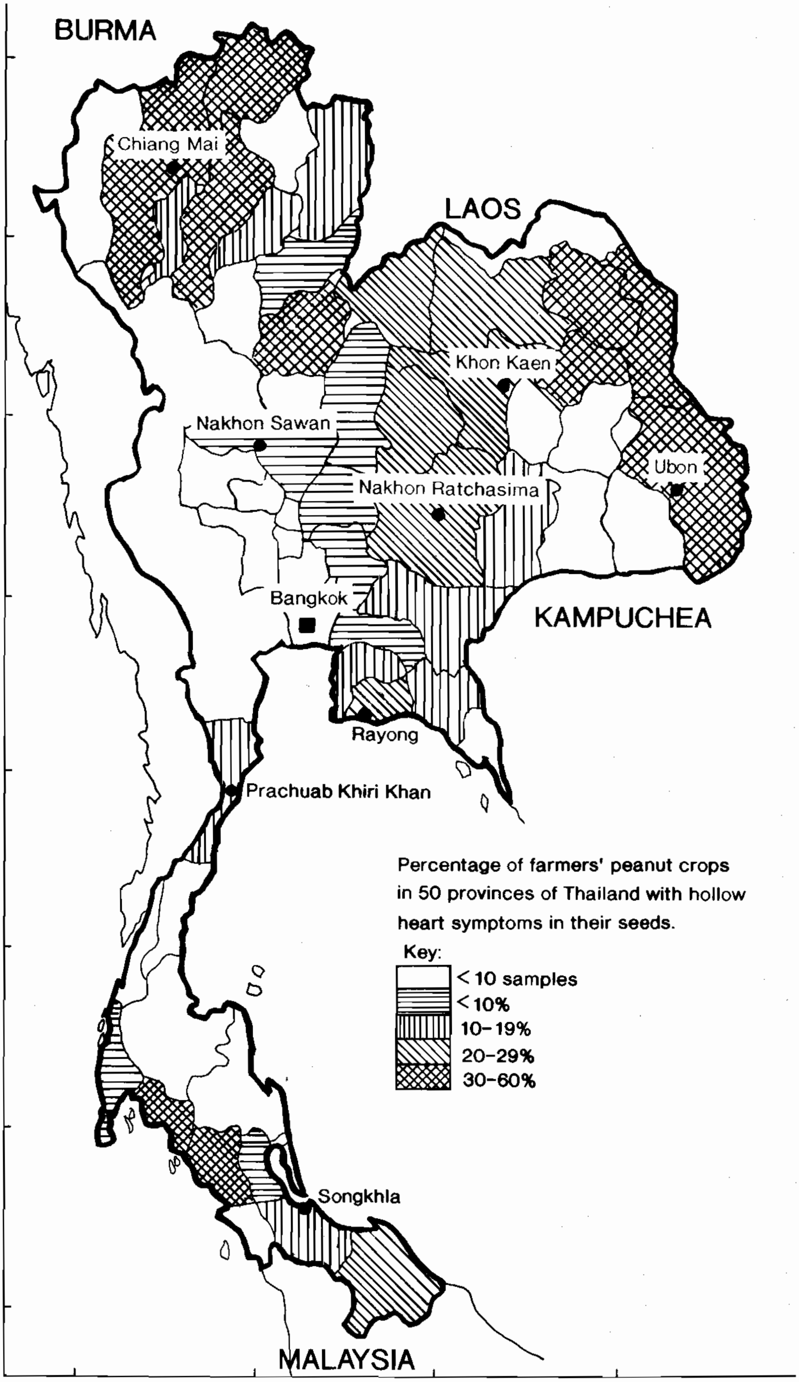

Fig. 3.1 The frequency of hollow heart symptoms in seeds of farmers' peanut crops in 50 provinces of Thailand

shoots above the unifoliate leaves, trifoliate leaves with ragged leaves, and premature development of the lateral shoots. In black gram sown on low B soil at Chiang Mai in January, increasing seed B concentrations progressively decreased the percentage of abnormal seedlings from 70% to 1%. In peanut, low B in seed depressed the percentage seedling emergence after 15 days from 83% to 47% and accelerated the decline in seed viability under storage at room temperatures (Keerati-Kasikorn et al. 1988b). The germination of seed from plants treated with complete fertilizer declined from 95% at one month after harvesting to 70% after seven months in storage. Seed from the plants treated with complete fertilizer minus B had the same germination percentage after one month storage but its viability declined more rapidly to 45% at seven months after harvest. The loss of seed viability is an important constraint for peanut production by small farmers in Thailand and elsewhere (Patanothai 1985). The present results suggest that in areas with low B soils, low B in seeds may be contributing to the loss of seed viability. Treating peanut plants with B may improve peanut production by decreasing the amount of seed required to plant a crop and increasing the vigour of young peanut plants, making them better able to cope with stresses such as weed infestations and low soil water levels.

Low B in soybean seed depressed final seed DM by 17–57% by its inhibitory effects on early seedling growth (Rerkasem et al. unpublished data). In one field study, final seed DM of crops grown from low B seed was depressed by 300–400 kg/ha, and in another by 700 kg/ha. The decrease in seed DM can be largely attributed to the severe stunting of up to 25% of the emerged plants (Plate 3.3). For cv. NW1, it was concluded that low B in seed caused a temporary B deficiency during seedling growth but its effects were irreversible for seed DM even on soils with adequate levels of B for subsequent growth

At higher rates than required to correct a deficiency, B fertilizer induced symptoms typical of B toxicity (Gupta 1979) in the four legumes studied. In peanut, interveinal regions at the margins of the oldest leaves became yellow and, with time, necrotic (Plate 3.4). In black gram, the margins of old leaf blades developed a bronze colour (Plate 3.5). Such differences in symptom expression among species are to be expected due to differences in the pattern of leaf venation which is the main factor determining the portions of the leaf blade that accumulate B (Oertli and Kohl 1961). No clear symptoms of B toxicity were observed in soybean or green gram.

While soil B treatments induced B toxicity symptoms in many experiments, it rarely depressed seed DM. For example, a B fertilizer application of 4 kg/ha which raised B concentration in the YFEL of peanut to 320 mg B/kg at early pegging, produced B toxicity symptoms in old leaves and depressed vegetative shoot DM by 36%, but had no effect on seed DM of peanut grown on a sandy soil at Samjarn in Khon Kaen province.

In contrast to peanut, seed DM in green gram was more sensitive to high levels of fertilizer B than vegetative DM. Thus, increasing B supply from 1.7 to 3.5 kg B/ha depressed seed DM by 19% but had no effect on shoot DM. Black gram planted in the same experiment exhibited no detrimental effects at the highest rate of B supply.

That the legumes responded differently to B may be attributed to differences in their development and physiology. Moreover, for each legume. response to B varied with cultivar and environmental conditions.

Physiological factors

Among the legumes, B deficiency depressed seed yields by affecting different yield determining characters. In black gram, it decreased the numbers of pods per plant through excessive shedding of flowers and flower buds (Plate 3.6). In peanut, green gram and soybean, other characters were generally more important. In peanut, B deficiency depressed seed DM largely by decreasing seed size; but, when severe, it also depressed pods per plant and, in some cultivars, the number of seeds per pod. In green gram, it depressed pods per plant and seeds per pod (Bell et al. 1990b). In soybean, it depressed seeds per pod and seed size and, to a lesser extent, pods per plant.

Environmental factors

In black gram, planting when temperatures were low at Chiang Mai increased the severity of B deficiency for seedling growth and for seed DM. Decreasing root temperatures have been shown to depress B absorption by some species (Forno et al. 1979) and this may account for the increased severity of B deficiency in black gram sown in the cool season.

Shading of black gram plants in the glasshouse decreased their B requirements for leaf expansion from 15 to 10 mg B/kg DM (Table 3.2), suggesting that low light intensity in the field may decrease critical B concentrations for the diagnosis of B deficiency. However, the increased sensitivity of black gram to B deficiency in the cool season at Chiang Mai could not be attributed to differences in light intensity.

Table 3.2 Critical B concentrations (mg B/kg DM) at various stages of plant development for diagnosis and prognosis of B deficiency in soybean, peanut, green gram and black gram plants.

Development stages[a]	Soybean	Peanut	Green gram	Black gram
	Diagnosis			
V2	12	12	16	15
V5	–	–	–	14–17
R3	–	–	14	15
	Prognosis			
R1–2	–	22–23	–	–
R3	24	–	–	25
R5–6	–	22–23	–	20

[a] After Boote (1982) and Fehr et al. (1971)

Low soil water contents correlated with low B concentrations in leaves of black gram on a loamy soil at Chiang Mai, confirming previous findings that sensitivity to B deficiency increases with dry soils (Hobbs and Bertramson 1949; Gupta 1979).

Genetic factors

The major food legumes and some other field crops of northern Thailand differed widely in the responses of their seed DM to B fertilizer. In initial field experiments at Chiang Mai, sensitivity among species to B deficiency decreased in the order: sunflower = black gram > peanut > soybean > wheat > rice (Rerkasem et al. 1988).

These results are consistent with previous reports that sunflower is very sensitive to B deficiency (Blamey 1976; Rerkasem 1986), that peanut often develops hollow heart on low B soil with no effect on seed DM (Morrill et al. 1977; Cox et al. 1982), and that soybean and rice are tolerant of low B soils (Touchton and Boswell 1975; Lucas and Knezek 1972).

However, subsequent studies have shown that variations among cultivars invalidate the above species comparisons. For example, soybean cv. NW1, the most sensitive of the soybeans, was as sensitive to B deficiency as peanut cv. Tainan 9 whereas soybean cv. SJ5 was appreciably less so. Among recommended cultivars of peanut and soybean, their sensitivity to B deficiency decreased in the order: peanut, SK38 > KK60-2 > Tainan 9 > Lampang > KK60-1 > KK60-3 (Keerati-Kasikorn et al. unpublished data): soybean, NW1 > SK1 > SJ5 (Rerkasem et al. unpublished data).

The peanut cultivars tested by Keerati-Kasikorn et al. (unpublished data) included nine Virginia-types, four Valencia-types and one Spanish-type so that they varied substantially in seed size, numbers of pods per plant and seeds per pod. In B-adequate soil, pod numbers per plant were more strongly correlated with seed DM than the other yield-determining characters, seed number per pod, and seed size. Hence, for B-adequate soils, peanut cultivars should be selected for high pod numbers per plant regardless of seed size or numbers of seeds per pod. However, in low B soil, cultivars which produce 1–2 seeds per pod appeared better able to obtain their B requirements than those which have the capacity to set 3–4 seeds per pod.

Black gram cv. Uthong 2 was extremely sensitive to B deficiency whereas recommended green gram cultivars, Uthong 1 and Kampangsaen 1 were relatively tolerant of low B soils. As with peanut and soybean, the response of black and green gram to B on low B soils varied with cultivar. Black gram cultivars tolerant of low B soils are needed urgently to increase seed production on low B soils and to extend the range of soils on which this crop can be grown without B fertilizers.

Basal fertilizer supply

In many soils, basal fertilizers increased the response of peanut to B (Keerati-Kasikorn 1987, 1988a, 1990; Ratanarat et al. 1990a). The higher levels of hollow heart in the fertilised peanut were probably caused by the greater vegetative growth, resulting in depletion of soil B from the pegging zone during the seed filling stage. In the case of cv. Lampang, basal fertilizer without B doubled vegetative shoot DM, increased the incidence of hollow heart from 7 to 63% and depressed seed DM by 23%. These results suggest that the levels of hollow heart in farmers' unfertilised peanut crops underestimate the potential for B deficiency with fertilizer treatment on soils with multi-element deficiencies. Furthermore they emphasise the futility of treating peanut with fertilizer minus B on low B soils since seed quality and seed DM may be depressed compared to the unfertilised crops.

The contrasting effects of basal fertilizer in depressing seed yield in the absence of B and of enhancing it in its presence are well illustrated in Fig. 3.2 showing the response of peanut in a simple field trial at Hang Chat, Lampang province, Thailand.

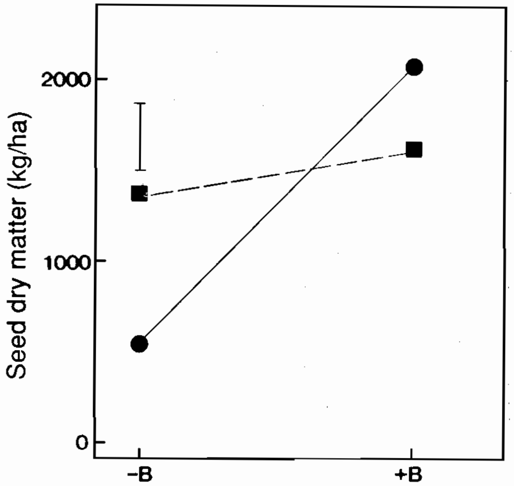

Fig. 3.2 Response of peanut seed dry matter to borax and basal fertilizer treatments at Hang Chat, Lampang province, Thailand. Borax (+B) increased yield in the presence (●) but not in the absence (■) of basal fertilizers. Basal fertilizers increased yield in the presence of borax (+B) but in its absence (-B) they depressed it. The vertical bar denotes the LSD (P = 0.05). Unpublished data from Ratanarat et al.

Seed boron

Early plant growth of soybean, black gram and green gram growing in low B soils was depressed because of the large percentage of abnormal seedlings. Increasing B concentrations in their seeds alleviated this problem (Rerkasem et al. 1990 and unpublished data). In two experiments with soybean, the effects of low seed B persisted to final harvest, depressing seed DM even in soils treated with B . The results of both experiments suggest that higher levels of soil B than those tested (0.20 mg B/kg) may alleviate the decrease in seed DM from low B seed. Further experimentation is required to test this hypothesis.

In further experiments with black gram, the extent to which seed B concentrations affected the incidence of abnormal seedlings was strongly influenced by soil B levels and seasonal factors.

Methods for diagnosis and prediction of B deficiency

Response of food legumes to B in the field is the best form of diagnosis of B deficiency, provided good experimental techniques are used and adequate precautions taken against contamination (see Chapter 2). Field experiments are, however, expensive to conduct. Plant symptoms and plant analysis both proved useful and reliable alternatives for the diagnosis of B deficiency. Soil and plant analysis also proved reliable for the prognosis of B deficiency.

Symptoms

In peanut, the incidence of hollow heart in seeds (Plate 3.1) which earlier workers have shown to be a specific expression of B deficiency, was found to correlate well with soil B treatment: it was more sensitive than seed DM to low B in soils and was used to diagnose B deficiency .

Although leaf symptoms of B deficiency in peanut were a less sensitive indicator of B deficiency than those in seeds they were sufficiently distinctive to aid in the diagnosis of B deficiency during plant growth. In peanut, leaf symptoms of B deficiency appeared first on young expanding leaves. On the upper blades of affected leaves, irregular shaped patches of water-soaked tissue developed accompanied by distortion of the leaf shape and crinkling of the surface (Plates 3.7 and 3.8). The affected patches on the leaf blade had an irregular pattern of distribution, were olive-brown and had a shiny surface. Symptoms of leaf miner damage in peanut leaves resembled those of B deficiency, but could be distinguished from them by holding the affected leaves up to bright light. In the case of leaf miner damage, the outline of the organism within the leaf or the path of its passage through the leaf can be identified.

Plate 3.1. *Hollow heart symptoms in peanut seeds.*

Plate 3.2. *Malformed black gram seedlings germinated from low B seed; note abscission of cotyledons and absence of epicotyls.*

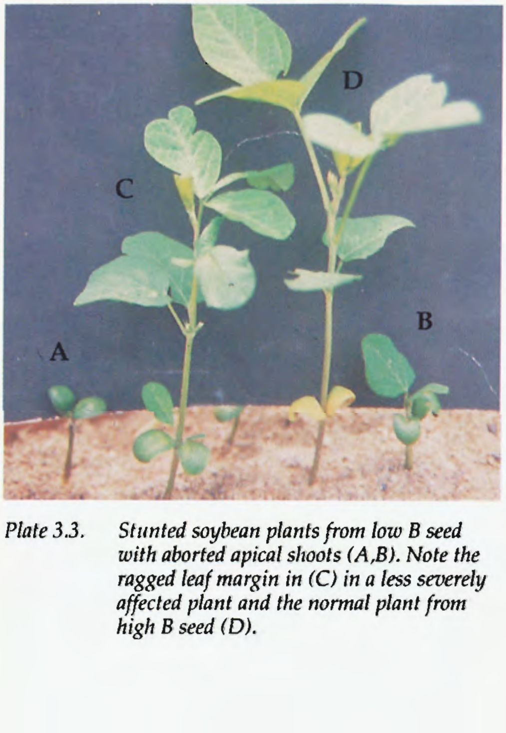

Plate 3.3. *Stunted soybean plants from low B seed with aborted apical shoots (A,B). Note the ragged leaf margin in (C) in a less severely affected plant and the normal plant from high B seed (D).*

Plate 3.4. *Boron toxicity symptoms in blades of old leaves of peanut. Note: yellowing at the margins and between the veins and necrosis of the margins.*

Plate 3.5. *Boron toxicity symptoms in black gram. Note the bronzing at the margins of blades of old leaves.*

Plate 3.6. *(A) Peduncles of B deficient black gram showing scars from shedding of floral parts. (B) Normal pod development in B adequate plants.*

Plate 3.7. *Water soaked lesions on a recently matured leaf blade of B deficient peanut.*

Plate 3.8. *B deficiency symptoms in upper leaves of peanut. Note the crinkled leaf blade and shiny appearance of the lesions on affected leaves.*

Plate 3.9. *Necrotic lesions on the surface of pods of B deficient black gram plants.*

Plate 3.10. *Abaxial curvature of unfolding leaf of B deficient black gram plants.*

Plate 3.11. *Interveinal yellowing of blades of recently matured leaves of B deficient black gram plants.*

Plate 3.12. *Severely B deficient black gram plant. Note dark green foliage, dieback of the shoot apex, and thickened stems, petioles, and leaf blades.*

Plate 3.13. *B deficiency symptoms in young leaves of soybean cv. SJ4.*

Plate 3.14. *(A) Dimples on the external surface and (B) hollow heart on the internal surface of the cotyledons of low B soybean seeds.*

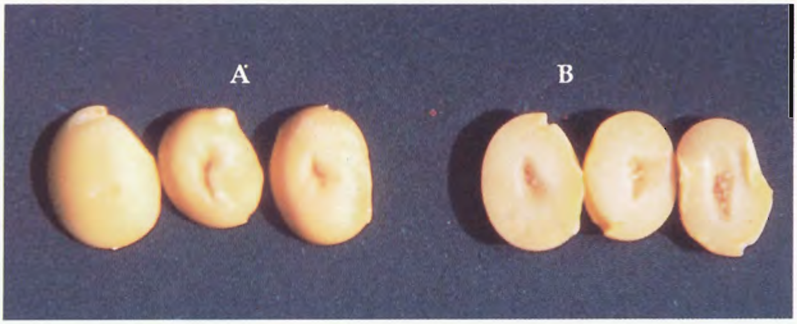

Plate 3.15. *Nitrogen deficiency symptoms in shoots of Mo deficient blackgram. Note pale foliage of -Mo plants in the plot in the left foreground compared to that in +Mo plants in the plot on the right.*

Plate 3.16. *Copper deficiency symptoms in young leaves of peanut. Note wilted young leaves and bleaching at the margins and between the veins of young leaves.*

With B deficiency the entire patch was uniformly translucent. In more severe cases of B deficiency, petioles of new leaves were stunted, internodes were shortened, and development of lateral shoots was stimulated giving plants a bushy appearance.

In black gram shoots, excessive abscission of the flowers from the bud stage through to young pods was the most sensitive symptom of B deficiency. Thus, at podding, black gram plants exhibiting no leaf symptoms of B deficiency often had many peduncles bearing the scars of abscissed floral parts but completely free of any pods or flowers (Plate 3.6). Pods retained on the affected plants sometimes developed light-brown necrotic lesions on their pod surface (Plate 3.9).

In leaves of black gram, B deficiency symptoms varied with leaf age. In young unfolding leaves, the petioles and petiolules recurved abaxially and became brittle, abscissing when handled: the blades were pale green and their expansion and that of their petioles was severely restricted (Plate 3.10). Leaves which had almost completed their expansion and recently matured leaves developed interveinal yellowing (Plate 3.11), while mature leaves generally became a darker green than normal. Plants with these leaf symptoms, often had shortened internodes and petioles in their upper canopy. In severe cases of B deficiency the apical shoot died, the plants became stunted, bushy and very dark green and developed thickened leaf blades, stems and petioles (Plate 3.12).

Black gram seedlings germinated from low B seed exhibited a range of symptoms soon after emergence (Rerkasem et al. 1990). In severe cases, the epicotyl or the shoot apex of the emerged seedling was aborted (Plate 3.2). In less severe cases, the first trifoliate leaf was crinkled or missing one or two leaflets. In both cases, lateral branches developed prematurely.

In soybean, B deficiency symptoms appeared first in unfolding and recently matured leaves as a thickening of the leaf blades giving them a stiff leathery feel. Margins of the affected leaves curved towards the abaxial surface. In soybean cv. SJ4, the tip and the margins of affected leaves developed a dull yellow appearance. With time, the yellow areas of the leaf blade enlarged and developed brown mottles (Plate 3.13). By contrast, in soybean cv. NW1 the unfolding leaves did not yellow at the margins but they developed brown necrotic spots in the interveinal portions of the leaf blade resembling those reported for B deficient soybean by Grundon (1987). Pods of soybean plants exhibiting other B deficiency symptoms developed brown necrotic lesions on their surface and, in severe deficiency, withered and abscissed.

Seeds of B deficient soybean developed hollow heart symptoms. In addition, they became 'dimpled' from small depressions in the external surface of one or both cotyledons (Plate 3.14). These symptoms were equally sensitive as seed DM to B deficiency. They may be a useful diagnostic symptom to alert farmers to the incidence of B deficiency in their soybean crops.

In green gram, the symptoms of B deficiency in leaves and reproductive development closely resembled those in black gram. They have been previously described by Smith et al. (1983). Low B seed of green gram was often darker in colour than normal and characterised by dark brown lesions on the seed-coat but in contrast to peanut and soybean, the seed symptoms were not sufficiently specific to B deficiency to be used for diagnosis.

Plant analysis

For the diagnosis of B deficiency by plant analysis, the slow response of shoot DM to B deficiency in non-renewed culture solution made it an unsatisfactory criterion for defining the critical concentration. An alternative procedure was developed by correlating the B concentration of young leaves with their expansion rate. Critical concentrations in young leaf blades were defined for diagnosis of B deficiency in soybean, peanut, green gram and black gram (Table 3.2) and proved to be reliable for the diagnosis of B deficiency in the field. The critical values did not differ with leaf age among the young leaves, and in black gram remained constant with plant age, but they did decrease under low light intensity.

In peanut, soybean, black gram and green gram, B concentrations in the YFEL at early flowering to early pod-filling were closely related to seed DM or quality at maturity. Consequently, the critical B concentrations established in the YFEL can be used to predict the incidence of B deficiency in the field (Table 3.2). In peanut, the critical values remained constant at 22–23 mg B/kg DM with plant age between early flowering and pod-filling but increased with decreasing leaf age so that strict sampling of the YFEL is required for reliable prognosis of B deficiency. The critical values obtained for prognosis of hollow heart in peanut cv. Tainan 9 in this study were slightly lower than those proposed for Spanish-type peanut in Oklahoma (26–30 mg B/kg DM; Hill and Morrill 1974). The latter values were higher probably because Hill and Morrill recommended sampling leaves younger than the YFEL, and they set standards for the elimination of hollow heart.

In black gram, strict sampling according to plant age is essential for reliable prognosis since critical values in this study declined with plant age from 45 mg B/kg during early vegetative growth to 25 mg/kg at pod set and 20 mg/kg at pod-filling. In soybean, the critical B concentration for the prognosis of deficiency which was determined only for YFEL sampled at early pod setting (R3), varied with variety being higher for the B-sensitive cv. NW1 (24 mg B/kg DM) than for cv. SJ5 (16 mg B/kg DM).

Boron concentrations in seed were diagnostic for low seed quality in black gram, green gram, soybean and peanut. In black gram and soybean the seed germination percentage was depressed when seed B concentration was less than 6 and less than 10 mg B/kg DM, respectively (e.g. see Fig. 3.3 for black gram). For normal early plant growth in the field, critical B concentrations in the seed were higher than those for germination: they decreased with increasing soil B, and increased with sowing when temperatures were cooler.

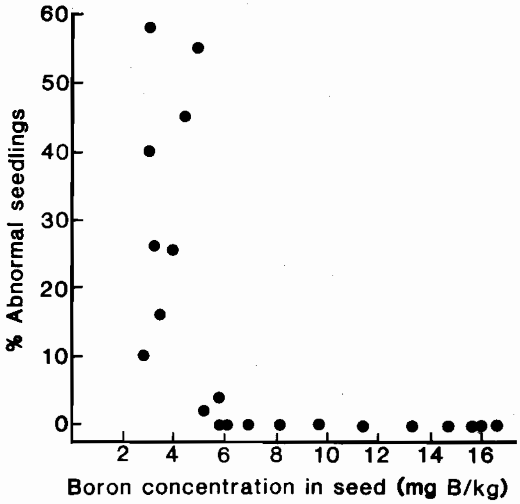

Fig. 3.3 Relationship between B concentration in seeds and the percentage of abnormal seedlings that had developed seven days after imbibition began for seeds of black gram plants grown with and without B on three soils (from Bell et al. 1989).

Soil analysis

HWS B levels in soils at planting correlated with seed DM and quality, suggesting that soil analysis can also predict the possible incidence of B deficiency (Table 3.3). The relationship for soil samples collected from 0–25 cm was less variable than that for 0–10 cm (Bell et al. unpublished data) and is therefore preferred.

Table 3.3 Critical hot water soluble B values (mg HWS B/kg soil) in the 0–10 and 0–25 cm layer of soils for the prognosis of seed DM or quality in peanut, green gram, soybean cvv. SJ4 and NW1 and black gram. Unpublished data from Hiranburana et al. for peanut, green gram and soybean grown in 20 kg pots of soil. Black gram data from Bell et al. (unpublished) for field experiments in Thailand 1985–1987.

Soil depth (cm)	Peanut	Green gram	Soybean cv. SJ4	Soybean cv.NW1	Black gram
			Seed DM		
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
			Seed quality[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, seed-coat lesion; soybean, dimple, hollow heart, and withered seed

[b] No defects observed in cv. SJ4 or black gram

In pot experiments the critical concentration for predicting B deficiency increased with increasing sensitivity of legume species and cultivars to B deficiency (Table 3.3). In the case of peanut, the critical HWS B value for the prognosis of hollow heart (0.14–0.16 mg B/kg) agreed closely with that proposed by Morrill et al. (1977) for the prognosis of hollow heart in Spanish-type peanuts in Oklahoma (0.15 mg B/kg).

In 37 experiments in farmers' fields in Thailand, hollow heart symptoms developed in peanut on few soils with HWS B values at sowing above 0.16 and on only one above 0.2 mg B/kg. However, on many soils with HWS B below these values, peanuts had no symptoms, so that HWS B values were less reliable for predicting B deficiency in peanut in the field than in the pot experiments. The greater variation in the field than in the pots can be attributed to the greater heterogeneity of soils, more variable soil water supply during the growing season, and to other factors such as nutrient deficiencies, pests and diseases etc. which may have limited crop growth.

For predicting B deficiency in peanut in the field, HWS B values at planting were also less reliable than leaf analysis at early pegging. The soil values were appreciably less reliable where no other fertilizer had been applied than where they were added. By contrast, leaf analysis was equally reliable for the prognosis of hollow heart in both fertilised and unfertilised peanut crops.

The fertilizer B requirements estimated by the B sorption method were remarkably similar for the six soils tested despite their variation in texture, pH, and organic matter levels. Furthermore, the estimated fertilizer B requirements from soil tests (0.35–1.8 kg B/ha) were in close agreement with estimates obtained from the field experiments (0.25–2.0 kg B/ha) notwithstanding the fact that the B sorption method gave higher estimates than the incubation procedure. The small variation among soils in the fertilizer B required to raise soil B levels suggests that B sorption by the soils was relatively weak considering the large differences among the soils in their percentage of clay, pH, and organic matter levels. By contrast, species, cultivars, seed B levels, and seasonal factors such as soil water levels and sowing date affected the response of the legumes to B deficiency and as a consequence affected the accuracy of the prognosis of B deficiency. Thus soil tests to determine how much fertilizer B is required to raise soil B to levels adequate for legume growth warrants less emphasis than those directed towards the accurate prognosis of B deficiency in the legumes.

In farmers' fields, the B-adequate soils had higher clay contents than the B-deficient soils suggesting that determination of soil texture may be a useful guide to the likely occurrence of B deficiency in peanut and perhaps other crops (Tables 3.4 and 3.5).

Boron deficiency in legume crops in Thailand

Occurrence and severity

Nearly 30% of some 4000 farmers' peanut crops in 50 provinces of Thailand were B deficient with hollow heart disorder in their seed. The B deficiency was most common in northern and northeastern Thailand but was still important in the southeastern, central and southern regions (Fig. 3.1). Whilst most samples were from wet season crops on upland soils, B deficiency was also prevalent in the dry season peanut crops grown on lowland soils.

Since most of the sampled farmers' peanut crops suffered one or more other deficiencies, correction of these deficiencies would intensify the expression of B deficiency as it did in simple trials on farmers' fields in Thailand. Of 37 such trials, 15 had >5% hollow heart in unfertilised peanut (Table 3.4). Adding basal fertilizer without B increased to 22 the number of sites with >5% hollow heart: it also increased the mean level of hollow heart at the affected sites from 15 to 29%.

Basal fertilizer enhanced the response of seed dry matter to B in a similar way. Thus in the absence of basal fertilizer, B only rarely increased seed dry matter. When considered over all B deficient sites, B alone had no effect on the average seed dry matter. By contrast, when applied in combination with basal fertilizer, B increased the average seed yield of marginally B deficient sites by 130 kg/ha and of severely deficient sites by 440 kg/ha (Table 3.4; Fig. 3.2).

Considering all sites, the levels of hollow heart were correlated with hot water soluble B levels in the soil as already discussed. Moreover, the incidence of hollow heart was higher in the soils with the lowest clay and organic matter levels (Table 3.5). Hollow heart symptoms were found

Table 3.4 Effects of B and fertilizer treatment on mean levels of hollow heart and dry matter of peanut seed at B-adequate, marginally B-deficient sites, and severely B-deficient sites. Unpublished data from Ratanarat et al.

Site class[a]	Treatment			
	Nil	+B	All-B	All
		% Hollow heart		
B-adequate (15)[b]	1.6	1.4	1.8	0.7
Marginally B-deficient (7)	1.9	0.6	9.2	3.5
Severely B-deficient (15)	15.0	3.4	37.8	2.3
		Seed DM (kg/ha)		
B-adequate	1260	1130	1490	1330
Marginally B-deficient	570	540	630	760
Severely B-deficient	1150	1220	1270	1590

[a] Sites classified on the basis of the incidence of hollow heart and seed DM by cluster analysis:
B-adequate: no hollow heart in any treatment
Marginally B-deficient: >5% hollow heart in All-B only
Severely B-deficient: >5% hollow heart in Nil and All-B

[b] Numbers in parentheses indicate number of sites.

Table 3.5 Soil series and mean soil properties at sites which were B-adequate, marginally B-deficient and severely B-deficient for peanut grown on farmers' fields in Thailand. Unpublished data from Ratanarat et al.

Site class[a]	Soil series[b]	Texture %			Soil B	Organic	pH
		sand	silt	clay	(mg B/kg)	matter %	(1:1 H_2O)
B-adequate	Sh(3), Wr(4),Re(3), Bj, Kl	78	10	12	0.173	1.22	5.3
Marginally B-deficient	Kt(2), Re(2), Nm, Hh, Sh	79	10	11	0.097	1.14	5.1
Severely B-deficient	Kt(6), Np(3), Sp(2), Re(2), Nm, Un	81	11	7	0.089	0.79	5.1

[a] Sites classified on the basis of the incidence of hollow heart and seed DM by cluster analysis:
B-adequate; no hollow heart in any treatment;
Marginally B-deficient; >5% hollow heart in All-B only;
Severely B-deficient; >5% hollow heart in Nil and All-B.

[b] Numbers in parentheses refer to the number of sites of each soil series. Key to soil series: Bj – Ban Chong; Hh – Hua Hin; Kl – Klaeng; Kt – Korat; Nm – Nong Mot; Np – Nam Phong; Re – Roi Et; Sh – Sattahip; Sp – San Patong; Wr –Warin; Un – unidentified soil series.

in peanut on all sites of the Korat, Nam Phong and San Patong soil series and at none of the four sites of Warin series. The incidence or level of hollow heart symptoms was not consistent in any of the other soil series.

That peanut responded to B treatment at 22 sites widely distributed throughout northeastern, northern and southeastern Thailand is strong evidence that many upland soils in Thailand are deficient in B for peanut production. That B responses were more severe and more prevalent in fertilized peanut again indicates that the B status in unfertilized farmers' peanuts greatly underestimates the potential for B deficiency.

Correction

For the correction of B deficiency in food legumes in Thailand, rates of B fertilizer application varied with the severity of the deficiency, the plant species, the placement of B fertilizer, and the method of application. Soil B treatment by banding along rows at 0.25 kg B/ha corrected B deficiency for seed DM in peanut and black gram. To decrease levels of hollow heart in peanut seed to less than 2%, rates of B fertilizer ranging from 0.5–1.0 kg/ha were required when applied by side dressing along rows or up to 2.0 kg/ha when broadcast.

Foliar application of B fertilizer was compared with soil application at Chiang Mai and found to be a promising method for correcting B deficiency in black gram (Predisripipat 1988; Rerkasem et al. unpublished data). Provided the B was applied strategically during reproductive growth, foliar application of B fertilizer was as effective as soil application of the fertilizer for correcting B deficiency (Table 3.6). Thus, sprays of 0.05% B at the rate of 5 g B/ha at flower bud and again at early podding completely corrected B deficiency. In terms of cost-effectiveness, the foliar application was far superior since a soil treatment of at least 450 g B/ha was required for black gram at Chiang Mai (Predisripipat 1988). A single spray with 0.05% B (as borax) was only partially effective in correcting B deficiency in black gram when applied at flower bud at the rate of 5 g B/ha, but by increasing the amount of B applied in a single spray at early flowering to 290 g B/ha (as 0.05% B), Predisripipat (1988) was able to correct B deficiency in black gram.

Table 3.6 Effects of foliar and soil B applications on seed dry matter (DM) of black gram at Chiang Mai. Values are means of four replicates. Means in a column followed by the same letter were not significantly different at P = 0.05. Unpublished data from Rerkasem et al.

Treatment	Seed DM (kg/ha)
– B	650^{a}
Soil application 1.1 kg B/ha as borax	1400^{bc}
Foliar spray one time (5g B/ha)[a]	1000^{ab}
Foliar sprays two times (10g B/ha)[b]	1710^{c}
Foliar sprays three times (15g B/ha)[c]	1400^{bc}

[a] 5g B/ha as 0.05% borax sprayed at flower budding growth stage (Rb)

[b] sprayed at flower budding and early podding growth stages (Rb, R3)

[c] sprayed at early vegetative, flowering budding, and early podding growth stages (V3, Rb, R3)

In green gram by contrast, neither a single application of 290 g B/ha at flowering nor an application at flowering followed by one at early podding corrected B deficiency (Predisripipat 1988). More frequent foliar application of B or more concentrated B sprays may be required for green gram which has larger pods than black gram. Because of the larger pod size in green gram the amount of B deposited on the flowers or pods by the spray application of 0.05% borax may be too small to meet the seed's requirements for growth unless it is re-applied often during pod development.

Foliar application of B to soybean crops has not been tested. In the case of peanut the foliar B application may not be effective unless the spray is directed at the soil at the base of the plant where the pods develop since the pods appear to absorb most of their B directly from the soil (Bell et al. unpublished data). Indeed, Hill and Morrill (1974) found that B applications made as a foliar spray directed towards the base of peanut plants corrected hollow heart in seeds provided it was applied within 60 days of planting.

A B rate of 2 kg B/ha was required to depress hollow heart in peanut seed to less than 2% in one experiment on a very sandy soil at Samjarn (Keerati-Kasikorn et al. 1988a, 1989), but this level of B induced B toxicity symptoms in the leaves during early growth. In the case of green gram at Chiang Mai, 3.3 kg B/ha depressed seed DM by 22% (Predisripipat 1988). The same rate of B supply to black gram grown in the same experiment was not toxic indicating that considerable variation may exist among legumes in tolerance to B toxicity. The results confirm earlier reports that the range of B rates which are optimal for correcting B deficiency in food legumes is very narrow (Gupta 1979).

The residual value of B fertilizer (as borax) declined with time under intensive cropping at Chiang Mai. The number of crops for which the B fertilizer was effective in correcting B deficiency varied with species sensitivity to the deficiency. Thus, an initial B treatment of 1.1 kg B/ha corrected B deficiency for seed DM for ten crops in the case of black gram but was inadequate after six crops for sunflower.

On two very sandy soils in Khon Kaen province, the residual value of B fertilizer (as boric acid) declined even faster; initial applications of 0.25, 0.5, and 2 kg B/ha were required to correct B deficiency for black gram seed DM in the first, second, and third crops, respectively.

Two forms of B fertilizer, borax and boric acid, have been used in this study but they have not been compared directly. Previous studies have shown little difference between soluble B fertilizer sources in their effectiveness in correcting B deficiency (e.g. Hill and Morrill 1974; Sherrell 1983). In the present studies, the rapid decline in effectiveness of applied B fertilizer, especially on the very sandy soil at Samjarn in Khon Kaen

Province, suggests that B fertilizers with greater residual value should be evaluated as alternatives to boric acid and borax. Ulexite and colemanite, both mixed calcium-sodium borates, have been effective as B fertilizer sources for pasture (Sherrell 1983) and should be tested for their efficiency in correcting B deficiency in food legumes on sandy soils in Thailand. Their lower solubility would decrease both B losses by leaching, and the uptake of luxury levels of B in the shoot during vegetative growth, thus conserving B in the soil for seed production and decreasing the risk of B toxicity. Further studies to increase the residual value of B fertilizers should examine the options for recycling B taken up by plants by returning harvested plant residues to the soil rather than removing them from plots as is done with peanut.

Recommendations

Fertilizers

For soil application, side-dressing the B fertilizer along rows is strongly recommended especially in the case of peanut since the B is required in the pegging zone for correction of hollow heart. Rates ranging from 0.6 to 1.2 kg B/ha are recommended. Lower rates may not be completely effective on all soils especially on very sandy soils or when seasonal conditions or soil water levels depress B uptake by plants. Higher rates of soluble B fertilizers should also be avoided because they may be toxic especially for green gram.

For correction of B-deficiency in farmers' legume crops, the efficacy of foliar B application needs to be more thoroughly examined, particularly for peanut since it has potential for being a simple, low cost corrective measure. Its effectiveness will depend on accurate and timely diagnosis or prognosis of B deficiency.

Careful consideration has to be given to the form of B fertilizer recommended for use on food legume crops in Thailand. Borax is the most commonly used B fertilizer worldwide but its supply in Thailand is restricted because of its misuse as a food additive. Even if borax was available, we do not recommend it as a pure fertilizer for soil treatment by farmers because of the difficulty of evenly applying the small quantities required and the risk of toxicity from rates of application only marginally greater than required. Neither of these factors would limit the use of borax as a foliar spray treatment. A number of B-enriched NPK fertilizer formulations are available in Thailand for use in tobacco and oil palm (see Appendix 1 for examples), but the level of B in them (0.05–0.09% B) is probably too low to reliably correct B deficiency. For food legumes, it is recommended that the level of B in such products be increased so that when the fertilizer is applied at close to the recommended rate for food legumes, B is supplied at 1.0 kg B/ha.

Priority should be given to increasing the residual value of B fertilizers. Soluble B fertilizers had poor residual value especially on the very sandy soils at Khon Kaen. The poor residual value of the B fertilizers can be attributed to both leaching and excessive B uptake in vegetative plant parts. Fertilizers of lower solubility such as the calcium borates, colemanite and ulexite should be considered. Agronomic practices which retain plant residues in situ should also be examined since their removal from fields may be a major source of B loss.

Cultivars

Among the recommended varieties of peanut and soybean, both B-sensitive and B-tolerant types have been identified in this study. In the short term, small farmers who use little fertilizer of any type may be able to manage food legume production on their low B soils by growing cultivars which are tolerant of the low soil B. For low B soils, soybean producers should be advised to plant cvv. SJ5 or CM60 which are efficient in obtaining their B requirements from low B soils: alternatively, B fertilizer treatment should be considered for soybean cv. NW1. Similarly, for low B soils, peanut producers should be advised to grow cvv. Lampang, KK60-1 and KK60-3 in preference to cvv. Tainan 9, KK60-2, and SK38. The recommended green gram cultivars, Uthong 1 and Kampaengsaen 1, are both tolerant of low B in the soil.

Since low B soils appear to be prevalent in north and northeastern Thailand where much of Thailand's food legumes are grown, testing for B tolerance should be incorporated into the evaluation program for new food legume cultivars before their release. In the case of black gram, breeding of B-tolerant cultivars should be accorded high priority since the recommended cultivar, Uthong 2, is very sensitive to B deficiency.

So acute was the B deficiency for black gram in low B soils at Khon Kaen that it was not a viable crop option for farmers without B fertilizer treatment. Thus for black gram, B tolerant cultivars or B fertilizer treatment could markedly extend the range of soils on which farmers could grow the crop.

Just as varieties of food legumes differ in their sensitivity to B deficiency, so too may their B fertilizer requirements and critical B values for the prognosis of B deficiency. On-going collaboration between plant breeders and plant nutritionists is recommended so that the fertilizer B requirements and critical B values are determined for new crop varieties.

Molybdenum

Molybdenum responses

Leaf Mo concentrations suggested that N fixation was limited in up to 45% of farmers' peanut crops at Khon Kaen (Table 3.7). In a limited number of field experiments, Mo deficiency induced pale green foliage (Plate 3.15) and depressed seed DM by 10–35% in black gram and by 20–25% in peanut. However, responses by legumes to Mo treatments were fewer and smaller than for B. Soybean was not grown at any of these sites. Where it was treated with Mo at two sites in Lop Buri province and a further two sites in Chiang Mai province, no response was obtained.

Mo response varied with species being more severe for black gram seed DM than for peanut on four sandy, acidic soils in Khon Kaen province. Differences among cultivars in their response to low soil Mo have not been studied but in peanut warrants further examination. In particular, the response of seed DM to Mo may be greater in cultivars such as Lampang, KK60-2, SK38 and KK60-3 which have higher harvest indices than cv. Tainan 9.

Standards for the diagnosis and prognosis of molybdenum deficiency

Molybdenum concentrations in leaves and nodules were closely correlated with shoot DM and nitrogen content during vegetative growth for peanut, soybean, green gram and black gram. Critical Mo concentrations for the diagnosis of Mo deficiency were established for each of these legumes (Table 3.8).

In green gram, critical values varied markedly with leaf age making it essential to strictly sample the YFEL (McLay 1989). By contrast, in black gram plants the critical values for the YFEL were very similar to those for adjacent leaves (Jongruaysap unpublished data).

Molybdenum concentrations in the YFEL were generally correlated with seed DM at maturity suggesting that the critical values established (Table 3.8) could be used for the prognosis of Mo deficiency. In the case of peanut, the relationship between seed DM and leaf Mo concentrations at pod-filling was more reliable than that with leaf Mo concentrations at early pegging.

In soybean and black gram, the critical values for the prognosis of Mo deficiency for seed production were the same or slightly greater than those for its diagnosis during vegetative growth, whereas in peanut they were much lower. The lower critical value for the prognosis of Mo deficiency in peanut was attributed to the poor response of seed production in cv. Tainan 9 to improved soil fertility. For cultivars with higher harvest indices, critical values for the prognosis of Mo deficiency could be appreciably higher than for cv. Tainan 9.

Molybdenum status in soils and its relation to soil properties

The soils on which Mo responses were obtained were acidic with pH values of 4.7–5.2 and sand content of 76–88%. They were typical of many soils in northeastern Thailand. For the prognosis of Mo deficiency by soil analysis the NH_4–oxalate extraction procedure appeared to be satisfactory whereas the Mo sorption procedure was not. Soils deficient in Mo for seed DM of black gram contained NH_4–oxalate extractable Mo levels less than 0.074 mg/kg. For peanut, NH_4–oxalate extractable Mo levels greater than 0.050 mg/kg prevented the appearance of N deficiency symptoms in shoots. These values for acidic sandy soils are not valid for heavier clay soils (Pichit unpublished data). Indeed, peanut had barely enough Mo for growth when grown on a heavy clay Ustoxic Paleustult from Lop Buri with an NH_4–oxalate extractable level of 0.36 mg Mo/kg.

Table 3.7 Classification of nutrient status of peanut crops by analysis of youngest fully expanded leaves collected from farmers' fields in Khon Kaen province, northeastern Thailand, and in various provinces of central and south-eastern Thailand.

	Severely deficient	Deficient[a]	Marginally[b] adequate	Adequate	High
Nitrogen					
Concn (%DM)	< 3.2	3.2–3.7	3.8–4.1	4.2–4.5	> 4.5
% sites (627)[c]	15.1	27.8	21.1	17.3	18.7
Phosphorus					
Concn (%DM)	< 0.19	0.19–0.23	0.24–0.26	0.27–0.40	> 0.4
% samples (636)	48.4	23.1	15.4	12.5	0.6
Potassium					
Concn (%DM)	< 0.7	0.7–1.3	1.4–1.7	1.8–2.5	> 2.5
% samples (636)	2.7	21.5	28.1	40.8	6.8
Sulphur					
Concn (%DM)	< 0.15	0.16–0.20	0.21–0.25	0.26–0.3	> 0.3
% samples (633)	9.6	25.2	27.8	23.9	13.1
Boron					
Concn (mgB/kgDM)	< 13	13–23	24–30	30–50	> 50
% samples (636)	1.3	15.5	26.1	54.5	2.5
Molybdenum					
Concn (ngMo/gDM)	< 20	20–50	51–130	131–1000	> 1000
% samples (636)	5.5	11.3	28.1	54.2	0.8
Copper					
Concn (mgCu/gDM)	< 1.3	1.3–1.7	1.8–2.1	2.2–5	> 5
% samples (636)	0.6	0.3	1.9	28.5	68.7

[a] Deficient concentrations were set at values lower than the critical values for diagnosis of deficiency in Tables 3.2, 3.8, 3.10, and 3.11

[b] Marginally adequate concentrations were set at values between the critical values for diagnosis and prognosis of deficiency (see Tables 3.2, 3.8, 3.10, and 3.11).

[c] The number in parentheses is the number of crops analysed.

Correction of molybdenum deficiency

At Mo responsive sites, Mo rates of 0.25 and 0.50 kg/ha corrected Mo deficiency in the wet season crops in northeastern Thailand. In a dry season crop on a paddy field, the lower rate was not sufficient to raise leaf Mo to adequate levels, suggesting that its surface placement may not be appropriate for the dry season. On a heavy clay soil at Koktoom, Lop Buri province, the higher rate was insufficient to maintain adequate Mo levels in leaves into late in the season. Thus further studies are required to determine the minimum rates and residual value of Mo fertilizer to correct deficiency on different soils.

Molybdenum in upland farming systems

The significance of the low soil Mo levels for upland crop production may be much greater than that suggested from the seed DM responses to soil Mo treatment. In the legumes, especially peanut, N fixation was more sensitive to low soil Mo than seed DM suggesting that Mo deficiency may depress the total amount of soil N available for crop production especially for the non-legume crops grown in rotation with the legumes. Furthermore, by stimulating the amount of organic residues returned to soils, Mo treatment of legumes may improve overall fertility of the poorly buffered soils of northeastern Thailand (Ragland and Boonpuk-

Table 3.8 Critical Mo concentrations (ng Mo/g DM) in the youngest fully expanded leaf (YFEL) and nodules for the diagnosis and prognosis of Mo deficiency in peanut, soybean, green gram, and black gram.

Plant part	Growth stage[a]	Peanut[b]	Soybean[c]	Green gram[d]	Black gram[e]
			Diagnosis		
YFEL	R1–2	130	17–23	90–130	35
Nodules	"	7000	2000	3900–4300	7000
YFEL	R5–6	[f]	20	–	25–30
Nodules	"	–	2000	–	2500–3000
			Prognosis		
YFEL	R1–2	15–50	20	–	50
YFEL	R5–6	15–18	–	–	–

[a] Growth stages after Boote (1982) for peanut, and Fehr et al. (1971) for soybean, green gram, and black gram

[b] From Bell et al. (unpublished data) for diagnosis of N content in shoots

[c] From Chotechaungmanirat (1988)

[d] From McLay (1989)

[e] Unpublished data from Jongruaysap

[f] Not determined

dee 1987). Further studies on Mo requirements should examine its role in the N economy of upland cropping systems.

Iron

Iron responses

Peanut cv. Tainan 9 responded strongly to Fe fertilizer on the Typic Calciustolls of central Thailand (Table 3.9) as it has in previous studies (see review by Parkpian et al. 1988). However, Fe fertilizer treatment of cv. Tainan 9 is not recommended for farmers because the rates required are prohibitively expensive and have to be repeated for each peanut crop.

Cultivar variation in iron response

The more effective long term solution to Fe deficiency on the Typic Calciustolls in Thailand is to select Fe-efficient cultivars which are able to obtain their Fe requirements for growth with little or no fertilizer Fe input. Farmers in effect are already using this approach by growing alternative species such as cotton, maize, sesame, soybean etc. which are free of Fe deficiency symptoms. Useful cultivar variation in Fe uptake exists among peanut cultivars (Ratanarat et al. 1985, 1987, 1990b), suggesting that Fe-efficient types could be selected or bred so that peanut production could be increased on the Typic Calciustolls of Thailand. Among the currently recommended cultivars KK60-3 appears to be markedly more Fe-efficient than Tainan 9 (Table 3.9) and could be recommended for use in the short term. In the longer term, a more extensive collection of Fe-efficient peanut cultivars should be assembled by introducing Fe-efficient cultivars from Israel (Hartzook 1982) and Timor (Field and Kameli 1987).

More importantly, plant breeders should be aware that Fe-efficiency is an essential attribute for high yielding cultivars of the major economic crops on the Typic Calciustolls. For example,

Table 3.9 Effect of foliar Fe treatment on seed dry matter (kg DM/ha) of three peanut cultivars on a Typic Calciustoll at Takfa, Nakhon Sawan province, Thailand. Values are means of four replicates. Data from Ratanarat et al 1990b.

Cultivar	+ Fe[a]	– Fe
Tainan 9	1075	425
KK60-3	2020	1580
Robut 33-1	2160	2200
LSD (P = 0.01)	53	

[a] Foliar Fe applied as 0.5% (w/v) $FeSO_4$ with Tween 80 wetting agent (0.25%) at 10, 20, 30, 40, and 50 days after sowing.

green gram cvv. Kampangsaen 1 and 2 were selected on non-alkaline soils in Thailand where they outyielded existing cultivars (Srinives and Yang 1988) but are both unsuitable for the Typic Calciustolls because of their extreme sensitivity to Fe-deficiency (Lawn et al. 1988; Parkpian et al. 1988). By contrast, soybean cvv. SJ5 and NW1 were both largely free of Fe chlorosis symptoms when grown on a Typic Calciustoll (Parkpian et al. 1988). That other soybean cultivars were very sensitive to Fe chlorosis on the same soil suggests that new soybean cultivars for the Typic Calciustolls in Thailand should be Fe-efficient. Similar studies should be considered for maize, cotton, sorghum and sesame.

Effect of iron on symbiotic development

In addition to inducing leaf chlorosis symptoms in peanut, Fe deficiency directly depressed nodule development (O'Hara et al. 1988a). Iron deficiency in peanut plants prevented the infecting rhizobia from obtaining adequate amounts of Fe from the plants so that nodule development was arrested and plants fixed inadequate amounts of N (O'Hara et al. 1988a,b). Furthermore, strains of bradyrhizobia differed in their ability to obtain Fe from their environment for the development of nodules and for N_2 fixation (O'Hara et al. 1988b). With strain NC92, for example, peanut grown under Fe-stress conditions in water culture formed many nodules, fixed N_2 actively and contained adequate N concentrations in their shoots for growth. By contrast, with strain TAL 1000, the Fe-stressed peanut plants were N deficient because they developed few nodules. When Fe was applied to an Fe-deficient soil, peanut nodulated and fixed N as well with TAL 1000 as with NC 92 (O'Hara et al. unpublished data).

That Fe-deficiency specifically limited nodule development in peanut suggests that diagnosis of Fe deficiency in legumes and its correction may be more complex than in non-legumes. The implications of these findings for the adaptation of peanut to Typic Calciustolls in Thailand are still not clear. For example, although Fe chlorosis symptoms are commonly reported in peanut grown on the Typic Calciustolls in Thailand, early Fe deficiency symptoms are sufficiently similar to those of N deficiency as to sometimes cause incorrect diagnosis. Plant analysis could be used to improve the accuracy of the diagnosis. Since total Fe concentration in leaves is often poorly correlated with Fe chlorosis symptoms (Wallace et al. 1976), alternative methods for determining the physiologically active Fe levels in leaves should be examined (e.g Katyal and Sharma 1984; Parkpian et al. 1988).

The extent to which peanut performance on Typic Calciustolls can be improved by inoculation with Fe-efficient bradyrhizobia strains such as NC92 also remains to be tested.

Copper

Copper responses

Copper deficiency symptoms (Plate 3.16; see also Nualsri 1977) have often been observed by the authors on fertilized peanut crops in northeastern Thailand. By contrast with unfertilized plants, the fertilized peanut plants in field experiments on Oxic Paleustults contained lower Cu concentrations in their young leaves. In some of the experiments, complete fertilizer treatment of the peanut depressed Cu concentration in the leaves below 1.5 mg Cu/kg DM, the critical values for the diagnosis of Cu deficiency, even when Cu fertilizer was applied to the soil.

Effects of fertilizers and calcium carbonate on copper uptake

In a subsequent pot experiment, Bell et al. (unpublished data) confirmed that fertilizer treatments on an Oxic Paleustult decreased leaf Cu concentration. Omitting KH_2PO_4 increased Cu concentrations in the leaves and shoots of peanut. By contrast, omitting $CaCO_3$ decreased the leaf Cu concentrations. The depression of leaf Cu concentration by omitting $CaCO_3$ and its increase by omitting KH_2PO_4 were associated with a parallel increase and decrease, respectively, in levels of vesicular arbuscular mycorrhizae (VAM). These results suggest that peanut depends on VAM for adequate Cu uptake in unfertilized Oxic Paleustults. Treatment of the soil with P fertilizer may induce Cu deficiency by depressing VAM. Treatment of the soil with $CaCO_3$ appeared to partially alleviate the effect of P-fertilizer in depressing leaf Cu by decreasing the P levels in plants. In the field, treatment of soils with $CaCO_3$ generally increased leaf Cu concentrations and tended to increase pod DM, possibly by alleviating Cu deficiency.

Copper status in farmers' crops

In northeastern, central and southeastern Thailand, barely 1% of farmers' peanut crops were diagnosed by plant analysis as Cu deficient: a further 2% contained marginally adequate Cu concentrations in their YFEL (Table 3.7). The infrequent diagnosis of Cu deficiency in farmers' peanut crops can be attributed to the low levels of fertilizer used on them in Thailand (Tianaran et al. 1985). However, the above results suggest that a significant percentage of the soils on which farmers' crops were diagnosed as Cu adequate may suffer Cu deficiency when treated with P-fertilizer. No cases of Cu deficiency were diagnosed in farmers' soybean crops in northern Thailand.

Biochemical tests for copper deficiency

The Cu metallo–enzyme, ascorbate oxidase (AO) has been used as an indicator of plant Cu status in citrus (Bar-Akiva et al. 1969) and subterranean clover (Loneragan et al. 1982). In the present study, the activity of AO in peanut and that of polyphenol oxidase activity in soybean increased with increasing Cu supply suggesting that both could be used to diagnose Cu deficiency (Mahmood et al. 1987; Mahmood and Lam 1987).

In peanut, AO activity in the YFL correlated with shoot DM and pod number responses and was a more sensitive indicator of Cu deficiency than Cu concentrations in the youngest open leaf (Mahmood et al. 1987). As a semi-quantitative test for Cu deficiency in peanut, the ascorbic acid test strips showed promise: it may be the basis for a simple field test for Cu deficiency in peanut, but further research is required to increase its sensitivity and reliability.

Macronutrients and other Micronutrients

Standards for diagnosis

Symptoms of P, K and S deficiencies were useful for the diagnosis of deficiencies in farmers' fields and in experimental plots. But they were not sensitive or specific and needed to be used in conjunction with plant or soil tests for accurate and early diagnosis of deficiency. For example, symptoms of P deficiency only developed in peanut and soybean when growth was depressed by 70–80%. In the case of S deficiency, symptoms were similar to early stages of N or Fe deficiency, with all of these deficiencies showing yellowing of the young expanding leaves. Potassium deficiency symptoms similar to those of B deficiency (Plate 3.11) have also been observed as marginal and interveinal yellowing on recently matured leaves. The similarity of these deficiency symptoms in black gram has led to a K deficiency being wrongly diagnosed as a B deficiency. The development of K deficiency symptoms on recently matured leaves observed in plants growing on sandy soils in pots (Bell et al. 1987a) and in the field, contrasts with the general observation that they develop first on old leaves (Robson and Snowball 1986).

Plant analysis appeared to be a promising method for the diagnosis of P, K, and S deficiencies in both peanut and soybean. For each of these elements, critical concentrations were established in a series of glasshouse trials (Table 3.10).

For P and S, the critical values remained relatively constant over several growth stages; for K, they declined markedly with plant age suggesting that they should be used in relation to the growth stage of the plant. However, the rapid decline in critical values was thought to result from a rapid decrease in K supply from the relatively small volume of sandy soil used in the pot experiment and to the slow response of shoot DM to declining K concentrations in the plant. Field evidence suggests that the critical value of 1.2% obtained at early flowering of plants (Table 3.10) may be a more accurate indicator of K deficiency at later growth stages in the field than the lower value reported from the pot experiments. Thus, the growth of peanut in the field at Khon Kaen was depressed at early pegging and early pod filling when the YFEL had K concentrations ≤ 1% but not affected when ≥ 1.2%. It is suggested that K concentrations of 1.0–1.2% in either peanut or soybean YFEL should be regarded as definitely deficient at all growth stages up to flowering and probably deficient thereafter.

For P, K, and S, the YFEL blade was suitable for diagnosis of deficiency and is recommended

Table 3.10 Critical concentrations in the youngest fully expanded leaf blade for the diagnosis of nutrient deficiencies in peanut cv. White Spanish and soybean cv. Buchanan at defined stages of growth.

Nutrient	Vegetative	Growth stage[a] Flowering (R1)	Pod set (R3)	Pod fill (R5-6)
		Peanut		
P (%)[b]		0.19	–	0.23
K (%)[c]	–	1.2	0.5–0.90	0.25–0.35
S (%)[d]	–	–	0.18–0.22	0.17
Cu (mg/kg)[e]	1.3 [f]	0.7 [f]	1.5	1.3[f]
Zn (mg/kg)[g]	–	8–10	8–10	–
		Soybean		
P (%)[h]	0.32	0.29	0.32	0.24 [i]
K (%)[j]	2.0–2.2	1.0–1.3	0.5–0.9	0.3–0.4
S (%)[k]	–	–	0.18–0.20	0.17
Zn (mg/kg)	6–10 [l]	15–17[m]	–	–
Cu (mg/kg)	1.8–2.3 [n]	–	–	–

[a] Growth stages after Boote (1982) for peanut and Fehr et al. (1971) for soybean

[b] From Bell et al. (unpublished data)

[c] From Brady (1986) and Bell et al. (unpublished data)

[d] From Supakamnerd et al. (1990 and unpublished data)

[e] Young folded leaf preferred for diagnosis; for which critical values are 1.7–2.2 mg Cu/kg DM (Robson et al. 1977)

[f] Nualsri (1977)

[g] From Bell et al. (1990a)

[h] From Bell et al. (unpublished data)

[i] Critical concentration unclear due to Piper-Steenbjerg curvature

[j] From Bell et al. (1987 and unpublished data)

[k] From Bell et al. (unpublished data)

[l] Occasional flowers only due to long day length. From Kirk and Loneragan, unpublished data

[m] Fom Okhi (1977)

[n] Occasional flowers only due to long daylength. Unpublished data from Bell et al.

for sampling in the field. For P and K, the critical values increased with leaves younger than the YFEL; they decreased for S. Consequently, for accurate diagnosis it is essential to strictly sample the YFEL. Moreover, petioles generally contained different nutrient concentrations to those in the blades so that they should be excluded from the leaf samples taken (e.g. Bell et al. 1987b).

The YFEL blade was also suitable for Zn and Cu in peanut and soybean (Table 3.10). But while the YFEL was suitable for Cu deficiency diagnosis in peanut, other studies suggest that the young folded leaf is better (Robson et al. 1977).

Standards for prognosis

From experience in the present study, a set of critical concentrations in the YFEL has been developed for prognosis of the more common nutrient deficiencies in legume crops in Thailand (Table 3.11).

For soybean and peanut, these values have been compiled from the results of leaf analysis of the field experiments with high seed DM (>1500 kg/ha) in fertilized crops in this study. Tentative standards have also been developed for black gram from a limited number of samples (Table 3.11). These values need further evaluation in the field. For the prognosis of macronutrient deficiencies, the proposed critical values for the YFEL are similar to those for composite plant samples comprising upper leaves and stems in peanut and leaf samples in soybean as proposed by Small and Ohlrogge (1973). The most notable differences are between the values for K in peanut and Cu in both peanut and soybean which are all lower in the YFEL. For nutrients which generally appeared adequate in the present study, the prognostic values proposed

Table 3.11 Leaf analysis standards for the prognosis of nutrient deficiencies in peanut cv. Tainan 9, soybean cv. SJ5, and black gram cv. Uthong 2 in Thailand. Unless noted, values are for the youngest fully expanded leaf blades sampled at early flowering (soybean, black gram) or pegging (peanut) and are minimum concentrations of elements of crops which produced seed dry matter >1500 kg/ha.

Element	Peanut	Soybean	Black gram
N (% DM)	3.8	4.2	3.8
P (% DM)	0.26	0.29	0.30
K (% DM)	1.3	1.7	1.0
S (% DM)	0.24	0.21	0.2
Mg (% DM)[a]	0.30	0.26	–
Ca (% DM)[a]	1.2	0.35	–
Cu (mg/kg)	2.1	4	4
B (mg/kg)[b]	23	16	25–30
Mn (mg/kg)[a]	12–15[d]	20[a]	–
Zn (mg/kg)[a]	20	20	–
Mo (ng/kg)[c]	15–50	20	50

[a] From Small and Ohlrogge (1973); for peanut, values are for upper stems and leaves at early pegging; for soybean, values are for upper, fully developed trifoliate leaf blades sampled prior to pod set

[b] Values are critical concentrations obtained from B rates experiments, see Table 3.2

[c] From Table 3.8

[d] From Parker and Walker (1986)

by Small and Ohlrogge (1973) were taken as a guide (Table 3.11). For Ca, experience has shown that leaf concentrations during growth bear little relation to problems of Ca deficiency in peanut seed at maturity (Cox et al. 1982).

Status in farmers' peanut and soybean crops

The standards developed for the diagnosis and prognosis of deficiencies by leaf analysis were used to assess the nutrient status of leaf samples collected from farmers' crops. In northeastern and central Thailand, deficiencies of P, S, K and N were extensive in farmers' wet season peanut crops (Table 3.7). In northern Thailand, P and K deficiencies were also extensive in farmers' soybean crops in the dry season (Table 3.12).

The prevalence of the macronutrient deficiencies in farmers' peanut crops was confirmed by Ratanarat et al. (1990a and unpublished data) who found that nutrient deficiencies other than B depressed seed DM of peanut at 16 of 37 sites tested; correction of the deficiencies by complete fertilizer treatment increased average seed DM from 930 kg/ ha to 1550 kg/ha. Leaf analysis suggested that the seed DM responses to fertilizers other than B in the on-farm trials could be attributed to deficiencies of P, S and K in about half of the sites: at the remaining sites, Ca deficiency for seed filling may have been responsible.

The severity of the micronutrient deficiencies B, Cu and Mo in farmers' crops in Thailand have been shown to be limited by the widespread deficiencies of macronutrients. Macronutrient deficiencies would similarly limit the expression of deficiencies of other micronutrients and Mg. Under existing cultural practices in northeastern, central and southeastern Thailand, all samples from farmers' peanut crops contained adequate concentrations of Zn, Mn, and Mg in their leaves. Similarly, concentrations of Zn, Mn and Mg were adequate for soybean in all the farmers' crops sampled in northern Thailand. However, soybean plants at the Mae Jo Field Crop Research Centre near Chiang Mai contained marginal concentrations of Zn (13–15 mg Zn/kg DM) and deficient levels of Zn and Mg were found in coffee crops in the highlands near Chiang Mai. Moreover, corn has been reported to respond to Zn on Typic Calciustolls in central Thailand (Ratanarat et al. 1989) and in soils of northern Thailand in pot experiments (Sanmaneechai, pers. comm.). Further monitoring of the status of Zn and Mg status in farmers' crops is warranted.

Table 3.12 Classifications of nutrient status of soybean crops at early flowering (R1) to early podset (R3) by analysis of youngest fully expanded leaves collected from farmers' fields in northern Thailand.

	Severely deficient	Deficient[a]	Marginally adequate[b]	Adequate	High
Nitrogen					
Concn (%DM)	<3.5	3.5–4.2	4.3–4.5	4.6–5.5	5.5–9.0
% samples (43)[c]	2.3	2.3	9.3	67.4	18.0
Phosphorus					
Concn (%DM)	<0.17	0.17–0.29	0.30–0.32	0.33–0.50	>0.5
% samples (156)	5.8	37.6	8.3	38.2	10.2
Potassium					
Concn (%DM)	<0.9	0.9–1.7	1.8–2.2	2.3–3.0	>3.0
% samples (156)	0	12.7	35.7	49.0	2.5
Sulphur					
Concn (%DM)	<0.15	0.15–0.18	0.19–0.24	0.25–0.3	>0.3
% samples (156)	0	0.6	2.5	15.3	81.5
Boron					
Concn (mg/kg DM)	<12	12–16	17–24	25–50	>50
% samples (157)	0	0.6	10.2	52.9	36.3
Molybdenum					
Concn (ng/g DM)	<15	15–20	20–100	101–1000	>1000
% samples (114)	0	0	3.5	90.4	6.1
Copper					
Concn (mg/kg DM)	<1.7	1.7–2.2	2.3–2.5	2.6–5.0	>5.0
% samples (157)	0	0	0	2.5	97.5

[a] Deficient concentrations were set at values lower than the critical values for diagnosis of deficiency in Tables 3.2, 3.8 amd 3.10

[b] Marginally adequate concentrations were set at values between the critical values for diagnosis and prognosis of deficiency in Tables 3.2, 3.8, 3.10 and 3.11

[c] The number in parentheses is the number of crops analysed

CHAPTER 4

Concluding Remarks

THIS study has shown that a high proportion of legume crops in Thailand suffer from one or more deficiencies of the micronutrients B and Mo and the macronutrients P, K, S, and N. The results suggest that, under present cultural practices, B deficiency affects about one-third of all peanut crops in Thailand and that Mo deficiency may affect nearly half the crops in the northeastern, central and southeastern regions. They also establish that some two-thirds of peanut crops are deficient in P, S, K, or N and that with correction of these deficiencies the severity and extent of micronutrient deficiencies would increase. It is suggested that macronutrient deficiencies would limit the response of other legume and nonlegume crops to micronutrients.

Since at present most upland farmers in Thailand use little or no fertilizer, recommendations on the management of B deficiency need to be formulated and tested specifically for low input production. The options are limited, but in the first instance, research and extension should make available to farmers cultivars that are tolerant of low B soils. This need is especially important for black gram and peanut. In peanut, the widely grown cvv. Tainan 9 and SK38 are especially sensitive to B deficiency even though they are well adapted to low fertility soils. Agronomic practices should be adopted to ensure better utilisation of soil B. This could be achieved by mulching or incorporating crop residues into the soil rather than burning them. The use of deep-rooted species such as perennial woody plants to help recycle B leached below the root zone should also be considered. Finally, the low B seed frequently sown by low input farmers should be replaced with a reliable supply of high B seed to maximise seedling emergence and vigour.

For medium–high input conditions, B fertilizer treatment is an option for increasing seed DM and quality on low B soils. However, to be fully effective, B fertilizer should be used in combination with other fertilizers and with cultivars which have a high yield potential. Deficiencies of other nutrients are so prevalent in northeastern Thailand that B alone only occasionally increased seed DM in peanut. For example, in the 'on farm' field trials, B alone increased seed DM by an average of 33% at only 3 of 37 sites. When used in combination with other fertilizers, B increased seed DM by an average of 67% at 16 sites. But, even these relatively large increases probably underestimate the potential for increase in seed DM since the cultivar, Tainan 9, used in the trials has a low harvest index under high fertility conditions; peanut cultivars with higher harvest indices than Tainan 9 responded much more strongly to B under high fertility conditions.

Developing simple fertilizer recommendations for soils with multi-element deficiencies needs careful consideration since various combinations of up to seven deficiencies (N, P, K, S, B, Mo, and Cu) may exist. Small farmers must be confident that there is a high probability of a return on their investment in fertilizers. Blanket recommendations for correcting mineral deficiencies are unlikely to be satisfactory. Clearly, a system of accurate diagnosis and prognosis of deficiencies is required. The results of this study have partly addressed that need for food legumes as have those of Ho and Sittibusaya (1984) who reported soil analysis standards for the prognosis of deficiencies of N, P and K in a number of field crops. However, the standards developed by Ho and Sittibusaya (1984) may need to be revised using a complete fertilizer treatment as the control for assessing crop response. Further research is required to develop plant and soil analysis standards for other field crops, rice and horticultural crops commonly grown on these soils.

In addition to soil and plant analysis, simpler alternative approaches for the prognosis of nutrient deficiencies would assist farmers and extension officers. Hollow heart symptoms in peanut seed is a simple biological indicator of low B soils. Additional indicators might be based on the association of nutrient deficiencies with soil properties such as soil texture and soil series, fertilizer and cropping history and topography. In this study, B deficiency was more common in sandy soils. With these tools, extension advice should aim to assist farmers develop a greater awareness of the nutrient limitations affecting production on their own farms and in their immediate district.

Increased awareness by farmers of nutrient limitations on their own land would call into question the current emphasis on blanket fertilizer recommendations and NPK fertilizer products. On sites with a single deficiency, compound NPK fertilizer treatment is wasteful. On sites with S or micronutrient deficiencies it is ineffective. For example, in the 'on farm' trials in this study a compound fertilizer mix without B often increased vegetative DM but decreased seed quality and either depressed seed DM or had no effect on it (Fig. 3.2). For peanut in northeastern Thailand, superphosphate enriched with B and Mo would provide a better fertilizer for general use than NPK compound fertilizers since P, S, B and Mo deficiencies are all common. Potassium could be applied as required.

The implications of these findings of low micronutrient levels in Thai soils and legume crops now need to be considered for rice because it is such a dominant crop in Thai agriculture, and for other crops especially the horticultural crops on which fertilizer use should be more profitable on account of their higher value.

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Appendices

Appendix 1 Range of micronutrient concentrations (mg/kg) in triple super, gypsum and NPK fertilizers with varying formulations. Unpublished data from Bell et al..

Fertiliser		B	Co	Cu	Fe	Mn	Mo	Zn
Triple Super	min	18	7.0	9	1350	13	5.5	108
(n = 5)[a]	max	383	10.0	58	11400	303	16.7	413
Gypsum	min	nil	0.1	1	9	2	0.2	1
(n = 4)	max	7	5.0	3	630	9	0.3	4684
23-7-8		316	nd[b]	1031	695	39	1	29
20-20-0	min	27	nd	13	786	9	46	246
(n = 3)	max	45	nd	25	2532	25	80	292
18-12-6	min	30	nd	6	2760	126	28	132
(n = 2)	max	34	nd	7	2823	135	58	145
16-20-0	min	39	nd	5	2602	106	50	100
(n = 3)	max	47	nd	16	2858	165	71	161
16-16-8	min	31	nd	3	1980	15	32	124
(n = 4)	max	52	nd	10	2742	191	58	180
15-15-15	min	27	nd	8	1500	75	14	207
(n = 3)	max	46	nd	35	2835	168	72	425
13-13-21	min	28	nd	9	1270	48	27	193
(n = 3)	max	32	nd	26	2570	185	45	293
12-24-12		71	nd	20	2310	56	65	225
12-12-17 + MgO		304	nd	12	2970	768	29	352
12-12-17		683	nd	10	3800	246	1	56
6-18-24 + MgO + B		535[c]	nd	30	1620	48	47	389
6-18-24		476	nd	12	1450	83	7	195
6-12-24		222	nd	4	9500	114	5	29
6-8-24		311	nd	17	1130	24	7	190
5-15-25		641	nd	10	710	24	1	127
5-15-20		533	nd	6	5880	123	4	41
4-16-24	min	546	nd	16	9500	315	3	117
(n = 2)	max	626	nd	19	9500	329	4	119
4-16-24 + MgO		577	nd	4	5000	111	1	28
4-16-24	min	473	nd	14	4650	110	2	26
4-16-24	max	475	nd	4	5000	115	3	27
4-16-24 + MgO + B		952[d]	nd	10	1900	209	17	345
4-12-18		262	nd	2710	6550	1120	2	276

[a] n = number of samples analysed when n>1: min and max indicate the lowest and highest concentrations determined.

[b] not determined.

[c] Certified boron concentration 0.05%

[d] Certified boron concentration 0.06%

Appendix 2 Rates of fertilizer salts (kg/ha) applied in omission trials on different soil series

Fertilizer salt	Soil series								
	Khorat[a]		San[b] Sai	Lam-pang[b]	Pak Chong[c]		Takli[c]		Ubon[a]
	(1)	(2)			(1)	(2)	(1)	(2)	
$Ca(H_2PO_4)_2$	410	410	90	90	135	205	150[e]	205	205
K_2SO_4	330	330	–[f]	90	69	69	–	69	200
KCl	200	–	100	–	–	–	59	–	–
$CaSO_4.2H_2O$[d]	236	600	0	0	0	1250	0	0	236
$MgSO_4.7H_2O$	60	60	100	100	62.5[g]	62.5[g]	–	–	60

Continued on next page.

Appendix 2 (cont.)

Fertilizer salt	Soil series								
	Khorat[a]		San[b] Sai	Lam-pang[b]	Pak Chong[c]		Takli[c]		Ubon[a]
	(1)	(2)			(1)	(2)	(1)	(2)	
MnEDDHA	0	0	0	0	0	0	19	19	–
$ZnSO_4.7H_2O$	14	14	20	20	19	19	19	19	14
$CuSO_4.5H_2O$	4	4	20	20	9	9	9	9	4
H_3BO_3	1	3	–	–	–	–	–	–	1
$Na_2B_4O_7.10H_2O$	–	–	5	5	6.25	6.25	20	20	–
$CoSO_4.7H_2O$	0.6	0.6	0.6	0.6	0.06[h]	1.25	0.06[h]	0.06[h]	0.6
$NaMoO_4.2H_2O$	0.6	0.6	0.3	0.3	0.6	1.25	0.6	0.6	0.6
Fe EDTA	0	0	0	0	0	0	18	20[i]	0

[a] From Keerati-Kasikorn (1987)

[b] From Rerkasem et al. (1988)

[c] From Ratanarat et al. (1985)

[d] For peanut only: total amounts applied as two or three equal split dressings

[e] Supplied as NaH_2PO_4

[f] Elemental S supplied at 100 kg/ha

[g] As MgO

[h] Co citrate

[i] FeEDDHA

Appendix 3 Methods of ashing plant samples and determining elemental composition

Element	Ashing method	Determination method	Reference
B	dry[a]	Azomethine/ UV–VIS Spectro[b]	Lohse 1982
	dry + $CaCO_3$[c]	"	Plaskett unpublished data
Zn, Mn, Fe, Cu	wet[d] or dry	Flame AAS[e]	Allan 1959, 1961a,b; Simmons 1978
Cu	"	Graphite furnace–AAS	Simmons and Loneragan 1975
Mo, Co	wet or dry	Graphite furnace-AAS	Kim et al. 1974
	extraction		
N	Kjeldahl	UV–VIS Spectro	Issac and Johnson 1976
P	wet or dry	UV–VIS Spectro	Boltz 1958
S	Schoniger O_2 flask	Turbimetric/Spectro	Iismaa 1959
Ca, Mg, Na	wet or dry	Flame AAS	
K	dry	Flame AAS	Horwitz 1980

[a] Dry ashing at 500°C for 8 hours, after Isaac and Johnson (1975)

[b] UV–VIS Spectro denotes ultraviolet-visible wavelength spectrophotometry

[c] For B determination in peanut and soybean seed, 100 mg $CaCO_3$ powder was sprinkled over samples in crucibles immediately prior to dry ashing to prevent loss of B by volatilisation.

[d] Wet ashing in $HNO_3/HClO_4$ after Johnson and Ulrich (1959)

[e] AAS–atomic absorption spectophotometry

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