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TROPICAL LEGUME IMPROVEMENT

Proceedings of a Thailand/ACIAR Planning and Coordination Workshop, Bangkok, 10-12 October 1983

Editor: G.J. Persley

Cosponsored by the
Thai Department of Agriculture
and the
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Contents

Foreword

A planning and coordination meeting on food legume improvement was held in Bangkok, Thailand, from 10 to 14 October 1983. The meeting, sponsored by the Thai Department of Agriculture and the Australian Centre for International Agricultural Research was in response to a Thai request to ACIAR for collaborative research between Thai and Australian scientists on food legume improvement.

There were approximately 50 participants at the meeting. They included representatives from the Department of Agriculture and four universities in Thailand, and eight Australians, from institutions conducting research on food legumes, and from ACIAR.

The papers presented at the workshop represent an important record of research on legumes in Thailand, and the Australian contributions combine to make this a useful reference volume. ACIAR hopes that the recommendations which flowed from the workshop will result in further collaborative research.

ACIAR would like to thank the Thailand Department of Agriculture for the excellent arrangements for the workshop. We would also like to dedicate this volume to two of the Thai participants, Sawing Nathribhop and Amnuay Manitaya, who died in a traffic accident shortly after the workshop, together with six other colleagues from the soybean research group from the Department of Agriculture Chiang Mai Field Crops Research Centre. We also wish to thank Mr Reg MacIntyre for his valuable contribution to the editing of the proceedings.

J.R. McWilliam,
Director
ACIAR

Introduction

G.J. Persley*

CLOSE to 50 Thai and Australian researchers participated in a 3-day workshop on legume improvement in Thailand, with a view to identifying areas for collaborative research. At the workshop, an overview of food legumes in Thailand was presented, with papers on the current importance of food legumes and research in progress on varietal improvement, crop protection, legume nutrition, and *Rhizobium*-legume symbiosis. Papers on legume improvement in Australia, diagnosis and correction of nutrient deficiencies, the effect of nutrient disorders on nitrogen fixation by legumes, and legume bacteriology were presented by the Australian participants.

Four working groups, covering plant improvement, plant protection, plant nutrition and biological nitrogen fixation discussed current research, future research needs and possible areas for collaboration between Thai and Australian scientists. Each working group reported back to a final meeting of all participants where plans for Thai/Australian cooperation on food legume improvement were discussed. A summary of the working group reports is given below.

Plant Improvement Working Group

General Aspects

The plant improvement working group recommended that soybean and mungbean (green gram and black gram) be the target crops since these were crops of high priority to Thailand, in which there was relevant Australian expertise. Thailand is planning a coordinated program for research on soybeans similar to that which exists on groundnuts, and Australian participation in this program would be timely.

The group considered that groundnuts were well covered by the existing Thai coordinated program, and made no recommendations for Thai/Australian work on groundnuts. The groundnut program is assisted by the Canadian-based International Development Research Centre and the United States Agency for International Development (USAID). Rice bean is an important crop in Thailand, but is one with which Australia has little expertise. It was decided that no research on this crop be recommended, but that a watching brief should be maintained for the future. There is some research on cowpea and pigeonpea in progress in existing ACIAR projects in Thailand.

The Asian Vegetable Research and Development Centre (AVRDC) has a program based in Thailand. Although it was recognised that AVRDC had useful genetic material for soybean and mungbean, particularly with respect to disease resistance, much AVRDC material was not considered suitable for Thailand in its present form, particularly in relation to its duration, seed quality and adaptation to the tropics.

Quarantine

Thailand has no formal quarantine system. Much genetic material is being introduced into Thailand and there is a risk of disease importation. It was agreed that the current quarantine procedures were not sufficiently rigorous, in that seed from overseas was sent directly to the areas of major culture of the crop concerned. It was agreed that some voluntary quarantine precautions were

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desirable in which imported seed was treated with fungicide to remove pathogens on the seed surface, grown in an area isolated from the crop concerned, and inspected by pathologists and entomologists during its growth.

Soybean

ENVIRONMENTAL ADAPTATION

The key issue for soybean improvement in Thailand is to address the needs for soybeans in different cropping systems, i.e. the specific challenges to the crop in different systems. These include:

- *Cold tolerance* in dry season crops in the Chiang Mai region, particularly with respect to the germination and early growth phases
- *Drought tolerance* in wet season crops
- *Waterlogging tolerance* and exploitation of wet soil culture
- *Crop duration* to fit soybeans into different cropping systems and to reduce risk of weather damage.

Study of these aspects would constitute the central part of a soybean improvement program concerned with the evaluation of the adaptation of soybean to the Thai environment and the mechanisms of variability in a wide range of genetic material. These studies would include the identification of appropriate cultural practices and management strategies for soybeans in different cropping systems.

The anticipated outputs of such research would be varieties better adapted to the Thai environment and improved cultural practices and production systems for soybeans in new cropping systems. There are prospects for collaborative work with existing Australian programs in these areas.

BREEDING FOR ADAPTATION

Breeding for adaptation would emerge from the adaptation work described above, in which specific needs would be identified. It was considered desirable but unlikely that it would be possible to develop one soybean cultivar that would be suitable for all systems in Thailand.

DISEASES

The soybean diseases of high priority in Thailand are rust, anthracnose and bacterial pustule.

It was recommended that no breeding for *rust* resistance be undertaken, but material selected for rust resistance by AVRDC be screened in Thailand. Research to identify methods for screening for field resistance, and to document the races present in Thailand, was recommended. Research to identify sources of resistance and suitable screening methods for anthracnose was also recommended.

Bacterial pustule was considered to be a significant problem. Sources of stable resistance exist in Australia, and USA, amongst others, and these should be incorporated into existing Thai varieties as soon as possible.

INSECTS

At present, low priority is given to host resistance, and high priority to other means of insect control (see below). There was some debate as to the efficiency of insecticide spraying and the possible future need for host-plant resistance.

CHEMICAL QUALITY

There is no current work on seed quality in Thailand and limited capacity with currently available equipment. There is a need to develop a capacity to analyse seed quality within Thailand.

SOIL FACTORS

There is a need to identify genetic material tolerant of the acid soils in the northeast.

There was some discussion as to the level of nutrition that should be used for varietal evaluation. It was agreed that initial varietal improvement studies should be under non-limiting (but not high input) conditions, where deficiencies should be corrected. This approach allows the genetic potential of the crop to be assessed. Subsequent research into plant improvement may address genetic tolerance of mineral nutritional stress, where appropriate.

RHIZOBIUM

The issue of whether the plant breeders should be working with specific or nonspecific strains of *Rhizobium* was discussed, but not resolved.

Mungbean

With regard to mungbeans the key issue is to fit the crop effectively into a wide range of cropping systems. Mungbeans (green gram and black gram) are important in Thailand because of their short duration and flexibility to fit within different parts of a system. A number of aspects requiring attention in a crop improvement program were identified. These are listed below in order of priority.

ADAPTATION ANALYSIS

There is a need to analyse the factors influencing adaptation. This would reveal options and areas for rapid advance, particularly in regard to cultural management.

VARIETAL IMPROVEMENT

Genetic material from AVRDC was considered to be of limited immediate value in Thailand. For green gram, there is a need to evaluate available genetic material for its adaptation to different cropping systems and environments.

For black gram, there is a need for both short season— photoperiod insensitive material and for photoperiod sensitive— and long season material.

WEATHERING

Weathering resistance is important as a major market for mungbeans is in their use as bean sprouts.

DISEASES

The important diseases are *Cercospora* leaf spot and powdery mildew. AVRDC has sources of resistance to both diseases, but in genetic backgrounds relatively poorly adapted to Thailand. Resistance to these diseases should be transferred to better adapted material. There is a need to clarify the taxonomy of *Cercospora* on mungbeans in Thailand, as there may be more than one species present, and this has implications in selecting resistant material.

SOIL FACTORS

The need to adapt mungbeans to the acid soils in the northeast is considered very important.

INSECTS

A similar spectrum of insects attacks mungbeans as soybeans, and a similar approach was recommended, with low priority to host resistance at this stage.

SEED QUALITY

The effects of environmental factors on the quality of flour produced from mungbean seed is unknown. This may need to be examined in the future. Sprout quality was not considered to be an important issue.

Plant Protection Working Group

Diseases

The priority research topics identified for plant diseases were:

- Collaboration with plant breeders on the identification of resistance to the major diseases: *Soybean*— rust, anthracnose, bacterial pustule; *Mungbean*— *Cercospora*, powdery mildew.
- Evaluation of techniques for screening for resistance.
- Study of pathogen variation.
- Epidemiological studies to identify the disease cycle and the conditions favouring disease development.
- Taxonomy of the causal agents of *Cercospora* leaf spot on mungbeans. There may be more than one *Cercospora* spp. in Thailand and this has implications in the identification of sources of resistance.
- Control of fungal contaminants on mungbean seed for export.
- Identification of virus diseases.

Insects

The major insect pests on soybeans and mungbeans are bean flies, pod borers and green stink bugs. The priorities identified by the plant protection working group on entomological research were in order of priority:

(1) Population dynamics of insect pests;
(2) Crop loss assessment; and
(3) Screening for host plant resistance.

It was considered that there was insufficient information on the biology of key pests on which to base control measures, including recommendations for insecticide spraying. There was also a need for more information on crop losses in order to identify the economic threshold for damage.

Nutrition Working Group

The key problem identified by the nutrition group was the low yield of legumes in Thailand, which varies with crops and soil types and may be caused by nutrient deficiencies or soil acidity. The most important problem was considered to be plant nutrient deficiencies.

The objectives of the nutritional studies are: to investigate the nutrient status of legumes on different soils and establish critical levels for various nutrients; and to establish response curves from which to derive fertiliser recommendations for specific crops on specific soils.

Sites and Soils

North — low humic gley (low in trace elements)
— brown laterite (high in trace elements)
Central — red-brown laterite
Northeast — Gray podzolic

Priority Crops

North — soybean
Central — soybean
Northeast — mungbean

There was some discussion as to whether there should be work on the soybean in the northeast. There was some debate as to whether the major problems limiting soybean development in the northeast are the lack of suitable genetic material, soil acidity, nutritional problems, availability of soil water or an inoculation problem with *Rhizobium* sp. There would be scope for collaboration between the various working groups to identify the factors constraining the use of soybeans as a crop in the northeast. It was suggested that there may be useful genetic material available from the acid soil areas of Brazil for northeast Thailand.

Nitrogen Fixation Working Group

The working group on nitrogen fixation identified several areas requiring research:

Inoculation techniques — when to inoculate — suitable carriers

Strain selection — strain selection for special areas (e.g. salinity, drought)

Ecological studies — in Thai soils

Quality control — of inoculants

A key issue discussed was whether the plant breeders should breed for varieties adapted to specific strains or for promiscuously nodulating varieties which nodulate with the *Rhizobium* strains present in the soil. There is also a need to determine the implications on nitrogen fixation of the use of promiscuous varieties in contrast to the use of cultivars having effective symbiosis with a specific strain of *Rhizobium*.

Recommendations

Plant Improvement/Plant Protection

The meeting recommended that a Thai/Australian collaborative program on soybean and mungbean improvement should be developed, centered on and coordinated by the Department of Agriculture, and involving Thai universities as appropriate for regional and specific disciplinary research.

Plant Protection

The possibility of collaboration on specific research topics identified between pathologists and entomologists in Australia and Thailand should be examined. Disease and insect control would be an important component of the plant improvement program.

Nutrition

A collaborative project on the nutrition of tropical legumes, including studies on biological nitrogen fixation and *Rhizobium*, should be initiated.

Agronomic Aspects of Grain Legume Farming*

Arwooth Na Lampang†

'TOA' is the common Thai word for legume. To identify a specific kind of legume, an adjective is used such as 'leung' (yellow legume) meaning soybean. Besides the generic meaning of legume, 'Toa' is used in colloquial Thai to mean 'nut.' Thus there is a close association of legumes with the Thai people. Furthermore, Thai people know how to cultivate legumes and how to prepare each kind of legume for their own consumption.

Kinds and Varieties

There are several kinds of grain legumes grown in Thailand. The kind and quantity may vary from place to place and, to a certain extent, from season to season. However, there are five grain legumes of commercial importance in Thailand at present. They are soybean (*Glycine max*), peanut (*Arachis hypogaea*), green gram (*Vigna radiata*), black gram (*Vigna mungo*), and rice bean (*Vigna calculatus*). Only these five legumes will be discussed here. Statistics of these five legumes are given in Table 1a and b.

In addition, other grain legumes are grown on a small scale in certain areas (e.g. kidney or field bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), sweet or garden pea (*Pisum sativum*), pigeonpea (*Cajanus cajan*), broad bean (*Vicia faba*), hyacinth bean (*Lablab purpureus*), Bambara ground nut (*Voandzeia subterranea*)), and others. They are considered minor crops and have insignificant impact on both research activity and in the market. However, some of these 'minor' grain legumes deserve attention because of their tolerance to drought and adaptability to low soil fertility. Promising results have been obtained in the varietal improvement of the five major grain legumes, and brief discussions follow.

Table 1a. Statistics* on soybean, peanut and mungbean in Thailand.

Year	Acreage ('000 ha)	Production ('000 t)	Yield (kg/ha)
Soybean			
1970	58	50.4	850
1971	57	54.3	944
1972	80	72.0	900
1973	123	104.2	850
1974	132	110.4	838
1975	119	113.9	963
1976	102	113.6	1120
1977	153	96.2	632
1978	162	158.9	981
1979	108	102.1	938
1980	126	100.0	794
1981	128	131.5	1031
Peanut			
1970	104	124.9	1200
1971	114	133.5	1179
1972	119	152.8	1288
1973	124	146.5	1181
1974	130	160.9	1238
1975	118	142.2	1206
1976	122	151.5	1244
1977	103	105.6	1031
1978	106	127.5	1206
1979	105	125.8	1225
1980	122	146.5	1200
1981			
Mungbean			
1972	227	204.2	900
1973	255	209.3	819
1974	207	187.9	906
1975	164	120.6	738
1976	223	124.8	562
1977	435	206.9	475
1978	422	259.0	612
1979	424	250.7	588
1980	447	261.0	581
1981	486	283.7	588

*Source: Office of Agricultural Statistics, 1981 Annual Report.

Soybean

Four varieties have been released to farmers. SJ 1 and SJ 2 have small seed size (about 10–12 g/100 seeds) and have been very popular with farmers. The other two newly released varieties SJ 4 and SJ 5 have medium seed size (about 13–15

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Table 1b. Statistics* on green gram and black gram in Thailand.

Year	Acreage ('000 ha)	Production ('000 t)	Yield (kg/ha)	Exports ('000 t)	Exports ($USM)
Green gram					
1970	168	105	631		
1971	106	103	975		
1972	170	153	900		
1973	208	170	819		
1974	164	148	906		
1975	104	76	737		
1976	151	91	600		
1977	347	165	475		
1978	224	137	613	100.8	32.6
1979	275	157	569	57.5	21.6
rate (%)	+7.46	+2.07	+5.03		
Black gram					
1970	72	43100	598		
1971	42	36930	879		
1972	35	38080	1088		
1973	47	39051	830		
1974	43	39720	924		
1975	60	44252	738		
1976	71	34116	480		
1977	88	41861	476	59711	25.5
1978	197	121952	619	69132	27.8

*Source: Office of Agricultural Statistics 1979 Annual Report.

g/100 seeds) and are moderately resistant to rust disease. All the four cultivars are day-neutral and have relatively short growing periods, maturing in about 90 days (range 85–100 days depending on environmental factors). This growth period fits into the existing cropping systems. Details of soybean varieties are given in Table 2.

Peanut

Three varieties have been released. The first two cultivars are of Valencia-type with medium seed size (about 40 g/100 seeds). One of them (Lampang) has a white seed coat while the other (Sukothai 38) has a red seed coat. Both of them are selections from locals and require a growing

Table 2. Certain characteristics of soybean standard varieties.

Characteristics	S.J.1	S.J.2	S.J.4	S.J.5
Colour stem and flower	purple	purple	purple	purple
Growth types	indeter	deter	deter	deter
Plant height at harvest (cm)	78.8	58.2	56.2	56.8
Leaf types	thin and green		thick and dark green	
Seed weight (g/100 seeds)	12.7	11.5	14.3	14.1
Hilum	black	reddish brown	tan	light tan
Pod shattering[1]	5	1	2	2
Yield (dry season kg/ha)[2]	1544	1532	1600	1412
Yield (rainy season; kg/ha)[3]	1906	1825	1900	2013
Yield (year round; kg/ha)	1725	1668	1750	1713
Resistances to rust	343	343	333	333
to anthracnose[3]	2	2	3	3
to bacterial pustule[3]	3	3	2.5	2.5
to downy mildew[3]	3	3	1	2
to soybean mosaic virus[3]	S	S	S	R
Oil content (%)	18.4	20.1	17.6	18.7
Protein content (%)	37.1	39.1	39.1	41.9

[1] Score: 1 = least shattering; 5 severely shattered.
[2] Average of 3-year period.
[3] Except rust, disease scored as 1 = susceptible to 4 = resistant.

period of about 100 days. The third and recently released variety, Tainan 9 (an introduction from Taiwan), is a bunch Virginia-type with white and bold seed (about 55 g/100 seeds). Higher yield and shelling percentage make it highly acceptable to the farmers. Its growth period is about 110 ± 10 days. Table 3 describes three peanut varieties.

Green Gram

Both domestic and foreign markets demand green gram with large, uniform and glossy seed and the recommended cultivar, U Thong 1, has quickly replaced all native varieties. It is an early variety, about 65 days in duration. Because of uniform flowering, pod setting and maturity, only one or two pickings are required for the total harvest compared to the old varieties which may need five to six pickings. Furthermore, this variety is day-neutral and can be planted year-round, except during winter in the north where temperature is usually lower than 20°C.

Black Gram

U Thong 2 is the standard variety of black gram. It is photoperiod-sensitive and matures within 90 days. Its large and uniform seed size meets the requirement of the world market. Varietal description of U Thong 1 and 2 is given in Table 4.

Rice Bean

This new grain legume found its place as a commercial crop in the past decade. The ease of cultivation and the demand in the foreign markets led to its widespread planting in the corn-growing

Table 3. Characteristics of three recommended peanut varieties.

Characteristics	Lampang	SK 38	Tainan 9
Types	Valencia	Valencia	bunch Virginia
Stem types and colours	erected, green	erected, purple	erected, green
Leaf types	large, green	large, green	small, dark green
Days to flowering	37	37	41
Days to harvesting	100–110	100–110	110–120
Beak and reticulum on pod	prominent	prominent	prominent
Average seeds/pod	2–3	2–3	2–3
Shelling percentage	65–75	67–74	72–80
Seed colour weight (g/100 seeds)	pink, 42	red, 43	pink, 48
Seed colour weight (g/20 l)	pink, 5	red, 5	pink, 5.5
Yields (dry season; kg/ha)[1]	2280	2475	2650
Yields (rainy season; kg/ha)[1]	2240	2160	2510
Yields (year round; kg/ha)	2260	2250	2580
Oil content (%)	48–52	48–54	46
Protein content (%)	24–25	24–25	33

[1] Average from 3-year period.

Table 4. Certain characteristics of green gram and black gram standard cultivars

	Green gram		Black gram	
Character	U Thong 1	Local	U Thong 2	Local
Plant types	bushy	bushy	bushy	twining
Days to flower	35	40	43	46
Days to harvest	65–70	75–90	89	91
Plant height (cm)	50–75	60–70	104	108
Pods per plant	14	11	53	46
Seeds per pod	12–15	9	7.5	7.3
Pods at 1st picking (%)	85	50	100	100
Number of pickings required	1–2	1–8	1	1
Seed weight (g/1000 seeds)	65	61	50.4	48.1
Seed colour	glossy	green	black	black
Yields in dry season (kg/ha)[1]	1325	1263	1125	1025
Yields in rainy season (kg/ha)[1]	1300	1180	1188	1050
Yields (year round, kg/ha)[2]	1225 (+ 5%)	1168 —	1156 (+ 12%)	1038 —

[1] Average of 5-year period.
[2] Weighted means.

areas. Thai farmers plant corn and bean seeds in the same hill early in the rainy season (April-May). The bean plants grow slowly during the early vegetative stage and do not seriously compete with corn. After cobs are harvested in July-August, the beans start to grow vigorously by twining up the corn stalk. Because of its photoperiod sensitivity, flowering is in October. Pods are ready for picking in November-December. Experimental results show that intercropping reduces neither the corn nor the bean yield. The extra income from bean is all profit since additional cost of bean cultivation is negligible. In other words, corn-rice bean is an ideal intercropping system.

Breeding work on rice bean began with varietal collection and evaluation. There are wide variations in plant types, crop duration, and seed size and colour. Attempts are being made to select for earliness, high yield and large seed size, and separate the red and white seed coat materials.

Methods of Farming

All grain legumes, except rice bean, are grown in either rotation or as a sequence crop. In both cases, grain legumes are grown as a sole crop. Intercropping and/or relay cropping with other row crops such as corn, cassava, cotton, castor, kenaf and sugarcane are under study. Preliminary results based on land equivalent ratio (LER) indicate the possibility of developing efficient and profitable systems of intercropping. The successful systems must be 'on-farm tested' before they are recommended to farmers. Attention and assistance to legume-based cropping systems are being given simultaneously by the Thai Government, World Bank, FAO/UNDP, EEC and ACIAR. Legume-cassava intercropping should receive high priority especially in the Northeast where cassava is a dominant field crop.

There are three main seasons for growing soybean. The first season is immediately after the main rice crop, usually from December to February. This crop grown in the lowland paddies is irrigated. The second season crop is in the uplands and is sown early in the rainy season (April-early June) depending on the local rainfall conditions. Harvesting of this crop is in July-August. After the soybean harvest, the sequence crops are cotton, green and black gram and in certain areas, corn and sesame, in order to utilise the rest of the rainy season which is generally until mid October. In the Central Plain where corn is planted early in the rainy season and harvested in July and August, the third season for soybean is August-September. In passing, it may be mentioned that in all the three seasons 90-day varieties of soybean are preferable to the longer duration varieties now available.

Wherever both can be grown, green gram and soybean compete with each other. Since green gram requires only 65-70 days to mature and commands a better price at present than soybean, greater acreage is under green gram. However, being a tropical crop, green gram does not tolerate low temperatures and it is in these situations that soybean takes over, for example, following rice in the Northern Region. Green gram is broadcast in the paddies in the Southern Region where it is warm throughout the year. As one moves northward, the sowing time of green gram shifts through January, February and March and in the northern part of the country it is in April. In the uplands, like soybean, green gram also has two planting seasons: one early in the rainy season (April-May) followed by corn, sorghum and cotton, and the other in late rainy season (August-September) following corn and soybean.

Unlike green gram, U Thong 2 black gram has longer growth duration (about 90 days) and long day behaviour. Thus it has only two sowing seasons. The first one is late in the rainy season under rainfed conditions and the other is in the dry post-monsoon season (December-April) in the paddies with supplemental irrigation. Black gram is mainly utilised for making bean sprouts. Hence, harvesting should coincide with the dry season.

Peanut requires friable (non-crusting and hardening) soils to facilitate harvesting of pods and also a brief rain-free period to dry the pods rapidly after harvest to minimise aflatoxin hazard. These, together with its relatively longer duration, restrict peanut-growing seasons to only two. The first crop is in the dry season, soon after rice harvest (December-February) in the irrigated paddies. The field should be ridged up to facilitate gravitational irrigation. Harvest should be completed before May for ease of pod drying.

Rice bean is photoperiod-sensitive. Irrespective of its planting date, it flowers around mid October. Nearly the same yield is obtained if the crop is planted in May, June or July. Mid August seems to be the critical date, as later plantings result in reduced vegetative growth and lower yield. Moreover, because of its twining habit, stakes are needed to support plants. It is thus best to intercrop rice bean with corn as mentioned earlier. Sowing bean and corn seeds at the same time seems to be the most convenient practice. Some farmers delay planting beans until the first or second interculture of corn, depending on weed infestation.

Cropping seasons of these five legumes are given in Fig. 1. Some modifications occur locally.

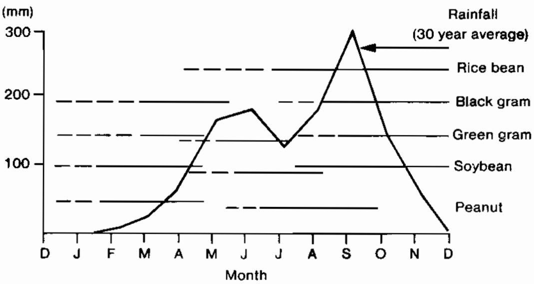

Fig. 1. Cropping seasons for five legumes.

Use of Farm Inputs

In spite of their contribution to Thailand's agriculture and economy, grain legumes receive less attention and investment than the other field crops. Farmers, traditionally, treat them as marginal crops. Cultivation and management are minimal and are given whenever other crops do not require attention. However, their rising price in this decade has slowly changed farmers' attitude towards providing more inputs to grain legumes. Good seed of improved varieties is the first step. Unfortunately, lack of a commercial seed industry restricts rapid expansion of recommended varieties. Application of inoculum and chemical fertilisers is taken up in certain areas. Spraying of chemical insecticides to control major insect pests is rapidly increasing. Mechanisation of land preparation, cultivation, harvesting and threshing is visible and is replacing manual and animal labour, particularly in areas practicing cropping systems. This may be considered as a sign of adoption of modern technology in grain legume production.

Research and development programs on grain legumes are aimed at better utilisation of farmers' natural resources based on cropping systems, manual labour and crop residues, since the majority of them have small holdings. The inputs essential for better crop production are good seed, inocula, chemical fertilisers, and crop protection, and the required financial support is provided by the Government-owned Bank of Agriculture and other similar agencies to certain farmers' associations. Price support programs for soybean, green gram and peanut are operating in major growing areas. To sum up, as the profitability of grain legumes increases, the area planted increases, and farmers tend to adopt better technologies to achieve higher and more stable yields.

Research and Development

Most of the research on grain legume production is actively undertaken in various divisions of the Department of Agriculture and is summarised below.

Breeding Better Varieties

SOYBEAN

Breeding objectives are earliness, photoperiod-insensitivity, and high yield with better seed quality. SJ4 variety is moderately resistant to rust and downy mildew. In addition to SJ 4, SJ 5 is tolerant to soybean yellow mosaic and anthracnose. Combining resistance or tolerance to several of the economic diseases is the ultimate goal. Other objectives are tolerance to drought, soil acidity and salinity and infertile soils, especially in northeastern provinces.

GREEN GRAM

Resistance to *Cercospora* leaf spot is the prime requirement. Segregating progeny of crosses between resistant varieties with U Thong 1 (a good agronomic variety) has been evaluated. Hopefully a desirable cultivar will be identified in the near future.

BLACK GRAM

The objective is to evolve day-neutral cultivars for growing the crop year-round. The major bottleneck is the lack of such a character in the existing germplasm collection. Induced mutation is being undertaken for this purpose. Large and uniform seed size are other additional objectives for both green and black gram.

PEANUT

Breeding for resistance to rust and *Cercospora* leaf spot is the main objective. Resistance to *Aspergillus flavus*, the organism that produces aflatoxin, is urgently needed. Resistance has already been identified in Indian material and is in the process of incorporation into standard cultivars SK 38, Lampang and Tainan 9.

Special breeding programs are underway to evolve varieties of soybean, green gram and peanut that fit into newly developed efficient and profitable cropping systems. One objective is to obtain short-duration varieties to be planted prior to, along with, or following major crops such as rice, corn, cassava and cotton. Preliminary results indicate such a possibility. The other objective is to evolve short-statured, erect genotypes to fit into corn, cassava and castor-based cropping systems. The problem is rendered more difficult by the additonal requirement of suitability of the grain legumes to soil and climatic environments, besides minimum interspecific competition.

Crop Management

In order to obtain maximum benefit, cultural practices should be combined with crop varieties. The following are the areas of research now underway.

SOIL FERTILITY

Soil conservation and fertility improvement are the main considerations. Application of local rock phosphate receives high priority. If it proves effective, dependence on high cost phosphatic fertilisers will be greatly reduced. Another aspect is utilisation of various forms of organic matter to improve soil tilth and fertility.

NITROGEN FIXATION

Selection of suitable rhizobial strains is of prime importance. Locally produced inoculum especially for soybean has become popular.

PEST CONTROL

As mentioned earlier, there are numerous diseases and insect pests on grain legumes in the humid tropics. Several means of control are studied in detail. These include crop sanitation, crop rotation, biological and chemical control. Chemical control when used extensively frequently damages the environment, leaves high residues on the produce and often leads to buildup of resistance to the chemicals. Furthermore, the rising costs of insecticides compels the researchers to reduce to a minimum the spraying schedules with the right kind of chemicals.

Seed Production

Under a USAID loan program the Seed Division, Department of Agricultural Extension, started to produce seed on a commercial scale for supplying to farmers. However, the supply falls far short of the demand as the private sector is still hesitant to enter the seed business.

Extension

Extension work is mainly under the Department of Agricultural Extension; several government agencies also undertake this service. Extension work on food legume is being intensified in every province at present. Soybean, green gram and peanut are included in the promotion program.

Marketing

The marketing system for grain legumes is poorly operated. Farm-gate prices are very low compared to what consumers pay for the food legumes; middlemen both at the local and city level enjoy a greater share of the price. This needs to be rectified in order to make grain legumes financially attractive. Recently the government has introduced a price support program for soybean, mungbean and peanut. It is too early to assess the program, however.

Legume Crops as Soil Conditioners

Farmers are already aware that growing of soybean and peanut in the paddies leads to better growth of rice in the following season. However, under upland conditions the beneficial effect is not unequivocal. Difficulty in incorporating the legume residues, lack of moisture in the topsoil to decompose them rapidly, and the inability of the base crops to utilise mineralised nitrogen late in the season are perhaps the major reasons for the inconsistency. It may be noted that in upland areas, sequence crops are not possible because of limited moisture. However, the role of intercrop legumes in protection of soil against the beating action of the rain is unquestionable. In general, legumes are harvested and threshed by hand. In the case of soybean and black gram, entire plants are transported to a specially-built platform outside the field for threshing. After beans are separated and collected, the residues are piled up and burnt. In the case of peanut, farmers separate and pick up the pods in or close to the field. Some of the residue will, thus, remain on the soil. In some cases, cattle are allowed to feed on the legume residues. Harvesting of green gram and rice bean is done by picking out individual pods. While entire plants are left behind in the field, only a small portion of them naturally return to the soil and the majority of the residue dries and is blown away by winds. After threshing, the pod residues are piled up and burnt. Only a few farmers return the thresh residue to their fields.

As the cost of chemical fertilisers keeps rising, several government agencies have launched programs to encourage the farmers to utilise crop residue and other forms of organic matter. Most of the Thai farmers collect cattle dung and poultry manure and apply them to their paddy fields before rice transplanting. However, they ignore the value of crop residues and do not compost them. Special demonstration programs are needed for this purpose. A good example is furnished by the soybean farmers in Chiang Mai area. After threshing soybean, crop residues are piled up under shade and watered to hasten decomposition. In this process, a natural crop of edible mushroom is produced and harvested. The decomposed residue is applied to paddies. There is an urgent need to educate farmers to appreciate the value and utilise all of the crop residues to maintain or improve soil fertility in both paddies and uplands.

Discussion and Recommendations

The results from experiments over the decades indicate that there are bright prospects for increasing grain legume production in the tropics, including Thailand. However, yield per unit area has to improve so that legumes can compete with cereals so far as returns are concerned, thus making the farmers enthusiastic about planting the legumes. Since the major area under food legume is rainfed, stability combined with high yield is of paramount importance. Some of the traditional practices which have stood the test of time possess enduring qualities which we should discover.

Adapted Varieties

As mentioned earlier, the newly recommended varieties were bred under tropical conditions and tested under conditions of actual users. They are more productive and more stable than local cultivars. Improved varieties of peanut, green gram, and black gram were well received by farmers in the test areas. For soybean, in seasons of severe rust infection, yield reduction is less than 20% in new varieties while it is about 50–100% in the old ones. In the disease-free season, soybean SJ 4 and SJ 5 have yielded about 8–10% higher than SJ 1 and SJ 2. Seed supply continues to remain a serious limitation.

Seed Supply

Good seed of adapted varieties must be available to farmers on time, at their doorstep, and at reasonable cost. At present, it is estimated that less than 10% of the farmers can procure good-quality seed. The rest depend on whatever they can find. The Seed Division, Department of Agricultural Extension, hoped to supply 5–10% of the demand by 1983. All necessary steps should be taken to encourage private seed business.

Soil Types

Generally speaking, legumes are highly adapted to various soil conditions. However, they do produce higher yield on light-to-medium soils with good drainage. On acidic soils and heavy clays legumes are less vigorous and so also is the rhizobial activity. Pod set and harvest of peanut become serious problems in nonfriable clay soils. Growing legumes in paddy fields with irrigation should be in large blocks to minimise seepage or inundation from adjacent second crops of rice.

Plant Population

A series of experiments showed that there is a range of proper spacing and plant population for each kind of legume over which the yield remains maximum and consistent. Low plant population will significantly reduce crop output and encourage weed growth. On the other hand, over population does not increase crop yield. In addition to higher cost of seed, lodging and reduction of seed size result from excessively high seed rates in the case of peanut and soybean. Modification of row spacing is permissible to facilitate intercropping, mechanisation and irrigation provided plant population is maintained in the optimum range for each set of conditions.

Inoculation and Fertilisers

It is advisable to inoculate soybean seed before planting. Inoculum is produced in the Department of Agriculture and is also available for peanut and green gram in addition to soybean. In the test plots, about 15–30% yield increase has been obtained in the major legume-growing areas.

Based on soil analyses, only phosphorus need be applied to achieve high production of food legumes. Rock phosphate is recommended as a source of phosphorus and to correct soil acidity. Only in a few cases is application of potassium needed. Farm manures and crop residues are recommended for soil conditioning. Generally, it is advisable to apply fertilisers to the previous crops; the following legumes are able to utilise the residual phosphorus.

Planting Times

To avoid crop losses both in quality and quantity, it is recommended that grain legumes be planted as early as possible. There will then be ample time to accommodate the following crops. In the late rainy season, early planting provides sufficient growing duration before cessation of rains in October. Planting legumes immediately after harvesting of rice in the dry season also significantly outyields the delayed planting, due to fewer diseases and insect pests as well as availability of irrigation water.

Other Cultural Practices

Appropriate cultural practices are necessary to raise yield level. For instance, soybean, green gram and black gram need 1 month of weed-free environment to produce high yields. Hand weeding twice, at 2-week intervals after emergence has doubled and tripled soybean yield over unweeded check at Maejo and Kalasin Experiment Stations.

In the northern provinces, farmers keep weeds growing in soybean and peanut fields for feeding cattle. It is possibly one of the reasons for low yield since irrigation and fertility are not limiting. Manual hand weeding and intercultivation of peanut should not be done after the sixth week, since it interferes with pegging and pod setting.

Pest Control

Insect pests are a more serious constraint to grain legume production than diseases. However, the number of devastating insect pests on a given grain legume that need special attention is only a few. One of these pests is bean fly (*Melana — gromyza* spp.), maggots of which live and feed inside soybean, green gram and black gram stem. Damage is high when infestation occurs in early seedling stage. In severe cases, seedings are completely wiped out, but in general, abnormal plant growth results in low yield. It is therefore recommended that systemic insecticides, such as dimethoate, be sprayed within 10 days after planting. .The occurrence of other pests varies with kind of crops, seasons and locations. Educating farmers to recognise these economic insect pests is essential for successful control.

Varieties with satisfactory level of resistance to major diseases are being developed and released to farmers, as chemical control of diseases is impractical and expensive at this time. Crop rotation and sanitation are suggested alternatives.

Harvesting and Threshing

Traditional practices, as mentioned earlier, involve several steps from harvest to grain storage, and seed losses apparently occur at each stage. Even a loss of one seed per plant results in loss of 10–15 kg/ha of green and black grams, 18–25 kg/ha of soy and rice beans, and 180–250 kg/ha of peanut. Minimum multiple handling and improved threshing and bean collection would reduce these losses.

Storage

In order to obtain a premium price good grain quality must be ensured. Proper drying and storage are needed. Peanuts should be stored in pods. The other four legume grains are commonly packed in a gunny bag. Periodic inspection and drying the stored grain would reduce damage due to store insects (bruchid), mould and others.

Cropping Systems

As stated earlier, all the four legumes, except rice bean, are short-duration crops which make it possible to plant them two to three times a year. However, raising the same crop continuously in the same field encourages accumulation of diseases and insect pests and should be avoided. It is best to rotate legumes with cereals or fibre crops such as rice, corn, sorghum, cotton, kenaf. The new cropping systems are designed for full utilisation of land, labour and water, both rainfall and irrigation. In order to obtain maximum benefit, careful and advance planning of cropping pattern and systems is necessary. Alternative cropping programs should be designed to meet contingencies such as delayed rains, floods and changes in product demand.

Conclusion

There is a great and urgent need to improve production of grain legumes which are a valuable source of protein for a balanced diet. Our considered view is that there is vast scope to achieve this objective. The first step is to increase the productivity of the grain legumes. This aspect, which has been covered earlier, consists of developing adapted varieties and good husbandry practices, including pest control. While it may not be possible to have varieties of grain legumes whose potential yield is comparable to that of cereals, it looks possible to have gross income from grain legumes comparable to cereals.

Because of their short duration, the productivity and income per unit time are indeed high in the case of grain legumes. Also, they fulfil a pressing need for mid-season cash flows to farmers for reinvestment in other crops or meeting their family requirements.

Expansion of areas under grain legumes is also possible. Again, because of their relatively short duration, grain legumes fit into the cropping systems either as catch crops preceding or following the main crops or as intercrops. That is, unlike most other crops, area under grain legumes can be increased without detriment to other crops which farms are used to growing.

These are the possibilities. To translate these possibilities into realities and to have a visible development impact, cooperation of many other agencies is necessary. First among them is extension to 'educate' the farmers and to provide the needed inputs. The second is the credit supply. The third is the marketing system and pricing policy. Only then can we expect the farmers to be sufficiently enthused to produce more grain legumes.

Soybean Varietal Improvement in Thailand

Amnuay Manitaya*

AMONG the field crops soybean is the one well known to Thai farmers, especially in the northern part of the country. It is believed that Chinese immigrants introduced soybeans into Thailand a century ago. Soybean grains are mostly produced in the north and central plain. In the upper north farmers grow soybean in paddy fields during the dry season. Here farmers grow the soybeans in the rice stubble, whereas in the lower north they are grown in upland fields in the rainy season. The farmers practice ploughing, intertilling, weeding and pest control, but less frequently than officially recommended. The amount of fertiliser being applied is also below the recommended level.

The low farm yields of soybean culture in Thailand are the result of many interacting factors, such as environment, agronomic, and genetic factors. Research on soybean emphasises the breeding of improved varieties to develop high-yielding, early-maturing varieties with resistance to pests and diseases. The soybean varietal improvement is mainly conducted by government institutions, such as the agricultural experiment stations under the Department of Agriculture, the universities, and institutes of agriculture.

At the Kasetsart University conference in 1969 Amnuay Vatanawasin cited the first report in the literature about soybeans in Thailand: 'the Chiangmai Governor... launched a program to encourage farmers growing soybean after the rice harvest in the year 1931'.

In 1941 the Agricultural Department reported that three Thai officials were working with H.W. Ream, a field crops specialist from USOM. They conducted a survey on soybeans and collected varieties from all over Thailand. These varieties were then grown at three different locations, Bangkhen in the Central region, Thapra in the northeast and Maejo in the north.

A few years later it was reported that out of the different varieties grown at those stations, the variety Maetang from Chiang Mai and the variety No. 27 from Indonesia were better-yielding than the others. Bannaisamrong Station reported Ottotan as the best-yielding variety with 2 t/ha, but the local market did not accept the black soybean.

In 1958 Thapra Station and Bannaisamrong Station reported that with 2 t/ha the variety Pakchong had a better yield than Ottotan. At the same time it was found at Maejo Station that SB-60 had a higher yield when grown in the dry season, whereas Pakchong was a dwarf variety with low yield.

In 1960 Vatanawasin obtained hybrid material from Taiwan and Japan for selection at Maejo Station. Three promising lines were selected and released in 1965, namely SJ 1, SJ 2 and SJ 3. However, the Agricultural Department committee accepted only two varieties, SJ 1 for the rainy season and SJ 2 to be grown during the dry season.

In 1967 the Maejo Agricultural Experiment Station received 360 soybean entries from Japan and Taiwan. However, from 1931 to 1969 soybean was still a minor crop and the growing area limited to the north of Thailand. The Economic Development Plan of 1970 demanded that soybean should be turned into an economically important crop and a target of 300 000 t was set for 1975.

The 'Oil Crops Project', established in 1970 under the Agricultural Department, was assigned to conduct research on soybean at Maejo Agricultural Experiment Station. In July the Japanese Government sent soybean experts through the Colombo Plan to Thailand. A varietal improvement program commenced at that time which continues to the present.

The soybean collection at Maejo Agricultural Experiment Station was started in 1970. (Table 1). Ten varieties were introduced through the Field Crops Research Institute in 1980, 74 in 1981, 54 in

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1982, and 157 in 1983.

The soybean varietal improvement by crossing and selection of hybrids was started in the rainy season of 1970. The characteristics to be achieved were high yield, early maturity, and good seed quality (Table 2).

Table 1. Maejo Agricultural Experiment Station collection, beginning in 1970.

No.	Source	Year of introduction			
		1970	1971	1972	1973
1.	Thailand	98	1	-	-
2.	Japan	1227	24	59	58
3.	Nepal	8	-	-	-
4.	Brazil	22	-	-	-
5.	Bolivia	3	-	-	-
6.	Pakistan	2	-	-	-
7.	Taiwan	3	-	4	-
8.	Peru	1	-	-	-
9.	Bhutan	2	-	-	-
10.	Mexico	8	-	-	-
11.	U.S.A.	6	1	-	22
12.	Indonesia	10	2	-	-
13.	Philippines	4	6	-	-
14.	Australia	-	1	-	37
15.	India	-	3	-	-
16.	U.S.S.R.	-	10	-	-
17.	Okinawa	-	52	-	-
18.	Chinese mainland	-	-	-	5
19.	Unknown	-	7	-	-

Table 2. Number of soybean crossings per year from 1970-83 conducted at Maejo Agricultural Experiment Station.

	Year of crossing													
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Amount	32	3	7	34	—	22	14	13	50	—	56	—	19	36

A survey of soybean diseases revealed that soybean rust caused serious damage in the rainy season in the north. In the Central Plain bacterial pustule could be found, but was not economically important. SJ 1 and SJ 2 did not nodulate in the northeast, but the variety SB-60 showed very good nodulation in the same location.

During the last 3 years there have been severe attacks of anthracnose at Maejo Agricultural Experiment Station. Close cooperation between plant pathologists and breeders is necessary in the breeding of anthracnose-resistant varieties.

Evaluation and Seed Yields

The initial crossing for the variety SJ 4 was made in 1970 at Maejo Agricultural Experiment Station and the variety released in 1976. SJ 4 has less yield loss under soybean rust than the varieties SJ 1 and SJ 2. The decrease in yield of SJ 4 was only 10–20%, while SJ 1 and SJ 2 had yield losses of 50–90%.

Five years after the release of SJ 4 the new line SJ 5 was released. SJ 5 is high-yielding and has tolerance to rust and mosaic virus.

There is still no variety in any country with resistance to rust. Another disease of importance is anthracnose, because it can damage the soybean plant at every stage of growth. Bacterial pustule can be found frequently in soybean fields in the Central Plain in Thailand.

Seventy per cent of the soybean production is carried out under rainfed conditions, which favour the growth of pathogenic fungi. Therefore resistant varieties must be found to minimise yield losses due to diseases during the rainy season.

Another future task for soybean breeders is to select soybean lines with early maturity and tolerance to drought. In the central upland, more than 1.6 million ha of corn are grown in the rainy season and harvested in August or early September. Soybean which matures within 75–80 days could be planted after corn. If only half of this potential area were used to grow soybeans, the higher production would help to meet our domestic demands.

Kasetsart University Soybean Breeding Project

Peerasak Srinives*

KASETSART University has been studying soybeans for over 20 years. The earlier experiments were conducted as student theses to fulfill the requirement of a bachelor of science degree in agriculture. In 1974 individual soybean projects were coordinated and became the first master project of the university. The project has now expanded to include mungbean, chickpea, pigeonpea, and cowpea, but the main activity is still concentrated around soybean, as it is the oldest crop of the project. The objectives of the master project are:

- To conduct research on the improvement of higher protein grain legumes of economic importance in Thailand according to the goals of the National Economic Social Development Plan;
- To coordinate research programs and activities with other agencies within and outside the country;
- To support research at the graduate level to provide expertise to researchers who will join other government agencies.

Since 1980 the project has been called the 'Kasetsart University Research and Development Project on High Protein Crops'. Soybean researchers from seven departments (Agronomy, Soil Science, Plant Pathology, Entomology, Applied Radiation and Isotope, Food Science and Technology, and Agricultural Economics) participate in this research program. Regular meetings among the researchers (every 2 months) help not only to shape the goal of the master project but also to update the research activities through an interdisciplinary discussion.

The soybean breeders work closely with researchers from other disciplines. The breeders have information that might be useful for cultivar development. An 'ideal' cultivar should have as many of the following characters as possible: high yield; non-shattering; high oil percentage (because yield is positively correlated with oil content but negatively correlated with protein content); resistant to some important diseases such as rust, anthracnose, and bacterial pustule; good branching ability to compensate poor stand; high seed quality; ability to form nodules with *Rhizobium* bacteria; drought tolerance; non-sensitive to photoperiods; others, such as maturing within 90–110 days, 50–80 cm high, 14–18 g seed weight, yellow seed coat without cracking, tolerance to some insects, and can be grown in several cropping systems.

Theoretically, such a cultivar could be achieved through stepwise building up by incorporating desirable genes into existing cultivars. Practically, however, such a cultivar is impossible to obtain unless all desirable genes are qualitative in nature (no negative correlation) and have no tight linkages among them. The situation is worse when there is no desirable gene available in the germplasm collected, such as there is no known rust resistant gene in nature. Kasetsart University researchers were aware of this problem since early 1970 and thus set up a mutation breeding project in which genetic variation could be created by exposing soybean seeds to gamma radiation. The rest of this report summarises work done by both mutation and conventional breeding methods.

Mutation Breeding

Researchers from the Department of Applied Radiation and Isotope, Faculty of Science, are provided with a gammator having Cesium-137 as the gamma source. The usual doses are 15 and 30 krad. Lines derived from mutation had been studied extensively from 1970 to 1978. Although no mutant yielded significantly higher than the recommended SJ-series, a few mutants posed variations as compared to their parental cultivars. Gamma ray was found to change flower colour from purple to white, seedling stem from green to yellow, seed coat from yellow to brown, etc. Thus it

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might be possible to induce rust resistance gene(s) by mutation breeding as well.

In 1979 seeds from 11 soybean lines and cultivars were irradiated under the gammator. The resulting M_1 seeds were grown at Suwan Farm to obtain enough M_2 seeds for rust reaction testing. The mutant lines were selected from M_2 to M_5 generation under natural epiphytotic conditions at Nong-Hoi Hill and Maejo Agricultural Research Station in Chiang Mai. It was found that six mutant lines derived from G 8596 (PI 230970) expressed highest resistance level. Other agronomically important traits of these lines are under investigation.

Conventional Breeding

The Kasetsart University conventional breeding project is taken care of by researchers from the Department of Agronomy, Faculty of Agriculture. Although intensive varietal evaluation has been done from as early as 1970, an official breeding program was established in 1975 with rather limited monetary support. Parental lines and cultivars were identified and used in making crosses to generate materials for selection processes. A summary of individual breeding experiments follows:

RUST RESISTANCE

In 1977 PI 230970, PI 230971, BM 33, G 8375, Orba and a few other lines and cultivars were found to have field resistance. They were crossed with some high-yielding cultivars to study the mode of inheritance of the resistance. Lines derived from these crosses were advanced and selected until uniform. Since there has been no rust outbreak at Suwan Farm since 1980, these lines were selected against bacterial pustule disease instead. Most of them were discarded due to high disease incidence.

BACTERIAL PUSTULE RESISTANCE

In 1982, three resistant cultivars (Davis, Clark 63, Bossier), three moderately resistant cultivars (Jupiter, Galland, and KS 473), and four susceptible cultivars (Wakajima, SJ 1, SJ 4, and SJ 5) were crossed to generate their F_1-, F_2-, and backcross progenies. Gene action analyses will be done using data from the 1983 planting. A few resistant lines will be extracted from this population.

ANTHRACNOSE RESISTANCE

Preliminary evaluation for anthracnose disease resistance was done on 65 lines and cultivars obtained from INTSOY in 1981. Under a very severe outbreak of the disease, 10 lines and cultivars indicated field resistance. They are Tunia, Jupiter, UFV-1(BP-2), F-73-13-9-5(1), Siatsa 1204 A, Siatsa 1204 B, Davis, Caribe, IGH 23, and SJ 5. Inheritance of resistance to the disease is being investigated. However, problems encountered in the study are: (1) low resistance level found, (2) no practical inoculation technique for mass screening, (3)no appropriate disease rating system available, and (4) environmental effect is rather high on this host-pathogen system.

INSECT RESISTANCE

Sources of resistance to bean fly and pod borers were introduced from AVRDC in 1982. Resistance level and mode of inheritance of the resistance are under investigation.

HIGH SEED QUALITY

Three hardseeded lines, D 67-5677-1, D 65-8232, and D 67-5679, were crossed to BM 33, SJ 4, and PI 230970 in 1979. Almost 100 high hard seed F_6 lines were grown in the early rainy season of 1983 to expose the maturing seeds to rain. It was found that hardseeded lines did not show any advantage over normal seeded lines in terms of resistance to deterioration from rain.

ADVANTAGES OF MULTIPLE LEAFLET

Three multiple leaflet lines derived from SJ 2 were crossed to normal leaflet IGH 23, GH 29-14-3(2), TN 4, SJ 2, and SJ 5 in 1982. Some reciprocal crosses were also made. Full evaluation of their F_2-progenies will reveal advantages/disadvantages of this trait.

MALE STERILITY

In 1981, male sterile lines from Northrup King, Woodworth, Bernard, Rampage, and Williams were crossed by normal SJ 1, 2, 4, and 5. In late 1982, F_2-seeds from each cross were grown to study mode of inheritance as well as possibility of exploiting this trait in a recurrent selection program in Thailand. The results revealed that it is possible to generate a population improvement program for soybean using these genetic male sterility genes.

Kasetsart University Legume Breeding Project

Peerasak Srinives*

THE Kasetsart University Mungbean Breeding Project is also included in the Kasetsart University Master Project Number One: 'KU Research and Development Project on High Protein Crops'.

Mungbean

The mungbean breeding project was established in 1977. Research done during 1977–79 concentrated on choosing parental lines and cultivars from several hundred accessions obtained from AVRDC in Taiwan. High yield potential cultivars were identified to be PHLV 18, MG 50-10 A(Y), M 304, M 7 A, CES 37 and CES 1 D-21. Cultivars resistant to *Cercospora* leaf spot disease were ML-3, ML-5, ML-15, and PLM-448 whereas those resistant to powdery mildew disease were ML-3, ML-6, LM-156, VC 1000-45-0-10, VC 1137-14-0-10, and PLM 689.

In 1979 the project started making crosses among the chosen parents and modes of inheritance of the diseases were known. Selections on the earlier segregating generation followed either bulk or single seed descent method. Pedigree selection was applied beginning from F_6-generation. Eleven lines had multiple resistance to the diseases and present high-yielding potential. However, their seeds were rather small. Few of these lines were also resistant to root and stem diseases. Multilocation yield trials are being done to identify more stable genotypes.

In 1982 bean fly resistant cultivars (LM 031, Jhain Mung 1-4, and PLM 322) were crossed to three susceptible ones (M 7 A, MG-50-10 A(G), and CES 1D-21). The F_1-, F_2-, and backcross progenies were evaluated for bean fly reaction in the dry season of 1983. Generation mean analyses are being done to find important gene actions associated with the resistance.

A mutation breeding program was also established in 1977 by researchers from the Department of Applied Radiation and Isotope. U Thong 1 and U Thong 2 were gamma-irradiated at 30 and 50 krad. The M_2- and M_3- plants were screened for yellow mosaic virus resistance in farmers' fields at Kamphangphet Province. Since there was no outbreak of the disease, the aim of mungbean mutation breeding was switched to determining lines resistant to *Cercospora* leaf spot and powdery mildew. A few elite lines were extracted for further evaluations.

In both conventional and mutation breeding projects, an 'ideal' cultivar is identified as follows: high yield; uniform maturity; resistant to *Cercospora* leaf spot, powdery mildew, basal stem rot, and yellow mosaic virus disease; resistant or tolerant to bean fly and bruchid; high starch content (55–60%) for industrial purposes; and others, such as large shiny seed, pods extruded from plant canopy to ease harvesting, and high protein content.

Other Legumes

Peanut

The Peanut Improvement Project is included in another master project. It is presently supported by the International Development Research Centre and much work has been done so far, which is reported elsewhere.

Chickpea and Pigeonpea

Since 1982 ICRISAT has sent seeds of chickpea and pigeonpea to Master Project No. 1 as an observation nursery. Few chickpea lines performed well under Suwan Farm conditions. Most of the pigeonpea lines were perennial and grew very tall in the second year. If these perennial pigeonpeas are to be used, insect pests might become a problem since it is difficult to spray such tall plants.

Cowpea

Cowpea was tested by Kasetsart during 1974–77 and again in 1979. The materials tested were not promising, so research on cowpea has been suspended.

Dry Bean

Materials from ICARDA were tried in 1978 and 1979. Their future seemed poor because of a lack of adaptability to Thai conditions.

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Varietal Improvement of Grain Legumes at Khon Kaen University

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KHON KAEN University has been involved in varietal improvement of various grain legumes, including groundnut, soybean, mungbean, cowpea, pigeonpea, and chickpea. The degrees of involvement for the individual crops vary from a well coordinated program with work in other disciplines as well, to simply yield-testing of a limited number of varieties. The amount of activity on individual crops has also changed over time, and some have been discontinued.

Work on groundnut and soybean was earlier organised in a multidisciplinary fashion under the IDRC-supported Semi-Arid Crops Project, with sizable breeding activities. With the termination of the project in 1980, breeding work on soybean substantially reduced, and will gradually be limited to routine cooperative yield-testing with other institutes.

Groundnut breeding work increased, however, as it became part of the Thailand Co-ordinated Groundnut Improvement Program in which Khon Kaen University is one of the main participating institutes.

Breeding work on mungbean and cowpea included yield-testing of promising varieties, plus a limited amount of selection in introduced or segregating materials. Work on cowpea has increased since the ACIAR-supported legume project started in 1983. Some yield testing of a limited number of varieties was done for pigeonpea and chickpea, but this work has been discontinued.

Groundnut

Work on varietal improvement of groundnut began in 1971 with the introduction of three large-seeded cultivars from Israel. These cultivars outyielded the local check but showed a high degree of unfilled pods. In 1972, 140 more lines from different origins, mainly from the USA, were introduced. When the IDRC-funded Semi-Arid Crops Project began in 1975, and groundnut improvement became part of the project, 94 new lines were received from USDA, SEARCA, Chiang Mai University, and the Department of Agriculture. These plus the earlier introductions constituted the collection which was evaluated in unreplicated nurseries for several seasons.

Three groups of cultivars were selected from these materials for replicated yield testing— one based on one season's data, the second based on four season records, and the third based on stability analysis of data for seven seasons. Yield testing of these three groups of cultivars continued throughout the life of the Semi-Arid Crops Project (1975–80), with the number of cultivars reduced in the later years.

By the end of 1980, five cultivars had been evaluated for 15 environments, and 16 cultivars for 3 years. Superior cultivars identified were: Moket, RCM 387, Tainung No. 2, No. 15626, Argentine 8-3, and Colorado fasserdi. These, plus some other promising cultivars, were supplied to the Department of Agriculture for further evaluation in the testing scheme of the Department. Some of these cultivars are now in the Region Yield Trial, and one (Moket) was also identified by the Department as one of the leading entries in their trials and has now been advanced to the Farmer-field Trial stage.

In 1978, 30 F_2 and 10 F_3 populations were received from ICRISAT. These were advanced and selected using the pedigree method. Selections from these materials are now under the initial stage of yield testing.

The year 1982 marked the beginning of a new phase of groundnut improvement at Khon Kaen University when it became part of the Thailand Co-ordinated Groundnut Improvement Program, which is supported by IDRC and the Title XII Peanut CRSP of the USA. In formulation of the coordinated program, past research was reviewed, future research needs were outlined, and scope and emphasis of work for the individual participating institutes were specified. Apart from improving yield potential, which is

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the general aim of the overall breeding program, groundnut breeding work at Khon Kaen University will emphasise breeding for resistance to rust and *Cercospora* leaf spot and developing varieties suitable for growing before rice and after rice under rainfed conditions of Northeast Thailand. As early varieties are required in such croppng systems, emphasis will also be placed on breeding for earliness. Since the crop will normally be grown in the main rainy season, selection for varieties suitable for growing in the main rainy season will also be done. Some work will be done on the improvement of the large-seeded Virginia type. Promising varieties identified will be channeled through the standard testing scheme of the Department of Agriculture, and Khon Kaen University will be a test site for the coordinated multi-location yield trials in the standard variety testing scheme. The University was also given responsibility for acquiring new materials from ICRISAT to use in the overall breeding program.

Since 1982, significant changes in direction of the groundnut breeding scheme have been made along the guidelines specified in the coordinated program. Materials were screened under the before-rice and after-rice growing conditions, and promising materials selected for subsequent evaluations. Selection and yield-testing in the main rainy season continued; among the advanced lines, superior entries were still those previously identified, namely RCM 387, Moket, and Tainung No. 2. Disease nurseries for rust and *Cercospora* leaf spot were successfully established, and in 1982, 184 groundnut lines were screened in each nursery. Several resistant lines were identified for each disease, 13 of which are resistant to both diseases. Substantially higher numbers of lines were screened in the two disease nurseries in 1983, including materials from both the Department and the University.

A total of 201 groundnut lines was received from ICRISAT in 1982. These were multiplied and supplied to the Department and the University for selection and testing in the respective breeding stations. In 1983, another lot of 118 lines was sent from ICRISAT. The Title XII Peanut CRSP (North Carolina State University) also sent 1364 groundnut lines of diverse origins. These are now being evaluated at Kalasin and will be made available to Khon Kaen University as well (Charoenwatana et al., 1981; Laosuwan et al., 1981; and Patanothai et al., 1983).

Future programs will continue along the same lines as in 1982 and 1983. Materials will be divided into groups and channeled through the testing schemes deemed appropriate for the individual groups. New materials will be sought, and crossing will be done but on a limited scale. Exchange of materials will be made between the Department and the University for effective utilisation of materials to meet the overall breeding objectives of the coordinated program.

Soybean

The soybean breeding work at Khon Kaen University began in 1970, five years prior to the start of the Semi-Arid Crops Project. Work done during 1970–74 included evaluation of 106 soybean lines obtained from within and outside the country, yield-testing of promising varieties, and conducting an International Soybean Evaluation Trial in cooperation with the International Soybean Program (INTSOY). When the Semi-Arid Crops Project began in 1975, and soybean breeding became part of the project, most of the earlier introduced materials had been lost due to poor storage facilities. The program, therefore, was a new one at the inception of the Semi-Arid Crops Project in 1975.

During the period of the Semi-Arid Crops Project more than 1000 lines or cultivars of soybean were introduced from various countries, including the USA, the Philippines, Australia and Taiwan. These were evaluated, characterised, and screened for good agronomic traits, for resistance to bacterial diseases, and for yield. Out of these, 754 entries were maintained, of which 554 were arranged according to their maturity groups. These were later supplied to the Department of Agriculture, and are no longer maintained at Khon Kaen University.

A number of yield trials were conducted during 1976–80, some of which were conducted in one season while the others were repeated up to 4 years. Superior entries identified included Clark 63, Improve Pelican, Orba, and UPLB SY-2 (2). These, plus some more promising entries, were also supplied to the Department for further testing when the Semi-Arid Crops Project ended. Well-performing entries from this group plus 10 more lines from Khon Kaen comprised the entries tested in replicated yield trials during 1981–83.

In 1981, 290 F_4 lines were received from the Department of Agriculture. Selections were employed in these materials using the pedigree method. They are now in the F_6 generation, and the number reduced to 60.

In future, soybean breeding at Khon Kaen University will be reduced to conducting cooperative trials with other institutes.

Mungbean

Varietal improvement of mungbean at Khon Kaen University started in 1975 with an introduction of 400 lines from AVRDC. These were evaluated and promising materials selected for subsequent yield trials. In the same year, a trial of 10 entries was also received from the IRRI Cropping Systems Program, and was tested for 3 years, out of which seven lines were selected for subsequent trials.

In 1976, 13 F_3 populations were received from AVRDC and were subsequently subjected to pedigree selection. Selected lines were entered into a series of yield trials, and by the end of 1979 the number was reduced to 10.

A trial of 24 lines was again received from AVRDC in 1977, and was tested for 2 years, out of which three lines were selected for subsequent testing.

Work done from 1980 involved yield-testing of selected materials mentioned above. Superior entries identified are 5-49-1, BPI glaborus #3, CES 1F-5, 5-49-5, UN-3, and M 118.

In future, yield testing of promising mungbean will continue and will include cooperative trials with the Department if needed. No expansion of mungbean varietal improvement work is envisaged in the near future.

Cowpea

Varietal testing of cowpea at Khon Kaen University began in 1975 with a cooperative trial of 11 entries with the IRRI Cropping Systems Program. Six of these are from the USA, three from Taiwan, and two from the Philippines. In 1977, another trial of 15 entries was received from IRRI, including the tested 11 varieties previously plus four new lines of which three were from IITA and one from the USA. Repeated testing of these materials revealed Red Cowpea 6-1US as a superior entry. This variety was used in various cropping patterns testing of the Khon Kaen University-Ford Cropping Systems Project and was found to have good production potential in the northeast. It was also used in the KKU-IDRC Home Legume Process Project aiming at improving nutritional value of the diet of the rural people. These activities have led to a growing interest in cowpea at present.

Khon Kaen University has been cooperating with IITA in conducting the International Cowpea Yield Trial since 1977. IITA has been sending a trial for testing at the University every year, except in 1982. Superior entries identified in these trials are ER-7, Vita-1, Vita-3, and TVX 3516-09F.

Breeding work on cowpea has been expanded under the new ACIAR-supported legume project at Khon Kaen University.

Pigeonpea and Chickpea

In 1975, 43 pigeonpea lines were received from ICRISAT. These included 14 early-maturing lines, 14 medium-maturing, and 15 late-maturing. Four more lines and two F_2 populations were obtained from ICRISAT in 1976. The lines were grown for general observation with data recorded for some characters, and selection done in the segregating populations. As insect pests were quite serious, particularly pod borers, this work was discontinued.

In 1980, a University staff member who went to ICRISAT for short-term training brought back 58 pigeonpea lines, mainly indeterminate type. These were grown in an unreplicated nursery (3-rows, 5.5m) in early August, and data were recorded for yields and other agronomic characters. High-yielding entries in this nursery were ICP 10063 (2036 kg/ha), ICP 8827 (1746 kg/ha), ICP 10108 (1607 kg/ha), ICP 10099 (1571 kg/ha), and ICP 8775 (1556 kg/ha).

Because the University had been cooperating with the Thailand Institute of Scientific and Technological Research, which was actively doing pigeonpea breeding at that time, no attempt was made by the University to increase its work. The nursery was kept for ratooning in the following year, but there was a high incidence of sterility, mosaic virus, and no yield was obtained for most of the entries. There was also a high incidence of insect damage.

Six varieties were received from ICRISAT in 1983, two early, two medium, and two late varieties. These are being multiplied and will be used in testing of some cropping patterns.

For chickpea, a trial of some 30-40 entries was received from ICRISAT in 1975 and was tested in the dry season with irrigation. Crop growth was good and no serious disease problem occurred in the test. However, there was a very high disease incidence (blight?) in the second-year test, resulting in a heavy crop loss. No further work has been done on this crop.

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Varietal Improvement of Legumes at Chiang Mai University

THE varietal improvement of legume crops at the Faculty of Agriculture, Chiang Mai University involves mainly soybean and peanut. The objective is to develop cultivars adapted to rainfed and irrigated production systems which will permit multiple cropping. Currently, the program involves hybridisation of introduced and adapted cultivars and evaluation of advanced materials.

Soybean Program

There were six breeding populations being maintained and tested under both rainfed and irrigated conditions. These were (SJ 2 × Biloxi), (Pakchong × Soja-F 58), (Pakchong × Biloxi), (SJ 2 × Imp. Pelican), (SJ 4 × Orba), and (SJ 2 × Wakashima)/(SJ 4 × Orba). The parents were formerly selected from adapted trials under highland conditions where heavy rust incidence was observed. Branching habit, seed size and rust tolerance were the main selection criteria. The populations were evaluated under lowland and highland conditions. Additional crosses were made to include tropical materials from INTSOY and Australia and local adapted cultivars.

Peanut Program

The parental materials were identified for characters such as high seed yield, tolerance to rust and leaf spot, early maturity (100–110 days), large seed size (55–60 g/100 seeds), and adapted to highland conditions. Several crosses such as (CES 101 × PI. 346379), (Tainan 9 × PI. 346379), (Tainan 9 × PI. 295171), (PI. 346379 × Bogor 815), (Bogor 817 × PI. 295171), (PI. 162408 × PI. 295171), (Bogor 818 × PI. 295171) and (Tainan 9 × PI. 295171) were being advanced to F_5 generations.

Research activities which support the legume breeding program include the investigation of effects of specific environmental limitations on grain legumes grown as components of upland rainfed cropping systems in Northern Thailand. These are water stress, soil acidity, low temperature and the role of microorganisms on crop nutrition.

Thailand Coordinated Groundnut Improvement Research Program

Aran Patanothai*

Cooperating Agencies

- Department of Agriculture, Ministry of Agriculture and Cooperatives
- Faculty of Agriculture, Khon Kaen University
- Faculty of Agriculture, Kasetsart University

Objectives

- To develop improved varieties of groundnut suitable for cropping systems in the different regions of Thailand
- To improve production practices and post-harvest handling of groundnut for increasing yield and improving seed quality
- To coordinate research on groundnut in Thailand and provide technical support to extension

Sources of Assistance

- International Development Research Centre (IDRC), Canada
- The Peanut CRSP under Title XII, USA

Background

Groundnut is an important food legume and oil crop of Thailand. It is grown by small farmers in all parts of the country, not only providing a significant source of cash income but also being an important source of protein for the rural people. The crop is consumed in various forms, and is a major source of edible oil and of protein for animal feed.

Over 100 000 ha is planted to groundnut annually. However, planted area has varied to some extent from year to year, and has declined slightly in recent years. Yields were about 1200 kg/ha, but lower in the drought years.

The crop is grown in upland areas in the rainy season (rainfed) and in the paddy fields following rice in the dry season (irrigated), but the rainfed acreage is much more than the irrigated acreage.

The major growing regions are the North, the Northeast, and the Central Plain. In the South, isolated fields of groundnut are grown for local consumption, mainly in the young rubber replantations.

Ninety per cent of the nuts are used domestically, and about 10% are exported. However, Thailand imports considerable amounts of unrefined groundnut oil and cake. The demand is anticipated to increase substantially in the future, particularly if groundnut quality is improved and consumed products are more diversified.

Increase in production can either come from increasing yield or increasing planted area or both. At present, groundnut yield in Thailand is low compared to those of the developed countries, even when grown under irrigation. Major constraints in production are erratic rainfall (for rainfed crop), low soil fertility, improper management, insects, diseases, and weeds. Most of the farmers are poor and cannot afford high inputs. Research is needed to remove these constraints, particularly by technologies appropriate to the capital-scarce small farmers.

There are also possibilities in expanding groundnut acreage. Recent work in cropping systems has shown good prospects for groundnut in various cropping systems, some of which utilise the idle period of land at a particular time (e.g. growing groundnut before and after rice under rainfed conditions). The possibility is greatest in the Northeast where soils are poor and only a few crops could be grown successfully. Past research on groundnut has been directed towards monoculture of the crop; to be able to utilise groundnut in these cropping systems, much more research in developing suitable varieties and production technologies is needed.

Aflatoxin is an important problem which restricts the use of groundnut, both for human consumption and for animal feed. Research is needed to minimise this problem.

Groundnut research in Thailand has been done mostly by the Department of Agriculture, Ministry of Agriculture and Cooperatives, and three agricultural universities (Khon Kaen, Kaset-

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sart, and Chiang Mai). The Department of Agriculture has overall responsibility, with research areas covering all components of production technology. At Khon Kaen University, groundnut research has been part of the IDRC-funded Semi-Arid Crops Project which emphasised the improvement of groundnut for Northeast Thailand. Some of the work was also done in the closely related Cropping Systems Project. Similarly, groundnut research at Kasetsart University is part of the Oil Crops Project. Though research has been initiated in several areas, little work has been done so far. There is no organised research project on groundnut at Chiang Mai University, however, groundnut research is an integral part of some projects, particularly the Multiple Cropping Project and the Highland Project. Emphasis has been on the Chiang Mai Valley and the hilly areas in the North.

Linkage among the various agencies has been on a personal basis, and through conferences, meetings, and exchange of research reports. Work plans have never been discussed among the institutes. This led to fragmentation of research which, in many cases, is not complementary, and progress has been slow. Though there appear to be several institutes working on groundnut, each has limited personnel and resources, and many of the research personnel do not work full-time on groundnut. Realising that with this structure progress in research will not be fast enough to support the growing demand for the crop, a coordinated groundnut improvement program was formed with the aim of utilising the strengths of the individual institutes.

The initial step in organising the coordinated groundnut program was the groundnut workshop held at Khon Kaen University on October 28-30, 1981. In this workshop, production and marketing problems and prospects were examined, past research was reviewed, and future research needs were discussed. The principle of a coordinated groundnut program had also been agreed upon, with the Department of Agriculture being the core institute and the three universities (Khon Kaen, Kasetsart, and Chiang Mai) being the participating institutes in the network. Outlines of coordinated research were specified in certain fields, and a working group was formed to serve as a coordinating body.

Following the workshop, further discussions were held, and outlines of future research and scope of work for the individual institutes were specified. The coordinated groundnut program between the Department of Agriculture, Khon Kaen University, and Kasetsart University was written and submitted to IDRC and the USAID-Peanut CRSP for their support. Both donors agreed to support the program in 1982, with IDRC being the main supporter for Khon Kaen University and Kasetsart University, and the Peanut CRSP being the main supporter for the Department of Agriculture. Chiang Mai University was not included in the program mainly because there was no organised groundnut project as such, though they do have some work on groundnut as an integral part of various projects, but cooperation has been sought to ensure overall coordination.

Program and Work Plan

Breeding

Breeding work will aim at improving yield and seed size combined with resistance to rust and *Cercospora* leaf spot, the major groundnut diseases in Thailand, and resistance to *Aspergillus flavus*, the aflatoxin-producing fungus. Emphasis will be placed on developing cultivars suitable to certain cropping systems, particularly for growing before rice and after rice under rainfed conditions. Varietal testing will be done in the environments representing most of the major groundnut growing zones. Screening for tolerance to salinity will be continued, and limited work on large-seeded (Virginia) type, high oil, and 'boiled peanut' will be initiated. The project will take full benefit of breeding material generated by ICRISAT and by the IPB-IRRI Program on Varietal Improvement of Upland Crops for Multiple Cropping.

Pathology

Plant pathologists will be working closely with breeders in screening for resistance to rust, *Cercospora* leaf spot, and *Aspergillus flavus*. Screening will be done both in the laboratory or greenhouse and in the disease nurseries in the field (for rust and *Cercospora* leaf spot), utilising the techniques developed at ICRISAT. Study on seed treatment for controlling soil-borne pathogens will be continued. Other pathological work will include monitoring of groundnut diseases, and studies on virus diseases.

Pest Control

Integrated pest control will be the major aim for controlling insect pests. This requires good understanding of the life cycle, habit, alternate hosts, natural enemies, and population dynamics of the insects. More work will be done to gather this basic information, particularly in the last area. Chemical control will still be the unavoidable means for controlling insect pests. Future work on chemical control will aim at minimising the use of insecticides, and the residual effects, and reducing the cost. Combinations of insecticides and other practices will be studied, and monitoring of insect pests in the farmers's fields will be done routinely.

Nutrition

More work will be done on improvement of the fertility of acid soils. Economics of fertiliser application will be evaluated in the areas which have not been covered. Emphasis will be placed on the utilisation of rock phosphate produced within the country. Future work on fertiliser application will consider the total cropping system, not just groundnut alone as usually done in the past. Calcium application will be evaluated in those areas which have the problem of poor pod filling, and studies will be done on minor element deficiencies. Management of crop residues is also another area of investigation.

Agronomy

Agronomic studies such as plant populations and spacings have already been conducted for the main growing seasons. More studies are needed for new cropping systems, particularly when growing groundnuts before and after rice in which crop growth is expected to differ from the main growing season because of limited moisture. Suitable time for harvesting of new varieties and in new cropping systems will be studied. Land preparations to conserve moisture, ensure good crop establishment, and reduce weed population will be evaluated. Close contact will be made with the cropping system scientists to avoid duplication of work.

Weed Control

Chemical weed control is costly, but hand weeding is time- and labour-intensive, and labour shortage is a problem in certain periods. Future work will aim at reducing the cost of the applied herbicide and decreasing the time and labour requirement (e.g. partial coverage of herbicide application in combination with manual weeding). Other studies on weed management will also be conducted.

Rhizobium Studies

Research on *Rhizobium* spp. will include: selection for more efficient strains which can survive in the dry conditions; survival of the bacteria over the dry season and in submerged condition of the paddy fields; influence of environmental conditions on survival of the bacteria; media to be used as carriers in producing inoculum granular; and techniques for more efficient production of *Rhizobium* inoculum.

Postharvest Technology

The problem of aflatoxin is very much related to postharvest handling and storage of groundnut and products. The toxin-producing fungus can occur at any stage. At present, it is unclear that, under the present postharvest handling and storage system, at which stage the problem occurs most. Good understanding of handling processes and storage conditions, at various stages in relation to the fungus development, is a prime prerequisite to the development of means to minimise the problem.

Loss of viability of seed is also a problem for the farmers who save their own seed. Studies will be conducted to investigate how the farmers store their seed, and develop cheap means to store seed which can retain seed viability.

Peanuts store better in the pod, but the crop is indeterminate in growth habit. A mixture of seeds with different maturity contributes significantly to low seed viability. Studies will be conducted to examine the relationship of pod characteristics with seed quality and storage potential, and establish practical methods in grading unshelled pods for use as seed.

Initially the program did not include groundnut utilisation. However, the Peanut CRSP started its groundnut utilisation research program in 1983, and the Thai coordinated program has expanded to cover groundnut utilisation as well.

Division of Work

Division of responsibilities among the three participating institutes is shown in Table 1. In some research items in which the responsibilities overlap, division will be on the ecological zones or different parts of the studies. While the Department of Agriculture (DA) has responsibility over all ecological zones, emphasis will be more in the Northeast. Khon Kaen University (KKU) will also concentrate in the Northeast, but Kasetsart University (KU) will concentrate in the Central Plain. The work plan will be discussed

Table 1. Scope of work for individual institutes.

Research item	DA	KKU	KU	Remark
Breeding				
A. Specific Character				
1. High yield potential	**	**	**	** More emphasis
2. Earliness	**	**	*	* Less Emphasis
3. Resistant to rust	**	**		Each institute will work with different
4. Resistant to *Cercospora* leaf spot	**	**		group of material.
5. Resistant to *Aspergillus flavus*		*		**
6. Tolerance to salinity	*			
7. Large-seeded (Virginia) type			*	
8. High oil			*	
9. Good pod type for boiled peanut	*			
B. Growing Environment				
1. Main rainy season	**	*	**	
2. Dry season with irrigation	**		**	
3. Before rice (rainfed)	*	**		
4. After rice (rainfed)	**	**		
C. Variety evaluation				
1. Initial yield trial	X^R	X^R	X^R	X = participating institute
2. Preliminary yield trial	X^R	X	X	R = responsible institute
3. Standard yield trial	X^R	X	X	
4. Regional yield trial	X^R	X	X	
5. Farmers' field trial	X^R			
6. Farm test	X			Cooperate with Department of Extension
Pathology				
1. Rust resistance	**L	**F		L = lab. evaluation
2. *Cercospora* leaf spot resistance	**L	**F		F = field evaluation (disease nursery will be created at KKU)
3. Race identification of rust	*			In collaboration with ICRISAT
4. Seed treatments	*			
5. Disease monitoring	*	*		Joint project
6. Epidemiology	*	*		Joint project
7. Viruses	*	*		Different emphasis
8. Pod abnormality and unfilled pod	*			Identification of causal agent
Aflatoxin				
1. Aflatoxin resistance	*		**	
2. Other studies	*		**	
Entomology				
1. Pests monitoring	*	*	*	Joint project
2. Population dynamics	*	**		Joint project
3. Ecology of subterranean ant		*		
4. Chemical control	*		*	Emphasis on minimising insecticide use
5. Residual effects of insecticides			**	
6. Yield loss assessment		*		
7. Insect biology	*			
Agronomy				
1. Plant population and spacing	*			In new cropping systems
2. Land preparation and cultivation	*			
3. Chemical weed control	*			Emphasis on cost reduction
4. Methods of planting and irrigation	*			
5. Management practices for better pegging formation			**	
6. Farmers' field trial of recommended practices	*			
7. Lime and fertiliser responses	*			
8. Solving the problem on unfilled pods		*		
9. Other studies	*			

(continued next page)

Table 1. Scope of work for individual institutes.

Research item	DA	KKU	KU	Remark
Soils				
1. Fertility improvement in acid soils	*			
2. Economics of fertiliser application in different zones	*			Emphasis on utilisation of locally produced rock phosphate
3. Improvement of upper paddy soils in the Northeast	*			
4. Crop residue management	*			
5. Minor nutrients	*		**	
6. Identification of causal nutrients in problem areas showing nutrient disorders			**	Expect to be very much related to minor nutrients
Rhizobium				
1. Strain selection	**	*		
2. Survival of the bacteria over dry season and in paddy field		**		
3. Population changes in different croppings	*			
4. Carrying media	*	*		For granular inoculum
5. Inoculum production	**			
Postharvest technology (material to be used as seed)				
1. Relation of pod characteristics and seed quality, and establishment of grading method for unshelled pod			**	
2. Study of farmers' seed storage conditions, and means to improve farmers' seed storage to retain seed viability		**		
3. Study of farmers' postharvest handling practices prior to seed storage		*		

annually to avoid duplication and ensure close coordination.

Strong emphasis in the Northeast deserves clarification. Though groundnut acreage at present is more in the North than the Northeast, the possibility for expansion is greatest in the Northeast. The Northeast is the poorest sector of the country, and poverty is widespread. In the Fifth National Economic and Social Development Plan, the government has put a strong emphasis on equity of income and poverty eradication. To reach this goal, special attention is given to agricultural development of the Northeast. While the farmers in the North have a wide range of crops to choose, only a few crops could be grown successfully in the Northeast because of poor soil conditions. Cassava and kenaf are the two dominant upland crops in the Northeast, both of which depend primarily on the fluctuating world market. Price fluctuation has long been experienced with kenaf and now with cassava because of the restrictions of the EEC market. The Northeast farmers are greatly affected. A general solution is to provide more alternative crops to the farmers, and groundnut is one of the best. With assistance from Khon Kaen University, the

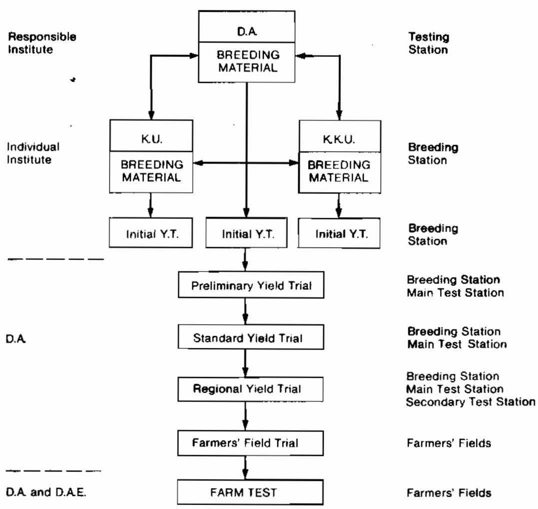

Fig. 1. Testing procedure and flow of material.

Department of Agriculture will be able to divert more of its resources to the North.

Administration

Amnouy Tongdee, Head of the Oil Crops Section, Division of Field Crops, Department of Agriculture, is the coordinator of the Coordinated Groundnut Program. He is also the coordinator of the DA Program, with assistance from research staff in breeding, plant pathology, entomology, agronomy, weed science, soil science, and microbiology.

Aran Pathanothai, plant breeder, is the coordinator of the KKU Program, with assistance from senior university staff in plant pathology, entomology, microbiology, and seed technology.

Aree Waranyuwat, plant breeder, is the coordinator of the KU Program, with assistance from senior university staff in agronomy, soil science, entomology, seed technology, and biotechnology.

Research on Diseases of Soybean, Peanut and Mungbean

Preecha Surin*

IN Thailand many governmental organisations have research projects on soybean, peanut and mungbean diseases, but the main ones are universities and the Department of Agriculture. Six branches (Oil Crop Pathology, Mycology, Virology, Bacteriology, Nematology, Seed and Post Harvest Pathology) of the Division of Plant Pathology and Microbiology of the Department of Agriculture have research projects on diseases of the above-mentioned crops. The Oil Crop Pathology Branch emphasises the research topics on survey, epidemiology and control measures. The Mycology, Virology, Bacteriology and Nematology branches study various aspects of pathogens that cause diseases. The Seed and Post Harvest Pathology Branch gives its attention to seed and postharvest disease problems.

Generally, soybean, peanut and mungbean are grown in Thailand as a second crop. Although losses of these legumes caused by diseases are obvious, no control measures are practiced by farmers, probably for economic and technical reasons.

The research project on diseases of these legumes of the Division of Plant Pathology and Microbiology can be divided into five main topics: (1) Evaluation of plant lines for sources of resistance to the following key diseases: of soybeans, rust, anthracnose, bacterial pustule, soybean mosaic virus; of peanut, rust, *Cercospora* leaf spot, and aflatoxin; of mungbean, *Cercospora* leaf spot, and powdery mildew; (2) Effectiveness of pesticides in controlling diseases; (3) Survey and epidemiology of diseases; (4) Identification and detailed study on key pathogens; and (5) Seed and postharvest pathology.

Research Results

The results of the past work can be summarised as follows:

(1) Evaluation of plant lines for source of disease resistance:

(a) Soybean

Rust: More than 1000 soybean lines were evaluated. Soybean lines that showed some tolerance were identified. In cooperation with breeders, SJ 4, and SJ 5 were released as recommended varieties for high yield and rust tolerance.

Anthracnose: Some soybean lines showed low levels of disease under field conditions; confirmation is needed.

Bacterial pustule: Source of resistance for this disease was identified.

Mosaic virus: Source of resistance for this virus was identified: SJ 6 has some resistance to this disease.

(b) Peanut

Rust and *Cercospora* leaf spot: Plants were evaluated both under laboratory and field conditions. Many lines gave low rust reaction. Some lines were tolerant to both rust and *Cercospora*; confirmation is needed.

Aflatoxin resistance: Work is in progress.

(c) Mungbean

Cercospora leaf spot: Plant lines were tested under both laboratory and field conditions. Source of resistance was identified.

(2) Controlling of diseases by pesticides: the following fungicides were recommended:

Soybean rust: Mancozeb, Triadimefon.
Soybean anthracnose: Benomyl, Mancozeb.
Peanut rust: Mancozeb, Oxycarboxin, Chlorothalsonil.
Peanut *Cercospora*: Benomyl, Thiophanate, Mancozeb.
Mungbean *Cercospora*: Benomyl, Thiophanate, Delsine.
Mungbean powdery mildew: Benomyl.

(3) Survey and epidemiology of diseases:

Diseases of these legumes were surveyed periodically: Disease occurrence was recorded, and key diseases identified.

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Epidemiology: Soybean rust epidemiology has been studied. Research is in progress. More data are needed before any conclusions can be made.
(4) Identification and detailed study of plant pathogens:

Soybean: More than 40 pathogens that attacked the plant were recorded and studied; most of the pathogens are fungi.

In cooperation with TARC (Tropical Agriculture Research Center) of Japan, the following viruses on soybean were studied: soybean mosaic virus, soybean mild mottle virus, soybean dwarf virus, soybean crinkle leaf virus, soybean yellow vein virus (was proposed as a new one), mungbean yellow mosaic virus, black gram mottle virus, and phylloidy (mycoplasma).

In cooperation with TARC, the bacterial pustule pathogen was studied in detail.

More than 25 plant pathogens were studied and recorded on peanut parts, most of them being fungi. Over 40 mungbean pathogens were studied and recorded.

In the Seed and Post Harvest Pathology program, 35 pathogens were recorded on soybean seeds; 20 pathogens were recorded on peanut seeds; 35 pathogens were recorded on mungbean seeds; and mungbean sprout rot caused by *Erwinia chrysanthemi* was first reported: Control measures were studied to help the soybean sprout production industry.

Crop Protection Research on Legumes in Thailand

Pisit Sepswasdi*

LEGUME crops, especially soybean, mungbean, and peanut, have been grown in Thailand for many years and required very little attention in terms of crop protection. Crop protection research on legumes in Thailand has been underway since the inclusion of these crops in the 5-year plan (1972-76) of Thailand's national economic and social development program. Since then the farmers have been persuaded and encouraged to grow legume crops 2-3 times a year as a second crop before or after the main crops such as cotton, corn and rice. As food was now available all year-round, recurrent pest problems were apparent in nearly every major legume-growing area. In response to the urgent need of farmers to keep the pests at an economically insignificant level, insecticides are so far the only reliable materials for this purpose.

Therefore, screening for effective insecticides to control particular key pests was the first priority. This work was to be carried out under field conditions of different seasons and locations (Sepswasdi 1976, 1981, Arunin and Sepswasdi 1980, Sepswasdi and Satayavirut 1980, and Sepswasdi et al. 1978, 1980). The level of insecticide use on legumes in Thailand is low because of possible overuse and potential ecological damage, efforts have been made to change from a purely chemical to an integrated method of control (Thanomthin et al. 1978, Thanomthin et al. 1979-81, Sepswasdi 1978, Sirisingh 1981). Our crop protection research thus emphasises the concept of integrated pest control to provide solutions to immediate problems, and to gather basic ecological information.

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Soybean Bacterial Pustule Research in Thailand

Sutruedee Prathuangwong*

SOYBEAN is mainly used for food (protein) and for oil. It has emerged as a potentially important economic crop for Thailand. Production increased from 54 300 t in 1971 to 131 500 t in 1981. However, the average yield per unit area in this period was approximately 900 kg/ha; and fluctuating yields per unit area were apparent. The Thai Government has proposed a plan to increase the production by 1986 to 540 000 t. It seems rather doubtful that the target can be reached.

Bacterial pustule disease of soybean is one of the limiting factors. It is prevalent throughout the year in all cultivated areas of soybean and all seasons, with the rainy season being the worst. The losses due to this disease are high in local cultivars, namely SJ 1, SJ 2, and SJ 4, that are commonly grown in Thailand. These soybean cultivars are very susceptible to bacterial pustule.

Soybean research on breeding for high yield production and disease resistance is carried out by the Department of Agriculture, Ministry of Agriculture and Co-operatives, and Kasetsart University. At Kasetsart University, there are three field stations: Banghken-Bangkok, Kamphaengsan Nakornprathom province, and Farm Suwan in Pakchong District in the area adjoining the Central and the Northeast regions.

The current status of research on soybean bacterial pustule, which has been carried on since 1977, is as follows:

Yield Loss Assessment

A 2-year survey program for soybean bacterial pustule in certain growing areas of Thailand was initiated in 1977. The results showed that this disease is the most destructive one. It was commonly found in all areas visited, causing high crop losses to farmers.

Wolf (1924) reported that losses due to bacterial pustule were 10–40%. In order to determine precise losses, two experiments were conducted during the dry season (November–March) of 1979 at Suwan Farm and Kamphaengsan, Kasetsart University. The results showed that the losses in yield caused through natural dissemination of the pathogen were 20.7% (482.1 kg/ha) for SJ 4 at Suwan Farm and 34.9% (396.1 kg/ha) for SJ 4 at Kamphaengsan. However, there was no natural epidemic of the pathogen during that investigation.

Description of Pathogen

Pustule bacteria were collected from all regions where soybean is cultivated. From this investigation 13 isolates were found. These isolates are rod-shaped, 0.23–0.93 by 0.57–2.59 μm. Colonies on solid media are round, curved with smooth edge, greasy, and yellow-coloured. Acid but no gas is produced when grown on various sugar-containing media. The organisms developed and grew profusely on culture broths and liquefied gelatin medium. During the observation, there was also evidence of proteinase production by the bacteria for clotting of the litmus milk test, and starch hydrolysis, indole negative, ammonia and hydrogen sulfide tests were positive. Other clinical studies on morphology, physiology and biochemical characteristics of these isolates were also carried out. The results of these studies confirmed that the causal pathogen of bacterial pustule disease was *Xanthomonas campestris* pv. *glycines* (Nakano 1919, Dye 1978).

Soybean Infection

BACTERIAL CONCENTRATION

Six-week-old SJ 4 soybean plants were inoculated with bacterial suspension of different concentrations, and the bacteria were infectious over a wide range of concentrations of inocula, under both field and laboratory conditions.

ENVIRONMENTAL CONDITIONS

Bacterial pustule disease had a high incidence and severity when the soybeans were inoculated

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between 1000 and 1200 h, and/or 1300–1500 h, the relative humidity was over 60%, and the air temperature 25–30° C. Symptoms will occur in 3–5 days if there is rainfall or water spraying within 24 h before inoculation and 4 h after inoculation and then sprayed three times with water at 2-day intervals.

AGE OF PLANTS

Soybean cultivar SJ 4 of different ages (i.e. 5, 6, 7, 8 weeks old) were inoculated with bacterial suspension at 30–35° C, and 100% RH, both in the laboratory and in the field.The results showed that all treatments were infected, but the most susceptible plant age is between 6 and 7 weeks after emergence (at the flowering stage).

HOST RANGE

The host range for the pathogen is limited to the leguminous plants. Twenty species of legumes were used for this investigation, while only six species have been successfully infected by artificial inoculation. Every species, such as lab bean (*Lablab purpureus*), groundnut (*Arachis hypogaea*), and yam bean (*Pachyrrhizus erosus*) could be inoculated with the soybean pathogen.

RESISTANCE TESTING

The resistance screening test for *X. campestris* pv. *glycines* was also conducted both in the greenhouse and under field conditions. Fourteen varieties of soybean were tested in 1977–79. Artificial inoculation was made when plants were 6 weeks old. Readings were taken 7, 14, and 21 days after inoculation. In the greenhouse at Khamphangsan Campus, Kasetsart University, Nakornprathom, the result showed that only four varieties, Clack 63, Colland, William and Jupiter, were highly tolerant to this pathogen; Davis was moderately tolerant; while TK 5, Improved Pellican, SJ 2, SJ 4, were susceptible. However, in the field trial of four varieties at Farm Suwan in Pakchong District, William and Clack were tolerant, SJ 4 was moderately tolerant, and Davis was very susceptible.

SEED-BORNE INCIDENCE

The percentage of seed-borne incidence of *X. campestris* pv. *glycines* on infected soybean plants was examined by the agar method. Four hundred soybean seeds of each variety were washed in 95% alcohol solution for 1 sec, followed by a 10-min soak in a 20% clorox, then placed in SX-agar, 10 seeds per plate. These plates were incubated in a dark room. Clear zone readings were made 2 and 5 days after incubation. The result showed that the percentage of diseased seed varied upon soybean varieties. For example: SJ 4: 7.75, Davis: 6.5, Clark: 63.60, and William: 0.75 respectively.

EFFECTS OF CHEMICALS ON BACTERIAL PUSTULE DISEASE

Four antibiotics at 500 ppm, and four fungicides at 2 concentration levels (500, 1000 ppm), were tested on *X. campestris* pv. *glycines* both in laboratory and greenhouse. Aureomycin was the most effective inhibitor in vitro. The others, chloromycetin, streptomycin, terramycin and the two fungicides vitavax and cuprous oxide at all levels of concentration gave moderate control. Captan and copper oxychloride at 1000 ppm also inhibited growth but were less effective controls than the other compounds. In the greenhouse, all of these chemicals tend to control soybean bacterial pustule disease.

In the field, five chemical compounds were tested to control this disease. Aureomycin, at 500 ppm, sprayed three times at 10-day intervals, starting 30 days after soybean emergence, was the best chemical to protect the plants and gave 21.6% higher yield than that of the control.

Treatments with four fungicides also provided higher yields than that of the control, i.e. with 20.6% more from vitavax, 19.7% more from cuprous oxide, 18.9% more from copper oxychloride, and 18.05% more from captan.

· Details are given in the Proceedings of the 1979–83 Annual Report of the High Protein Crop Research and Development Project of Kasetsart University.

Crop Protection Research on Legumes in Khon Kaen University

Sopone Wongkae*

THE ROLE of the Crop Protection Team at Khon Kaen University is to assist plant breeders and agronomists in solving pest problems affecting the legume improvement programs; to investigate specific subjects of interest relating to legume pests; and to give advice to farmers on legume pest control. The legumes involved are soybean, mungbean, cowpea, pasture legumes, and groundnuts (peanuts).

The team is comprised of: Dr Sopone Wongkae, groundnut pathologist; Dr Assanee Pachinburavan, pasture legumes pathologist; Dr Manochai Keerati-Kasikorn, groundnut and cowpea entomologist; Miss Vanla Dittapongpitch, cowpea pathologist; and Mr Niwat Banoamuang, cowpea pathologist.

The team conducts legume pest surveys in Northeast Thailand, and sets up pest-monitoring experiments to observe the disease development and population dynamics of insect pests. Members of the team also specify major destructive pests of the crops, study biological and epidemiological aspects of the pests, including their economic importance, and develop effective control measures for those particular pests.

Research Projects (1983)

GROUNDNUT PATHOLOGY

Screening for rust resistance (joint study with breeder)

Screening for *Cercospora* leaf spot resistance (joint study with breeder)

Monitoring of groundnut diseases (continuation of 1982 work)

Etiology of pod tumor disease in groundnut

Etiology of yellow mosaic disease of groundnut (joint study with the Department of Agriculture)

Race variation in *Puccinia arachidis* (joint study with DOA and KKU)

Detached leaf technique for screening rust resistance.

GROUNDNUT ENTOMOLOGY

Seasonal distribution of groundnut insect pests

Monitoring of groundnut insect pests in farmers' fields

Role of insect pests as disease vectors

Yield loss assessment due to insect pests

Evaluation of groundnut lines resistant to certain insect pests

Ecology of subterranean ant.

PASTURE LEGUMES PATHOLOGY

Survey on the microflora of Siratro seeds and their effect on seed quality

Effects of floral infection of *Colletotrichum gloeosporioides* on the seed quality of *Stylosanthes* spp.

COWPEA PATHOLOGY AND ENTOMOLOGY

Pest monitoring in cowpea

Yield loss assessment in cowpea due to insect pests.

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Study of the Potential Key Pests of Soybean in Northern Thailand

Jariya Visitpanich, Manas Tittayawan, and Vichian Hengsawad*

SOYBEAN in Thailand is produced extensively by large-scale farmers. Any significant increase in soybean production comes from several factors (e.g. an increase in land-holding capacity; the use of high-yielding varieties; improved cultural practices such as irrigation, fertilisation, crop intensification, etc.). Apart from the agronomic problems, significant damage to the crop by pests of various categories (i.e. insect, disease and weeds) presents a potential threat to soybean improvement.

More than 1500 species of arthropods were recorded in association with soybean (Turnipseed and Kogan, 1976). Cantelo and Pholboon (1967) listed eight species of insects that attacked soybean in Thailand. Sepsawad (1981) also listed 16 species of insect pests of soybean. In the northern part of Thailand, Thanormtin (1981) reported about 10 species attacked soybean. In Chiang Mai Valley, Visitpanich (1980) reported the following species as potential pests of soybean; *Melanagagromyza* spp., *Lamprosema* spp., *Aphis glycines*, *Megalurothips* spp., and *Empoasca* spp. However, current surveys in the soybean-growing area of Chiang Mai Valley have shown 21 insect species attack soybean (Table 1). Of these, about 10 species are potential key pests. It was noted that some insect species presently occur at a low population level but could become devastating when extensive areas of soybean are planted (i.e. *Empoasca* spp., *Lamprosema* spp.). These insect species are reaching key pest status. They are now causing consistent damage, and could reduce soybean production by developing resistance to insecticides.

Effective research evidence in insect pest management is almost entirely lacking. No reliable basic data of pest populations applicable to local conditions have been collected. For instance, different varieties of soybean and the same variety under different growing conditions can vary in tolerance to the 'eating rate' of the same size population of a pest. According to the generally accepted concept, a population system does not function in isolation. Its components are an expression of several factors: for example, the agroecosystem, climate, food, space, other aimals, the population itself, and other populations of the same species acting through the pathways of natality, mortality and dispersal (Andrewartha and Birch 1954). The soybean pest population is no exception.

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Tentative Work Plan

The current work plan is to develop an interim study program to supply immediate data of pest infestations. The feasibility and implementation of soybean pest management is being concurrently developed in the following areas:

Sampling and monitoring of some potential key pests and their natural enemies in the soybean agroecosystem will follow Kogan and Pitre (1979). Exotic organisms will be introduced where appropriate.

The Southwood and Reader (1976) and Varley et al. (1973) techniques will be used in the study of the population census data and key factor analysis, population trends prediction, life table, and various mortality factors expressed on key pest populations. The concept of air thermal-unit accumulations (day-degrees) as suggested by Allen (1976), Arnold (1960), Baskerville and Emin (1969), Eckenrode and Chapman (1972), will be used to develop the growth model of a key pest.

The economic injury level of each stage of soybean development and crop loss assessment will be determined.

The feasibility and practicability of cultural practices and/or pesticide management (selective and discriminate use of both biodegradable and persistent pesticides, safe and efficient chemicals, application techniques, monitoring pesticide pollution, and potential long-term pesticide effects on the ecosystem) will be developed.

Table 1. Insect species associated with soybean in Chiang Mai Valley.

Pests		Injured parts	Injurious stage	Damage
Common name	Sc. name			
Soybean stem miner	* *Melanagromyza sojae*	leaf, stem	larva	Mines petiole and stem, destroys tissue and sucks sap
Soybean root miner	* *Melanagromyza phaseoli*	stem about	larva	Attacks the basal part of stem, destroys tissue and sucks plant sap
Soybean aphid	* *Aphis glycines*	leaf, stem pod	adult nymph	Feeds on young leaves, buds and pods, sucks plant sap from outside. Transmits soybean viruses
Leaf hopper	* *Empoasca* sp.	leaf	adult nymph	Sucks plant juices, causes hopper burn leaf margins curled upward and inward
White fly	*Bemisia tabacci*	leaf	adult nymph	Sucks sap, secretes honeydew on which grows a sooty mold that interferes with photosynthetic processes. Transmits soybean viruses
Pod-sucking bug	* *Riptortus linealis*	pod, seed	adult nymph	Sucks young pods and seeds
Green stink bug	* *Nezara viridula*	pod, seed	adult nymph	Sucks young pods and seeds
One-banded stink bug	* *Piesodorus hybneri*			
Soybean leaf roller	* *Lamprosema diamenalis*	leaf	larva	Rolls and feeds inside leaves
	* *L. indicata*			
	* *Archips micaceana*			
Tobacco cutworm	*Spodoptera litura*	leaf	larva	Gregarious on under surface of leaf when young, becoming solitary when older and encroaches on leaf
Leaf miner	*Biloba subsecivella*	leaf	larva	Mines leaves
Pod borer	* *Heliothia armigera*	leaf, pod	larva	Primarily a foliage feeder, feeds predominantly on developing seed
Leaf-eating caterpillar	*Orgyis turbate*	leaf	larva	Feeds on leaves, makes large irregular holes in leaf
Soybean looper	Unidentified	leaf	larva	Defoliates leaves; a lace-like appearance
Stem borer	Unidentified	stem	larva	Bores stem, destroys tissue
Thrips	*Megalurothrips usitatus*	leaf	adult	Rasping tissue and sucks sap. Transmits soybean viruses
Beetle	*Monolepta signata*	leaf	adult	Bites and makes a small round hole in leaf
(Weevil)	Unidentified	terminal stem	larva	Attacks the terminate stem. Causes die-back.

* Potential key pest.

Sites

Five main soybean-growing areas of northern Thailand will be selected as follows: Chiang Mai, Lamphun, Lampang, Chiang Rai, and Prae. The intended duration of the investigation is 5 years. At the end of the project the follow-up study will evaluate accomplishments and adapt recommended techniques for the specific needs of the farmers.

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Soybean Diseases in Chiang Mai, Thailand

Prasartporn Smitamana*

SOYBEAN is one of the important field crops grown in the northern part of Thailand. Soybean can be grown either as an upland monocrop, a secondary crop following rice, or intercropped with plantation crops like corn. It has become a very important cash crop in many provinces in the North including Chiang Mai.

Soybean yields are affected by several factors: changes in temperature, day-length, rainfall, or soil conditions. In addition to these factors, diseases and insects are also a major problem.

The staff in this department have done some research on some major diseases, mainly in the Chiang Mai area. This study was part of this Department's contribution to a project on rainfed agriculture in the uplands supported by the Australian Contribution to the National Agricultural Research Project (ACNARP).

We started by testing for seed-borne pathogens, since soybean seeds can be contaminated with spores of fungi, bacteria, and viruses. These disease agents can reduce seed quality. They can also be a source of primary inoculum for the next season's crop and help to distribute the pathogen into areas where they may not yet be established. Samples of seed stock planted at Mae Jo Crop Research Center, Chiang Mai, and at the Multiple Cropping Research Station, Chiang Mai University, were obtained for investigation. The following fungi were found in the seed: *Aspergillus niger* and *A. flavus*, *Penicillium* spp. (all contaminants of stored seed), *Cladosporium* spp., *Fusarium moniliforme*, *Chaetomium* spp., *Nigrospora* spp. *Curvularia* spp., *Cercospora kikuchii* (purple seed stain), *Alternaria alternate* and *Collectotrichum* spp. In some seed lots *Xanthomonas campestris* pv. *glycines* (causing bacterial pustule) and some viruses (soybean mosaic virus and bean yellow mosaic virus) were found.

A number of diseases were observed after germination. The first disease to appear was downy mildew (*Peronospora manshurica*). This was followed by the most serious disease anthracnose (*Collectotrichum* sp.), then bacterial pustule (*Xanthomonas campestris* pv. *glycines*), halo blight (*Pseudomonas syringae* pv. *phaseolicola*) and bacterial blight (*Pseudomonas syringae* pv. *glycinea*). Rust (*Phakopsora pachyrhizi*) appeared after the beginning of the reproductive phase and was probably not important. Minor diseases were *Cercospora kikchii* leaf spot and target spot (*Phoma* sp.). Soybean mosaic virus, bean yellow mosaic virus, and possibly cowpea aphid-borne virus were present.

Since there is a multiple cropping project in this Faculty we hope in the future to apply the systems approach to the study of the population dynamics of some major pathogens.

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The ACIAR/University of Queensland Pigeonpea Improvement Program

E.S. Wallis, D.E. Byth and P.C. Whiteman*

PIGEONPEA (*Cajanus cajan*) is an important subsistence crop in India, Africa, Southeast Asia and the Caribbean. The dry split seed is the most commonly used. The protein content ranges from 20–25%. Although mechanised harvesting has been demonstrated (Wallis et al. 1979), the seed is almost invariably hand-harvested and there are few commercial applications of mechanised production systems.

Pigeonpea has several advantages over other leguminous crops for broadscale agricultural production. These include drought tolerance, lodging and shattering resistance, and perenniality which allows the possibility of ratoon crops. The potential exists to develop both a relatively high-priced export market for human consumption and a lower-priced feed grain market.

However, several disadvantages of the crop must be considered if broadscale production is contemplated. These include susceptibility to water logging and frost damage, a possible requirement for drying of seed after harvest, and damage due to insect pests (particularly pod borers). In addition, most cultivars are of long duration which restricts their adaptation. Crop losses due to several diseases can be serious in much of Asia and Africa.

The crop is best adapted to tropical or subtropical regions and well drained soil types. Many production systems are practiced, some of which will be discussed later in this paper.

The great diversity of habit and use of pigeonpea make its improvement a most complex and interesting challenge (Byth et al. 1981). As for most tropical and subtropical legumes, little formal plant improvement has been attempted in pigeonpea compared with the major cereal crops. This implies that relatively large genetic improvements in production can be attained rapidly. However, transfer of particular improvements between genetic materials adapted to the diverse production systems is a major problem.

Uses of Pigeonpea

Pigeonpea is an important component of human nutrition, particularly in vegetarian-based diets. The major producer is India but substantial production also occurs in Africa (Table 1).

The major use of pigeonpea is in the dry split form, often called dhal. In the Caribbean region pigeonpea is harvested and eaten as a green vegetable. Alternative uses of pigeonpea have been reviewed by Whiteman and Norton (1981). These include use as a green manure, and in animal feeding as a forage crop and as crop residues, seed and dhal mill by-products.

Table 1. World pulse and pigeonpea production 1970–80.

	1970	1974	1979	1980
	Total Pulses			
World				
Area harvested (1000 ha)	68831	71804	72303	73261
Yield (kg/ha)	701	672	680	673
Production (1000 t)	48225	48230	49141	42279
	Total Pigeonpea			
World				
Area (1000 ha)	2982	2999	3000	2951
Yield (kg/ha)	684	541	703	684
Production (1000 t)	2039	1622	2111	2017
Africa				
Area (1000 ha)	214	241	252	255
Production (1000 t)	127	136	149	153
North and Central America				
Area (1000 ha)	24	28	2	9
Yield (kg/ha)	1603	1411	2500	2222
Production (1000 t)	38	40	5	20
Asia				
Area (1000 ha)	2723	2723	2718	2656
Yield (kg/ha)	703	530	713	687
Production (1000 t)	1913	1442	1938	1824
India				
Area (1000 ha)	2655	2646	2663	2600
Yield (kg/ha)	709	532	719	692
Production (1000 t)	1883	1408	1914	1800

FAO estimates (includes China)
Source: Parpia (1981)

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Other uses of pigeonpea in human nutrition, folk medicine, and minor uses are well reviewed by Morton (1976).

Possible Systems

Pigeonpea is used in a wide diversity of farming systems internationally, mainly involving subsistence agriculture. Phenology is extremely variable, ranging from photoperiod-sensitive types grown as long-season (9–11-month) or full-season (6–8-month) to short-season (3½-month) crops of photoperiod-insensitive genotypes.

Such differences in phenology have major implications on vegetative development and canopy structure, and thus on agronomic use. The following examples demonstrate the range of systems possible.

TRADITIONAL INTERCROPPING SYSTEMS

In India most pigeonpea is grown in intercrop situations, in which late-maturing (9–11 months) pigeonpea is grown in wide rows (1–1.5m or greater) with another crop (commonly sorghum or millet) in the inter-row space. The cereal is harvested prior to flowering of the pigeonpea which then completes its crop cycle on residual moisture during the dry season.

A great diversity of intercropping systems are practiced including some in which the pigeonpea component is very low. However, Willey et al. (1981) have described intercropping systems of pigeonpea and other crops in which the intercrop yield of the other crop is not significantly reduced compared to a sole crop of that species, and up to 70% of a sole crop of pigeonpea crop can also be obtained. Such cropping systems are receiving considerable research input and appear to have potential in certain environments.

PURE CROP SYSTEMS

In general, pure crop systems are relevant to full-season and short-season genotypes although very high seed yields have been reported from pure-crop, long-season genotypes in north India. As with all pure-crop agriculture, there is a requirement to optimise plant population and arrangement if high seed yields are to be obtained.

Change of sowing date (or latitude) has substantial influence on the phenology and vegetative development of photoperiod-sensitive genetic material. As a result, large sowing date × plant density/arrangement interactions exist, and this makes management an important determinant of seed yield. For example, photoperiod-sensitive cultivars such as cv. Royes (Wallis et al. 1979), can be sown at or after the longest day (Fig. 1), in order to reduce the pre-flowering period and thus avoid excessive vegetative growth. Even then, plant population has to be varied from 50 000 plants/ha for sowing at the longest day to 250 000 plants/ha for sowings 2–3 months after the longest day, in order to obtain optimum canopy development and maximum seed yield.

Although high seed yields are possible using this production system, it has limited application in many Australian agricultural environments because of its complexity of management and because pod and seed development occurs during the coolest and driest period of the year. In warmer environments (e.g. Fiji), the production system has been successful. Ratoon cropping is feasible in favourable environments (Wallis et al. 1981) and experimental yields exceeding 4 t/ha/annum from two harvests have been achieved.

Photoperiod-insensitive cultivars that flower in approximately 60 days have recently received considerable research interest. These cultivars will flower and mature in approximately the same time regardless of sowing date, providing temperature is not limiting. Ratoon cropping is feasible (Fig. 1). Little plant improvement has been attempted in this production system so far. Despite this, extremely high seed yields have been obtained experimentally (Wallis et al. 1983), with line mean yields from a plant crop in excess of 8 t/ha under favourable conditions (Tables 2 and 3). Plant populations of 400–500 plants/ha are necessary (Wallis et al. 1981), and such canopies are suitable for mechanical harvesting.

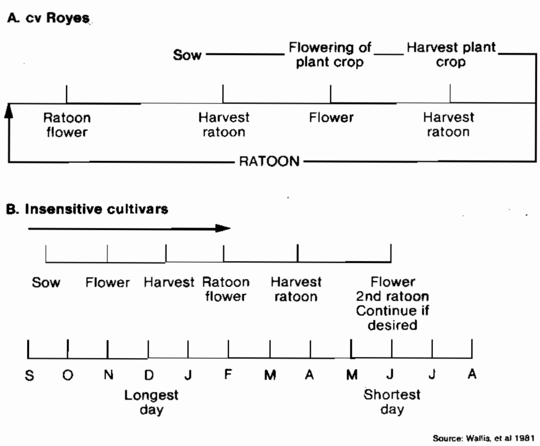

Fig. 1. Dry seed production systems for pigeonpea.

Since 1977, the program of research at the University of Queensland has been directed at the improvement of short-season photoperiod-insensitive (or nearly so) pigeonpeas.

A primary objective in this research has been to identify genetic material with high seed yield potential and which, under appropriate agronomic practices, will ensure that: (a) pods are borne at the top of the canopy, and (b) flowering and pod development are synchronised.

Simply, the pigeonpea remains, to some considerable degree, a relatively wild and undomesticated species. It is a perennial and can exhibit excessive vegetative growth and very prolonged reproduction. The above objectives were accomplished, in part, by selection of determinate genotypes and use of high plant populations which reduce branching. As a result of a relatively synchronised and short period of flowering and podding at the top of the canopy, control of insect pests can, where necessary, be achieved by a small number of applications of insecticide over a relatively short period.

Two other major objectives have been: (a) to exploit photoperiod-responsiveness of some genotypes to control the length of the pre-flowering phase and plant height, and to condition greater synchrony of flowering; and (b) to exploit the perennial nature of the crop, which can: (i) allow ratoon cropping in certain situations; and

Table 2. Yields of particular pigeonpea *(Cajanus cajan)* lines in replicated tests in various locations in 1982.

Location	Population plants/ha	Entry	Days to 50%	Seed size g/100	Yield kg/ha	Trial mean kg/ha	CV%	LSD 5%
Redland Bay	500 000	QPL67	67	9.5	6310	3800	19.8	1250
		QPL17	60	8.6	4780			
		Prabhat (Check)	60	7.2	4650			
		QPL56	60	9.5	4200			
		QPL61	69	11.7	4200			
Redland Bay	500 000	QPL31	64	11.7	3070	4200	17.6	1200
		QPL132	61	11.6	7540			
		Prabhat (Check)	60	7.0	5470			
Redland Bay	500 000	QPL503	66	11.9	8880	3200	22.8	1430
		QPL511	70	13.8	6690			
		QPL536	65	11.2	6420			
		Prabhat (Check)	60	7.2	4790			
Redland Bay	66 000	QPL246	87	-	4990	2200	18.6	680
		QPL247	89	-	4090			
		QPL242	85	-	3250			
		C322 (Check)	91	-	3160			
Kingaroy	500 000	QPL61	68	-	6310	4210	12.5	810
		QPL40	63	-	5050			
		QPL58	66	-	5030			
		QPL67	69	-	4960			
		Prabhat (Check)	62	-	3170			
Gatton	500 000	QPL67	-	9.7	5560	3730	26.1	1600
		QPL58	-	10.5	4930			
		QPL17	-	7.6	4740			
		Prabhat (Check)	-	5.4	2860			
Tamworth	100 000	QPL67	-	-	2200	1400	-	500
		QPL127	-	-	2100			
		QPL38	-	-	2000			
		Prabhat (Check)	-	-	1500			

Source: Wallis et al. 1983.

(ii) provide a homeostatic mechanism to stabilise yield where environmental or biotic factors impose stresses (e.g. drought, insects) at particular phenological stages. Perenniality enables pigeonpea to produce new flushes of flowering following the relief of such stress, and the plants can proceed to develop viable (albeit deferred) seed yields where other crops may fail. Examples of such deferred crops have been observed in subtropical Australia.

Limits of Productivity

Despite the demonstration of highly productive systems for pigeonpea culture in Australia, a number of aspects require considerable attention in research and production. Some of these follow:

ESTABLISHMENT/PLANT STAND

Where a poor stand has been obtained, photoperiod-sensitive cultivars can compensate by production of branches. However, such compensation will also induce loss of synchrony in flowering. By contrast, the photoperiod-insensitive cultivars have only a limited ability to compensate for poor establishment.

Establishment of optimal plant stands is thus a critical management factor, if the high yield potential is to be exploited and if difficulties of insect management and timing of harvest are to be avoided.

WEED CONTROL

Growth of pigeonpea is slow initially, and it is a poor competitor with weeds until canopy closure. Thus research to identify appropriate herbicides and their use should have high priority. This is of particular importance in early flowering cultivars for which narrow row culture will prevent mechanical control of weeds.

INSECT CONTROL

Pigeonpeas are particularly attractive to some insects after flowering (*Heliothis*, *Maruca*), and substantial damage can occur. Insect management is an important aspect of management. As indicated above, choice of genotype and appropriate management can reduce the duration of susceptibility to insect attack. Nevertheless, chemical control is inevitably an integral part of management, and must be justified economically in relation to potential seed yield.

Research into effective integrated pest management is required, including biological control, scheduling of appropriate chemicals, and host plant resistance. ICRISAT research is making significant contributions regarding the last aspect.

Table 3. Preliminary results of pigeonpea trials conducted in Southeastern Queensland in 1982/83.

Experiment site	Entry	Days to flower	Seed size g/100 seeds	Yield kg/ha
Redland Bay (October sown)				
Test 0	QPL17	51	8.2	5430
	QPL122	51	9.3	4670
	QPL569	52	13.8	4460
	QPL95 (Check)	50	9.0	2570
	Trial mean (n = 35)			3100
	CV %			18.3
	LSD 5%			920
Test 1	QPL131	53	10.9	4700
	Prabhat (Check)	50	7.1	4650
	QPL559	57	10.5	4470
	Hunt (Check)	64	8.5	2870
	Trial mean (n = 30)			3130
	CV %			20.7
	LSD 5%			1070
Test 2	QPL580	54	7.2	5200
	QPL39	58	10.4	4980
	QPL562	60	10.0	4400
	Hunt (Check)	65	8.5	2530
	Trial mean (n = 22)			3380
	CV %			26.2
	LSD 5%			1460
December sown				
Test 0	QPL128		8.2	4200
	QPL130		10.7	4100
	ICPL 6		6.3	4080
	QPL95 (Check)		9.1	2640
	Trial mean (n = 35)			3030
	CV %			16.5
	LSD 5%			820
Test 1	QPL40		9.6	3740
	QPL503		9.4	3600
QPL356			10.5	3440
	Hunt (Check)		8.6	2230
	Trial mean (n = 30)			2720
	CV %			17.4
	LSD %			770
Kingaroy				
Test 0	QPL146	57	7.4	2290
	QPL130	60	6.9	1820
	QPL95 (Check)	51	7.2	1630
	Trial mean (n = 5)			1850
	CV %			20.5
	LSD %			710

(continued next page)

Table 3. (cont'd)

Experiment site	Entry	Days to flower	Seed size g/100 seeds	Yield kg/ha
Test 1	QPL520	66	7.0	2750
	QPL58	60	7.2	2550
	QPL42	61	7.9	2480
	Hunt (Check)	71	6.4	1990
	Trial mean (n = 10)			2300
	CV%			14.1
	LSD 5%			550
Test 2	QPL207	61	9.0	3180
	QPL113	63	7.5	2840
	QPL61	62	6.8	2740
	Hunt (Check)	70	6.5	2620
	Trial mean (n = 10)			2710
	CV%			14.7
	LSD 5%			680
Millmerran Test 0	QPL130	60	7.7	990
	QPL146	61	7.5	940
	QPL95 (Check)	54	6.7	430
	Trial mean (n = 5)			740
	CV%			14.6
	LSD 5%			200
Test 1	QPL42	59	7.0	1060
	QPL13	57	6.6	930
	Hunt (Check)	66	6.3	910
	Trial mean (n = 10)			800
	CV%			23.3
	LSD%			320
Test 2	QPL61	61	7.1	1100
	QPL207	66	9.8	890
	QPL593	67	7.2	830
	Hunt (Check)	67	6.7	750
	Trial mean (n = 10)			760
	CV%			19.6
	LSD%			250

DISEASE CONTROL

The major diseases of pigeonpea include a *Fusarium* wilt, a *Phytophthora* blight, and sterility mosaic virus. Researchers at ICRISAT have identified genetic resistance to each of these diseases. At present, none of these diseases has been observed in Australia. However, where possible, resistance is being incorporated in local breeding populations by the use of parents known to be resistant.

SEED DRYING

Since it is perennial, pigeonpea retains green vegetative material at pod maturity. This is of no consequence with hand harvesting. With mechanical harvesting, there are few problems provided the plants are determinate with most pods at the top of the plant. However, seed drying may be necessary, at additional cost.

Research has been done at UQ into chemical desiccation of the canopy prior to harvest, with the objective of partial defoliation only in order to facilitate harvest of dry seed while still allowing subsequent ratoon growth. Further research into appropriate chemicals is required.

Current UQ Research

Several sources of funding have supported the research into pigeonpea at the University of Queensland since 1970, including Australian agencies and ICRISAT. The program is presently supported by ACIAR.

The objective of this program is to continue research into pigeonpea improvement, with particular attention to short-season production systems. The primary aim is to develop an improved scientific understanding of the basis for the high yield potential of such systems, their further improvement, and their extrapolation to other environments in Australia and elsewhere. This will involve integrated research into plant introduction, genetics and breeding, aspects of crop and plant physiology and agronomy. Close collaboration in research already exists with ICRISAT, and is being developed with the national programs in other countries.

The project is based on research in Australia and overseas, in a number of countries (including Thailand and Fiji), plus cooperation with other countries (Fig. 2).

The program now involves two full-time professional staff based in Australia plus technical assistance as well as a number of postgraduate students working at the University of Queensland.

The program outside Australia will concentrate initially on evaluation of production systems and genetic material in a number of countries. Scientists overseas contribute substantially to planning and execution of the collaborative research, and two-way visits enable close interaction between UQ staff and the collaborators in several countries.

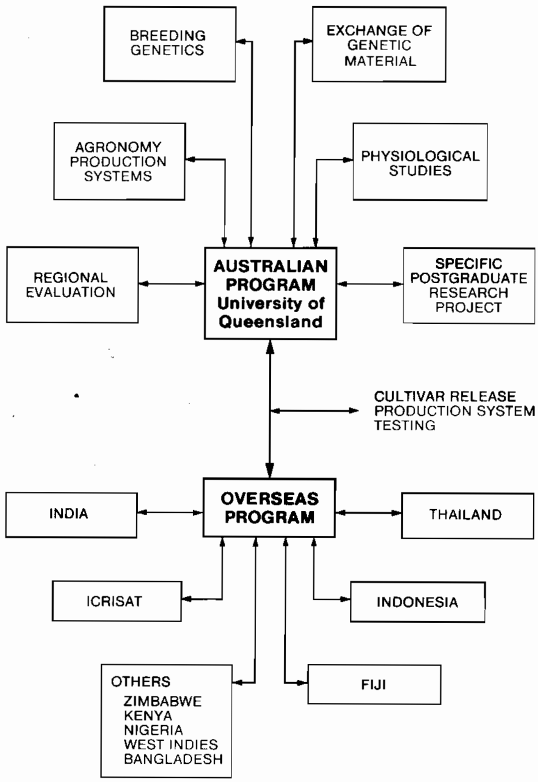

Fig. 2. ACIAR/University of Queensland pigeonpea project.

Conclusion

Pigeonpea is one of the few tropical food legumes with potential for broadscale, dryland culture in semi-arid regions. High seed-yield potential has been demonstrated in some production systems in favourable environments, and its ability to tolerate substantial moisture stresses is widely recognised.

Research is required to determine appropriate production systems for this crop in a range of environments. This should involve an objective evaluation which recognises both the potential advantages and limitations of this crop. Particular attention should be directed at cultivar adaptation and evaluation of production systems, and at the implications of perenniality, edaphic limitations and moisture availability on productivity.

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Correction of Nutrient Deficiencies of Legumes in Thailand

N. Tiaranan, S. Pimsarm, S. Claimon, and P. Punpruk*

RESEARCH on nutrient deficiencies and fertiliser response of legumes has been carried out extensively on the important economic crops, including soybean, peanut and mungbean. Limited research has been done on other leguminous crops.

The earliest report on nutrition of leguminous crops dates back only to 1968. The early research work was done on response of crops to phosphate and potassium fertilisers, secondary and minor elements including Ca, Mg, S and Mo, lime, sources of fertilisers, and fertiliser placement. Information obtained from the early research indicated that the important soil factors which affected yield of crops were soil type, soil reaction, and soil fertility, especially deficiency of phosphorus in many areas and sulfur in some areas. Recent research has emphasised the correlation between phosphate fertilisation and soil available phosphorus on yield of crops, the efficient use of fertilisers under various soil fertility levels, the use of rock phosphate and lime on strongly acid soil, and the response of each crop variety to fertilisers Tables 1-5.

Soil Texture and Drainage

The physical property of soil is considered to be the important limiting factor which affects yield of leguminous crops. All leguminous crops should grow on well drained soil, but soil texture is different. Soybean and mungbean prefer clay loam or clayey soil while peanuts prefer sandy soil. If the soil texture is not suitable, low yields will be obtained even if sufficient lime and fertiliser are applied.

Soil Reaction

Soil acidity is one of the important problems for leguminous crops in Thailand. The average soil pH ranges from 5.5-6.5, and in some areas is below 5. The critical level of soil pH for leguminous crops is around 5.5. In strongly acid soil, especially where soil has a pH level below 5.0, the average yield of the crops is reduced by 30-40%. In this case the addition of fertiliser will have little impact on yield.

Soil Fertility

In general leguminous crops do not require high soil fertility levels so responses of crops to fertilisation are not certain. Although leguminous crops require considerable nitrogen to produce their high yield, if the seeds are inoculated with *Rhizobium* only a low rate of nitrogen (about 18 kg N/ha) is sufficient. In spite of the low uptake of phosphorus, leguminous crops do respond to phosphate fertilisation in many areas. Of the three major nutrients, N-P-K, phosphorus is considered to be the most important limiting factor for leguminous crops. In some large legume-growing areas where available phosphorus content is as low as 1-5 ppm (Bray II), when fertiliser (37 kg P_2O_5/ha) was applied, soybean yield increased more than two-fold. There is a correlation between phosphorus content in soil

Table 1. Yield of soybean grown on sandy soil as compared to clay loam soil (average from four replications).

Treatment:	Average yield (kg/ha)	
$N-P_2O_5-K_2O$ (kg/ha)	Sandy	Clay loam
0 - 0 - 0	313	1800
18 - 0 - 37	419	1944
18 - 56 - 0	594	1913
18 - 56 - 37	638	1781
18 - 56 - 37 - Lime	781	1844

Table 2. Approximate amounts of peanuts nutrients required by some legumes in Thailand (primary data).

Crop	Yield (kg/ha)	Approximate amount of nutrient required (kg/ha) $N-P_2O_5-K_2O$
Soybean	1200	135 - 23 - 51
Peanut	2000	155 - 15 - 95
Mungbean	1000	69 - 14 - 32

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Table 3. Response of soybean to phosphorus and potassium fertilisation; yield average from four replications in irrigated farmers' fields in North Thailand.

K_2O (kg/ha)	P_2O_5 (kg/ha) 0	56	112	168	224	280	Mean	Soil analysis
0	681	1750	2425	2494	2543	2312	2034	pH 5.8
38	737	1900	2275	2406	2818	2606	2124	O.M. 1.30
76	668	1900	2537	2568	2763	2562	2166	Av. P 2 ppm
Mean	695	1850	2412	2489	2708	2493		K 48 ppm

Table 4. Average yield of peanut and mungbean in the fertiliser trial in farmers' field in 1982 (average from five locations).

Fertiliser rate (N-P-K)	Peanut pod yield (kg/ha)	Mungbean yield (kg/ha)
0 – 0 – 0	1506	818
18 – 0 – 38	1656	1112
0 – 56 – 38	1856	1075
18 – 56 – 0	1931	1181
18 – 56 – 38	2043	1531
18 – 56 – 76	2106	1462
36 – 56 – 38	1862	1443
18 – 112 – 38	2212	1456
36 – 112 – 76	2112	1475

soil having available potassium <40 ppm. However, if a high rate of phosphate fertiliser is applied, potassium fertiliser should be applied at the rate of 37 kg/ha for highest yield.

The suitable rate of fertiliser for farmers is 18-56-37 kg N-P_2O_5-K_2O/ha in soil having low potassium, or 18-56-0 kg N-P_2O_5-K_2O/ha in soil having a high potassium or clayey soil.

Soil Moisture

Even though the total average rainfall in legume-growing regions is about 1200 mm/year,

Table 5. Estimate of soil properties for soybean.

Soil productivity level	Soil analysis pH	O.M (%)	P (ppm)	K (ppm)	S (ppm)	Ca (ppm)	Mg (ppm)	Mo (ppm)	Al (ppm)	C.E.C. (me/100 g)
Low	5	1	8	40	4	300	60	1	400	10
Medium	5-6	1-3	8-15	40-99	4-8	300-450	60-100	1-5	100-400	10-24
High	6-7	3	16	100	8	450	180	5	100	25

and rate of phosphate fertiliser applied on yield of crops. The critical level of available phosphorus in the soil is considered to be around 8 ppm. Beyond this level fertilisation is not necessary. The economical rate of phosphate fertiliser is around 37 kg P_2O_5/ha, even if the soil available phosphorus content is as low as 2-3 ppm. If there is no other limiting factor (such as soil moisture, plant disease, etc.) yield from fertilisation should be around 2000 kg/ha. Attempts were made to compare effects of ground rock phosphate to super phosphate. Results indicated that ground rock phosphate at the rate of 1250 kg/ha can compare favourably to super phosphate at 56 kg P_2O_5/ha. In general, Thai soil does not present potassium problems for leguminous crops. Responses of potassium were found only in sandy

soil moisture content throughout the growing season is still deficient. The distribution of rainfall throughout the growing season is not consistent. Past research indicates that average yield as well as response to fertilisers under irrigation is greater than under rainfed conditions. The efficient use of fertiliser under irrigation is better than under rainfed conditions.

Economic Problems

In spite of the fact that fertiliser use in some areas can increase crop production more than two-fold, fertiliser use is still not popular with farmers. There are many factors involved, such as the high price of fertiliser, lack of capital, and the fact that farmers do not quickly adopt the technologies.

Diagnosis and Correction of Nutrient Deficiencies of Legumes in Northeast Thailand

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ONE of the most important growth-controlling factors is plant nutrients. The inadequacy of any essential element could lead to a decrease in crop production, or, on the other hand, an application of the nutrient elements in need could improve both the quantity and quality of plants. This paper summarises information, from documents held at Khon Kaen University library, on the nutrition of legumes grown in the soils of northeast Thailand. It is hoped that this will be helpful in planning future research on tropical legume nutrition in the region.

Climate and Soils

The northeast region of Thailand has a tropical savannah climate with a pronounced seasonal distribution of rainfall. The pattern of rainfall is influenced by the southeast monsoon and the low pressure systems. The rainy season extends from mid May to October. However, the amount and distribution of rainfall varies considerably. Mean annual temperature is 26–27°C with a maximum temperature of 42–43°C and a minimum temperature of 2–4°C.

The northeast region of Thailand (sometimes known as Korat plateau) consists of a relatively flat, saucer-shaped large southern basin (Korat Basin) tilted to the southeast, and a narrow, smaller northern basin (Sakon Nakhon Basin) separated from each other by hilly areas of the Phu Phan mountain range. The elevation ranges from about 280 m in the northwest to about 90 m in the southeast. It is bordered by the Mekong River in the north and east, and by the Petchabun mountains and the central highlands region in the west, and by the San Kamphaeng range and the Dong Luk scarp in the south. It covers an area of 17 million ha.

The surface of the interior of the plateau is gently undulating with low hills as well as numerous small shallow lakes. Bedrocks are sandstones, siltstones, shales and conglomerated of Triassic and Jurassic age (Pendleton 1962). In the southeast portion of this region, limestones and basalt outcrops can be found.

Parent materials of most soils in the northeast are alluvial sediments of the Mekong River, Nuun and Chi rivers and their tributaries. The deposition in varying ages alternates with erosion processes, resulting in valley-like patterns. The sedimentation and erosion cycles have left terraces which can be readily recognised in many parts of the region. Four main periods of erosion, represented by three terrace levels, were recognised by Moorman et al. (1964). These and the present flood plain predominantly determine the landforms in the northeast plateau.

Soil characteristics are closely associated with landscape features. Soils of the alluvial plains are located along the rivers and streams of the district and vary considerably in width. The wider alluvial plains show a pronounced levee-basin landscape with the textures of the alluvium being loam to clay loam, while in the basins clay to heavy clay. Most soils in the flood plain fall into the Ustifluvent Soil Group.

Most of the soils on the low terrace are usually flooded by rain water for a prolonged period and the drainage is poor. For the most part, the low terraces are dominated by the Paleaquult Soil Group.

Areas of the middle terrace are quite extensive throughout the northeastern region but are more concentrated in the northern part of the region. Topography is mainly undulating. In places where terraces are more or less complete, the geological profile of the terrace shows two distinctly different kinds of sediments, an upper sandy part and a lower clayey part. The main soil associated with this landscape is the widely occurring Paleustult Soil Group. Other soils that can be found are Quartzipsamment Soil Group.

High terrace soils occur only over a relatively small surface area of the northeast. It is the area that escaped the cyclic erosion. The surface layer

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is mostly loamy sand to sandy loam with a heavier subsoil. Most soils found in this landscape appear to fall into the Paleustult Soil Group and are characterised by well-drained oxic horizons.

The middle and high terrace are collectively called upland areas, where most of the field crops are grown.

Soil Nutrient Status

Phosphorus-deficient soils are widely spread over the northeast. An analysis of acid extractable phosphate of 32 soil profiles showed very low levels, with higher values in the surface than in the subsoil (Aitken and Topark-Ngarm 1979). Suda (1971) fractionated nine northeast soil series of upland and lowland for various forms of phosphorus. Most of the phosphorus in these soils was found as Fe-P compound. This was also confirmed by Wisit and Tyner (1971). Fe-P and reductant-soluble P were the most abundant inorganic phosphorus fractions of the Thai paddy soils, comprising about 38 and 19%, respectively, of the mean total P. The Al-P and Ca-P comprised about 5 and 4%, respectively, of the mean total P.

Under glasshouse studies, soybean growing in soil with 4.2 ppm P (by Bray II's method) responded to phosphorus application whereas soil with 11.3 ppm P showed no response (Amnat et al. 1978).

Chemical analysis of a wide range of soil profiles has shown an average value of less than 1 ppm sulphur as phosphate extractable sulphate in the soil. Very few soils had detectable levels of extractable sulphate in the subsoil below a depth of 50 cm (Aitken and Topark-Ngarm 1979). Analysis of upland soils has shown that they have very low levels of organic sulphur and that they have a low capacity for sulphate adsorption (Aitken 1979a). The consequences of this are: (1) mineralisation of organic sulphur is unlikely to provide adequate levels of plant available sulphur; and (2) sulphate in the soil will be very susceptible to leaching during the wet season when rain intensity is high. There were a number of experiments conducted to determine the extent of sulphate leaching in soils. Aitken (1979b) applied commercially available gypsum (powder) to the upland soil and vertical movement of sulphate in the soil profile was monitored after various increments of rainfall. Sulphate was rapidly leached and when applied solely as gypsum was completely removed from the surface horizons following 660 mm of rain. In a more sandy soil, it took only 225 mm to remove all sulphate at the equivalent amount of applied sulphur from the surface (Hengtrakul et al. 1978).

Nineteen soils from different terraces were extracted by three extracting solutions: 0.05 *M* HCl, 1 *M* NH_4OAc and 1 *M* HNO_3 for potassium. It was found that the extracted potassium by 1 *M* NH_4OAc and 1 *M* HNO_3 were highly correlated with dry matter yield responses of Verano stylo to addition of 100 kg P/ha (Topark-Ngarm and Aitken 1981). Amnat et al. (1978) reported that soil with NH_4Ac extracted potassium of 17.0 ppm K would respond to potassium application, whereas that with 36.8 ppm K would show no response.

Organic matter of the northeast soils was very low, being in the vicinity of 0.77–1.01 (Table 1). It is expected that the soils are also very low in nitrogen content. Besides, the nitrogen in nitrate form could be leached. Suda et al. (1974a) found that 82% of nitrate applied as KNO_3 at the rate of 150 kg N/ha was removed from 105 mm depth of Korat soil after receiving irrigated water equivalent to 112.5 mm rainfall.

Table 1. The average chemical properties of 311 northeast soil samples.

Properties	Upland	Lowland
pH	5.7	5.4
Organic matter	1.01	0.77
Phosphorus *(ppm)*	10.48	5.6
Potassium *(ppm)*	55.94	40.1

Source: Suda et al. 1974b.

Diagnosis and Correction

Various kinds of legumes have been grown in the northeast soils but only some of them were used as test plants in plant nutrient studies. They were pasture legumes, peanuts, soybean, and mungbean (the last three will be called grain legumes). The information concerning each group of legumes is as follows.

PASTURE LEGUMES

Most of the research work on pasture legumes was conducted by a group of researchers working under the Pasture Improvement Project, Khon Kaen University, Thailand (1976–81). They found that the nutrients of significance to pasture improvement in the northeast were phosphorus, sulphur, potassium, and nitrogen. Each are discussed below.

Phosphorus Omission trials in the glasshouse with Townsville stylo (Wilaipon 1976) indicated that almost all soils were deficient in phosphorus. The response to phosphorus application under a pot trial was also found in *Siratro, Centrosema* and *Stylosanthes humilis* CPI 61674 (Wilaipon 1980). Maximum yield responded to phosphorus application for a range of pasture legumes varied between 9 and 40 kg P/ha (Gutteridge et al. 1977 c; Hengtrakul 1976a and Panchaban 1976). However, many of the field trials with Townsville stylo and Verano stylo (Gutteridge 1976, 1978; Gutteridge et al. 1977 a, d; Robertson and Humphreys 1976) failed to demonstrate response to additions of phosphorus fertiliser. The lack of field response was not related to the accumulation of phosphorus in lower depths as conventionally thought (Gutteridge and Shelton 1978). It could be related to the ability of plant species to extract phosphorus from the soils. Hewitt (1978) found that Sabi grass (*Urochloa mosambicensis*) growing on Nam Phong soil responded to applied phosphorus whereas Verano stylo did not give any response.

A critical concentration of phosphorus in pasture legumes has been attempted. The critical concentration of Verano stylo (defined as the concentration of phosphorus in apical tissue at 90% maximum yield) declined sharply over an 18-week period following germination (Wilaipon et al. 1979).

Double superphosphate was normally used as the source of phosphorus since it was readily available from local markets. Since a number of rock phosphates are available in Thailand, these have been evaluated as sources of phosphorus for pasture legumes. Hewitt (1978) found that Sabi grass and Verano stylo responded to phosphorus application as rock phosphate from Roi Et in Yasothon soil but only Sabi grass responded in Nam Phong soil. Other work by Aitken et al. (1980) showed that Roi Et rock phosphate was ineffective as a source of phosphorus for Verano stylo on a range of northeastern soils, whereas Chiang Mai and Ratchaburi rock were only slightly inferior to double superphosphate.

The availability of phosphorus in rock phosphate is likely to be assessed by chemical analyses. Soonthonsorn and Aitken (1979) analysed rock phosphate from four places, viz. Roi Et, Lampang, Chiang Mai, and Ratchaburi for total phosphorus, acid extractable phosphorus, and water-soluble phosphorus. All rocks contained an equivalent amount of total phosphorus. However, both Roi Et and Lampang rocks contained relatively lower proportions of acid extractable phosphorus than Chiang Mai and Ratchaburi. On water soluble phosphorus content, Chiang Mai possessed the highest value. These analyses coincided with the Aitken et al. (1980) results. However, these were conducted in a glasshouse only. They need to be confirmed in field trials.

Sulphur Numerous glasshouse and field trials have confirmed widespread sulphur deficiency in the upland soils of Northeast Thailand.

Responses to added sulphate have been demonstrated with a range of pasture legumes, maximum yield being obtained at 20–40 kg S/ha (Aitken 1979 c, Gutteridge 1976, 1977 a, d). In terms of dry matter increase per unit of sulphur added, optimum rate of application is approximately 10 kg S/ha (Aitken 1979 c), but at this low level, consideration must be given to method of application. Experiments have shown that a split application of gypsum can give a higher yield than a single initial application (Aitken et al. 1980). Locally mined gypsum is available in large quantities and is the most appropriate sulphur fertiliser for use in the northeast.

Aitken (1979b) showed that there was practically no lateral movement of sulphate and that vertical movement was greater in the more sandy profiles. Gypsum of particle size <1 mm was leached to a greater extent than that applied as 5–2 mm and 2–1 mm particles (Aitken et al. 1980). It was concluded that the larger particle sizes would persist in the surface horizon for longer periods and that availability to plants would be increased. Aitken et al. (1980) set up two field trials to determine the effect of split application of gypsum on dry matter yield. There was a positive response to a split application at one site but not the other. A repeat of this experiment in the following year, again gave inconclusive results (Keerati-Kasikorn et al. 1981).

It is obvious that further investigation of sulphur responses in pasture legumes is warranted and that appropriate management techniques should be developed to maximise the economic benefits of additions of gypsum to the soil.

Potassium Potassium deficiency was found in many areas (Aitken 1979d; Wilaipon 1976). On application of 100 kg of potassium per hectare to

Verano stylo growing in 19 soils, eight of them exhibited significant increases in yield at each 2-month harvest over an 8-month period. Another five soils showed no response at the first harvest but gave increased yields at subsequent harvests when the initial potassium reserves had been depleted. The similar result was reported in field trials (Gutteridge 1979b). A response to potassium was not found in the first year but rather in the second.

In glasshouse studies on the effects of potassium fertiliser it was shown that potassium chloride can give rise to symptoms of chloride toxicity when used at levels greater than 200 kg of potassium per hectare (Gutteridge 1979a). By contrast, similar levels of potassium applied as potassium sulphate had no deleterious effects. An investigation of this problem in a field trial showed that the effect was much less and problems were unlikely to arise from the use of potassium chloride in a field situation (Gutteridge 1979b).

Nitrogen Establishment of legumes could increase nitrogen in soils through nitrogen fixation but this would be dependent upon plant species and soil types. Gutteridge et al. (1977g) tested four varieties of *Leucaena* in a Korat soil. The growth and nodulation of these varieties were restricted when nitrogen or inoculant was not applied. This indicated the lack of nitrogen fixation. Under the same soil type, 20 out of 21 accessions for *Stylosanthes hamata* tested could fix adequate nitrogen and produce good yields without nitrogen application (Ruaysoongnern 1978). When these accessions grew in a Nam Phong soil, only 11 could do well without nitrogen application. Subsequent field trials confirmed this result (Ruaysoongnern, 1979a, b).

Calcium Calcium application to Townsville stylo did not give any response (Hengtrakul 1976b). However, calcium in the form of lime when applied to pasture legumes was shown to affect the production. A response could be negative or positive depending on plant species. Townsville stylo gave less yield when limed whereas Verano stylo was higher yielding (Gutteridge 1977e, f). Since soils of the region are relatively acid and Verano stylo is currently one of the recommended species for the area, more field work should be undertaken in order to reconfirm the liming results.

Micronutrients There were some micronutrient deficiencies in the soils of this region. Wilaipon (1976) found copper deficiency in an omission trial with Townsville stylo on middle and low terrace soils. Hengtrakul (1976a) reported that Townsville stylo growing on a sandy soil responded to boron application at 1 kg B/ha. At this application rate, boron toxicity symptom occurred at seedling stage but disappeared after 4 weeks. In another experiment, Hengtrakul (1976b) applied molybdenum to Townsville stylo. No response was found. Further information of micronutrient status in soils of this region is needed.

GRAIN LEGUMES

Grain legumes growing in the northeast soils are peanuts, mungbean and soybean. Extensive work on plant response to fertiliser application in the northeast region has been carried out by the researchers in the Department of Agriculture.

Field trials were the main evaluation method used in diagnosing the nutrient deficiencies and correction. The focal nutrient elements tested were nitrogen, phosphorus and potassium. However there were some studies on secondary (Ca, Mg and S) and micronutrient elements (Fe, An, Mn, B, Cu and Mo).

Although there have been quite a number of field trials conducted in the soils of this region, conclusive statements made from the reported results were difficult to obtain. This might be partly due to the fact that most of the trials were conducted in Department of Agriculture stations and most were concerned with measuring only plant responses to fertiliser application.

At Mookdahan Experiment Station where the soil was classified as Korat Series, the soil appeared to be fertile. There was no response of mungbean to the application of nitrogen up to 75 kg/ha (Sutin et al. 1977); of soybean to the application of phosphorus up to 50 kg P/ha (Nouy et al. 1977a, b, and Satien et al. 1977a); of peanuts to the application of phosphorus up to 75 kg P/ha (Satien et al. 1977b); of soybean to the application of potassium up to 60 kg K/ha (Nouy et al. 1977a, b; Satien et al. 1977a): and of peanuts to applied potassium up to 93 kg K/ha (Satien et al. 1977b). Within the same area, Nouy et al. (1976) found a highly significant response of soybean to potassium at 30 kg K/ha. Suwapan et al. (1975 a, b) did not find any response to molybdenum or sulphur application at this site even though sulphur tended to give relatively higher yield. These results have limited application in defining broad recommendations for fertiliser use on crops in the area because of the very narrow soil resource used.

However, there were some results obtained from field trials in the Department Experiment Station as well on farmers' fields. Kanchit et al. (1974, 1976) obtained yield increases of soybean to sulphur application in upland soil, the average increase being in the range of 10–24%. In other upland soils, there was a decrease in yield of soybean when sulphur fertilisers were applied (Kanchit et al. 1976, 1977). The decrease was explained in terms of past fertiliser use on soils at the experimental sites. Sulphur response appeared to be obtained in most farmer's areas but very seldom in the Department Experiment Stations. They concluded that soils of sandy texture or low organic matter content at the surface with a prolonged period of exposure to leaching were likely to be sulphur deficient. The recommended rate of sulphur fertiliser was the minimum of 12–19 kg S/ha (Kanchit et al. 1977).

There are various sources of sulphur fertilisers available. Kanchit et al. (1975) compared different sources of sulphur fertilisers, viz. elemental sulphur (100% S), ammonium sulphate (22% S), double superphosphate (5.5% S), gypsum (18.6% S), sodium sulphate (22.6% S), and sulphur-coated urea (18% S) on soybean. Ammonium sulphate appeared to be the most effective in terms of seed and stover yield. Other fertilisers which gave similar results on soybean were elemental sulphur, gypsum and double superphosphate, whereas sulphur-coated urea was the least effective. The other different results were reported by Kanchit et al. (1974) and Santi et al. (1976). They found that double superphosphate was the best; sodium sulphate was the worst whereas the other four sources were almost as good as the double superphosphate. Thus, the best sulphur fertilisers have not been determined as yet.

In a long-term experiment for 3 years on Korat soils at Northeast Agriculture Centre, yield of soybean was not affected by application of either lime or chemical fertilisers. But by application of an organic fertiliser in addition to an inorganic one at the rate of 12.5 t/ha each year, yield increased substantially with organic fertiliser from 313 kg/ha up to 1688 kg/ha (Nouy et al. 1974). However, at the same location and treatment, when the test plant was peanuts, the yield was not more efficiently affected by nutrients from the soil. In addition, Terd (1974, 1976) did not obtain any response in peanuts to lime application.

However, some uncertainty about the effect of lime on the northeastern soils was created by Suwapan et al. (1975). They reported a response, although insignificant, in soybean to application of both lime and magnesium applied as magnesium chloride.

Very little information has been obtained on the status of micronutrients in the northeast soils. With grain legumes, molybdenum appeared to be the only micronutrient investigated. Suwapan et al. (1975 a, b) obtained a yield increase from molybdenum application in Korat soils, but in other areas no response was obtained (Kanchit et al. 1976, Pichit et al. 1977). Due to lack of supportive data, an explanation for these results could not be made.

Conclusion

For pasture legumes, the major nutrient deficiencies in the northeast soils are phosphorus and sulphur. Potassium is likely to be a deficient element. Some micronutrients could also be deficient. However, less work was conducted on micronutrients. To correct the deficiencies in pasture legumes, for phosphorus and sulphur, the recommended rates varied between 9 and 40 kg P/ha and between 10 and 40 kg S/ha respectively. Source of phosphorus fertiliser tested was gypsum. The comparison among various sources of sulphur has not been made yet.

For grain legumes, it was likely that phosphorus, sulphur and potassium are the major nutrient deficiencies. Nitrogen was also needed in order to increase yield. Less information was obtained on micronutrients. The results on level of nutrients to be applied to the plants was inconclusive.

Future research could be directed towards the following: (1) Soil test values; both critical level of soil nutrients and other properties should be investigated to assist correct fertiliser recommendations; (2) The status of soil micronutrients in the northeast region should be investigated in detail; and (3) The nutrient studies should be extended to soils of diversified areas.

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Rhizobium Research Activities in the Department of Agriculture

Yenchai Vasuvat and Nantakorn Boonkerd*

RHIZOBIUM research and inoculum utilisation for economic leguminous crop programs have been conducted in the Department of Agriculture for over 25 years. Prior to 1972, however, research activities were concentrated on green manuring legumes for increased yields of corn and cassava. Rhizobial strains used at that time were from the USA.

Since 1973, intensive isolation and selection of strains obtained from many locations have been conducted. From 1973 to 1975 research focused primarily on soybean rhizobia (*Rhizobium japonicum*), because average yields of soybean were relatively low and most soils were likely to be devoid of naturally occurring soybean rhizobia. Strains of *R. japonicum* from USA, Japan, and Thailand were selected for effectiveness with local recommended soybean cultivars. Preliminary screening was performed in glasshouse-leonard jars, with effective strains undergoing reselection under field conditions in various locations and seasons. The most satisfactory strains were then used for production of inoculum which was used for other research programs and distributed to interested institutions and farmers.

In addition, other aspects of the *Rhizobium*/legume symbiosis were investigated. Research projects included: rhizobial strain competition; effects of applied N, P, Mo, and lime on N-fixation; effects of seed-applied insecticides and herbicides on survival of rhizobia; rhizobial survival under flooded conditions; effects of diurnal fluctuation and defoliation on N-fixation; and evaluation of inoculum size and methods. *Rhizobium* strains for mungbean and peanut were evaluated in addition to those for soybean.

As a result of these research projects and the demonstrated importance of rhizobia to economic leguminous crop production, the Thai Government, through the Ministry of Agriculture and Co-operatives, decided to commit to a USAID loan fund for establishment of a commercial inoculum production plant. Management and coordination is supplied by the Department of Agriculture, with buildings supplied by the Thai Government and equipment for research and inoculum production from the loan fund. At full capacity, the plant will produce approximately 200 t of inoculum per year, enough for inoculation of 200 000 ha.

International collaborative research programs have also been an important aspect of activity within the Soil Microbiology Branch. A joint research effort with Texas A&M University, started in 1978, includes evaluation of survival and effectiveness stability of cowpea rhizobia under temperature and moisture stress, and field evaluations of effective/ineffective strain ratios on nodulation of peanut and cowpea. A 5-year collaborative project with North Carolina State University (NCSU) on various aspects of peanut *Rhizobium* under the Collaborative Research Support Program (CRSP), was started in 1983. Participation in an International *Rhizobium* Inoculation Trial, coordinated by ICRISAT, involves field evaluation of the interaction of rhizobia strains with local peanut cultivars. In cooperation with the NifTAL Project, participation in an International Network of Legume Inoculation Trials since 1980 has involved field evaluations of inoculation on soybeans, mungbean, and peanut. NifTAL and the Department of Agriculture recently signed a memorandum of understanding establishing the Soil Microbiology Branch as a Biological Nitrogen Fixation Resource Centre for Southeast Asia. Services which will be extended from the Centre include: adaptation of BNF technology to specific local conditions with resource and research support; distribution of communication materials (including a regional BNF newsletter, extension materials, publications, etc.) designed to link efforts in BNF research and promotion; and training programs oriented to regional needs, with emphasis on inoculum production and extension. All aspects

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of biological nitrogen fixation research, including that on *Azolla*, Blue-Green algae, associative N-fixation, and the legume/*Rhizobium* symbiosis, will be supported.

In addition to its research programs, the Department of Agriculture also collaborates in international training programs. Training programs already completed include: a 6-week *Rhizobium*/legume technology training course in collaboration with NifTAL for participants from the Southeast Asia region in November 1982; a 3-week course in Blue-Green Algae technology for participants from SE Asia sponsored by FAO in February 1983; and a 2-week course on *Rhizobium* for Thai extension personnel cosponsored by NifTAL and NCSU in May 1983. An intensive 3-month training session for participants from Indonesia and Philippines, sponsored by the Microbiology Resources Centre (MIRCEN), was completed in September 1983.

At present, interests within the Soil Microbiology Branch, Division of Soil Science, Department of Agriculture, cover a wide range of applied and basic research on various legume crops and tree species. Collaboration between institutions within the country is becoming more important as the use of BNF technology increases, and future research done within the Soil Microbiology Branch will depend greatly on this collaboration.

Research on *Rhizobium*-Legume Symbiosis In Khon Kaen University

Banyong Toomsan and Juckrit Homchan*

RESEARCH on *Rhizobium*—legume symbiosis in Khon Kaen University began a decade ago during the active phase of KKU-IDRC Semi-Arid Crop Project and KKU Pasture Improvement Project.

Little *Rhizobium* research on grain legumes was carried out before 1983, apart from the field inoculation trial of various varieties of soybean in 1972 on the university farm. However, at present, studies are in progress on peanut and cowpea, the former in collaboration with the Department of Agriculture and the latter sponsored by ACIAR, through the University of Queensland.

Research on forage species involved mainly assessing a number of introduced forage species for their inoculation requirements when grown on typical soil types of northeast Thailand. The results obtained so far are summarised and the future research on *Rhizobium*—legume symbiosis in Khon Kaen University discussed.

Past/Present Studies

GRAIN LEGUMES

Only a few *Rhizobium* studies with grain legumes had been done at KKU, due to the lack of trained personnel and facilities. Charoenwatana et al. (1975) reported the responses of five soybean cultivars to inoculation with three *Rhizobium joponicum* strains. All cultivars showed yield increments due to inoculation over the uninoculated control treatment (Table 1).

The above-mentioned experiment was conducted in cooperation with the Applied Scientific Research Co-operation of Thailand. Nodulation failure following soybean seed inoculation was always a problem at the KKU farm (Chareonwatana et al. 1975). The authors attributed the failure to poor inoculation technique.

There was virtually no groundnut *Rhizobium* work done at KKU prior to 1983. Our groundnut *Rhizobium* work began in July 1983. It forms one part of the Groundnut Improvement Project, sponsored both by IDRC and Title XII Peanut CRSP Program. Our groundnut *Rhizobium* program is a collaborated project among KKU, DA and NCSU. We are now conducting field experiments to study groundnut response to different rates of inoculation and different *Rhizobium* strains. We have begun to monitor the extent of *Rhizobium* in a paddy field and we will continue this monitoring on a monthly basis. We are also isolating nodule bacteria from nodules of different legumes hoping to get some good groundnut *Rhizobium* strains.

Cowpea *Rhizobium* work has not been done until recently. It is now a part of a project called Development of Legumes for Farming Systems in Northeast Thailand, sponsored by ACIAR through the University of Queensland, Australia. We are now conducting a field experiment to see the response of cowpea to different cowpea-type *Rhizobium* strains.

FORAGE LEGUMES

The research on symbiotic aspects of *Rhizobium* and forage legumes commenced some 7 years ago during the active phase of the KKU Pasture Improvement Project. A number of introduced forage legumes were assessed both under glasshouse and field conditions for their inoculation requirements. The soils adopted for the majority of studies were Korat and Namphong series. There were fewer cases in which Roi Et soils were used, because Korat and Namphong soils occupy relatively large upland areas of northeast Thailand on which pasture establishment is more feasible. The importance of Roi Et soil, on the other hand, has been realised as a result of an attempt to utilise the remaining soil moisture content for the establishment of some forage legumes following rice harvest. In various studies, the inoculation requirements of different forage species were evaluated on the basis of their relative growth (i.e. dry matter yield) on the aforementioned soil types. The treatments imposed were either:

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Table 1. Grain yield (kg/ha) of five soybean varieties inoculated with three strains of *Rhizobium* at Khon Kaen in 1972 (Charoenwatana et al. 1975).

Soybean variety	*Rhizobium* Strain				Mean
	Control	Chennat	Subpaton	CB 179's	
Acadian	1567	2287	1670	1870	1848a*
Davia	1343	1470	1823	1231	1467b
Geduld	1137	1327	1458	1307	1307b
SJ-2	1763	1788	2040	1953	1886a
Taichung	767	1343	1550	1457	1278b
Mean:	1316	1641	1708	1564	
	b	a	a	a	

L.S.D. (0.05) variety × strain 989 C.V. (%) 20.5

* Any two means not followed by the same letter differ significantly at the 5% level of probability.

Set 1 −N (uninoculated)
+N*

or

Set 2 −N (uninoculated)
+N*
+inoculation with appropriate *Rhizobium*

or

Set 3 −N (uninoculated)
+Basal**
+Basal and N*
+Basal and inoculation with appropriate *Rhizobium*

* 100–150 kg N/ha

** 40 kg P, 100 kg K, 25 kg S, 0.5 kg B, 3 kg Cu and 0.4 kg Mo/ha respectively

In general, marked variation was noted within the same as well as among different forage species. According to the results obtained by various workers, the forage legumes assessed could be divided into three groups:

(1) Species of forage legumes which nodulated effectively with indigenous strains of *Rhizobium* in Korat, Namphong or Roi Et soil

Stylosanthes spp.
S. humilis
S. hamata (cv. Verano, C.P.I. 55802, 55804, 55809, 55813, 55823, 55828, 16831, and 17871)
S. scabra (C.P.I. 34925 and 40205)
S. guianensis (cv. Cook)
Peuro (*Pueraria phaseoloides*)
Sun hemp (*Crotalaria juncea* Thai var.)
Crotalaria lanceolata
Sources: Homchan 1977; Ruaesoongnern, 1977, 1978, 1979; Shelton, 1977.

(2) Species of forage legumes which nodulated effectively on Korat soil but *Rhizobium* inoculation is required for effective nodulation on Namphong soil.

Stylosanthes hamata (C.P.I. 55812, 55820, 55822, 55824, 55825, 55826, 15830 and 20671)
S. scabra (cv.Seca and C.P.I. 55872)
S. viscosa (C.P.I. 34904)
S. guianensis (cv. Endeavour and C.P.I. 55872)
Sources: Ruaesoongnern, 1977, 1978, 1979.

(3) Forage legume species which showed positive response to *Rhizobium* inoculation (Table 2).

Table 2. Forage legumes which showed positive responses to *Rhizobium* inoculation.

Legume	Soil type		Sources
	Korat	Roi Et	
Leucaena leucocephala	+	NA	Homchan 1977
Cyamopsis psolaloides	NA	+	
Lablab purpureus	NA	+	Shelton 1977

+ = the soil on which the legumes were assessed.
NA = not assessed.

Future Research Plans

GROUNDNUT

Since the groundnut *Rhizobium* project is a collaborative one between KKU, DA and North Carolina State University, we will be concentrating on the research topics outlined previously in the Proceedings of the Second Groundnut Research Workshop for the year 1982 (Patanothai 1983). Table 3 shows the research topics and responsible institutes.

Table 3. Original outline of scope and emphasis of groundnut *Rhizobium* work for the two main participating institutes in the coordinated groundnut program.

Research topic	DA	KKU
1. Strain selection	**	*
2. Survival of *Rhizobium* over dry season and in paddy field		**
3. Population changes in different cropping	*	
4. Carrying media	*	*
5. Inoculum production	**	

** More emphasis; * Less emphasis.

COWPEA, LEUCAENA AND STYLO

The investigation on the symbiotic aspects of these legumes has been included within the scope of the KKU/ACIAR/UQ research project. The plans for future research are involved mainly with assessing a number of native and introduced varieties of cowpea and *Leucaena* for their inoculation requirements. Various aspects of *Rhizobium* ecology such as persistence and population dynamics of the introduced *Rhizobium* strains under prevailing soil and climatic conditions of northeast Thailand will also be investigated.

In the hope of bringing this knowledge and technology to the farmers, the KKU *Rhizobium* research team is always prepared for mutual exchanges of experience and ideas with teams from other institutes.

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Ecological Studies of Root Nodule Bacteria: An Australian Approach

R.J. Roughley*

ECOLOGICAL studies of rhizobia in soil were developed in Australia in response to the repeated failure of legume crops at many sites in New South Wales in the 1950s. Many of these failures could be attributed to attempts to grow new, little-known legumes, to exploit harsher environments, and to establish pasture in rugged country by aerial seeding.

During this time and subsequently, the following questions were posed by both extension and research workers: Is it possible to predict the need to inoculate? How does one select more suitable strains of rhizobia and what criteria should be used to evaluate them? How does one produce a reliable, high-quality seed inoculant? How does one improve their survival on seed? How can one best introduce rhizobia into the soil? What was their subsequent fate in the short- and long-term?

An approach we have found useful, once a suitable strain has been selected, is to study rhizobia quantitatively. We therefore count rhizobia in soil and in inoculants, we follow their survival on seed with time, and we count their numbers in the rhizosphere and the number of nodules they form compared with those rhizobia naturalised in the soil.

Such studies have given some insight into how many organisms need to be inoculated onto seed to provide nodules on plants to be established in a range of environments. Further, how the environment, or the method of inoculation, may be modified to favour survival and multiplication of rhizobia is now better understood. It is my experience that these same questions are being asked in many countries now. Some are still unanswered in Australia; new ones have since been posed.

In considering a generalised program on ecology of rhizobia which may be of interest in developing countries, and for which Australian scientists have some experience, the following aspects are included.

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1. Assessing need to inoculate

There are a number of instances where research and development programs have begun with selecting strains of rhizobia and preparing inoculants before establishing whether particular legumes respond to or require inoculation. This information can be obtained from simple, replicated field trials comparing the growth and nodulation of the legume where sown without inoculation, with inoculation and with combined nitrogen. Results of such trials would provide guidance as to the criteria required to select suitable strains for inoculants.

2. Selecting suitable strains

The prime requirement is that the strain be effective in fixing nitrogen with the selected host. However, other characteristics such as the ability to compete with less effective strains in the soil or ability to multiply and survive in the soil may also be particularly important.

3. Inoculant production

There are three main aspects to production of high-quality inoculants: (i) Identifying a suitable carrier material (e.g. peat). This includes availability and ease of preparation but is mostly concerned with its ability to promote multiplication and survival of rhizobia; (ii) Suitable fermentor technology to allow consistent production of pure cultures of rhizobia containing 10^9 cells/ml; and (iii) Implementation of a suitable program of quality control and nominating standards which reflect both the level of manufacturing technology and the agronomic demands on numbers of rhizobia.

4. Use of inoculants

Some forms of inoculant do not provide adequate protection for the rhizobia on inoculated seed. Thus it is necessary to evaluate methods of applying rhizobia to seed and soil to ensure that high numbers are present when seeds germinate. Methods vary and depend on crop husbandry.

5. Ecology of *Rhizobium*

Evaluation of the success of selected strains of *Rhizobium* is an aspect of understanding the field ecology of *Rhizobium*. In the first instance identification of *Rhizobium* from nodules provides an assessment of the success of inoculant strains. This is important when it is known that native (and often inferior) strains are present in the soil. The techniques used for identification are usually serological typing or antibiotic marking. These techniques can be used to evaluate native strains also, but development of newer techniques of DNA and protein band gel electrophoresis patterns have potential for studying changes in rhizobial populations, and providing an insight into the question of why many selected strains of *Rhizobium* fail to persist in new soil environments.

These programs may be considered as a series increasing in complexity from 1-5. Which is most appropriate for a given country or region will depend on the amount of care taken in previous research.

For a successful outcome it is essential that program 1 is not neglected if the answers to the questions it poses are not well defined. Should inoculation prove necessary, experiments to cover the points raised in program 2 may be considered, perhaps using inoculants produced overseas. If inoculants are produced locally, do they contain sufficient rhizobia and are they subjected to rigorous quality control? It may be that the need for consistent high quality inoculants is the most pressing problem. If so, the investigation may begin with program 3 and 4 combined.

Should the main problem be one of competition from poorly effective strains, program 5 plus selection of more competitive strains in program 2 may be the appropriate strategy.

The Mineral Nutrition of *Rhizobium* as a Factor in Considering the Mineral Nutrition of Legumes

M.J. Dilworth*

IN any consideration of the effects of mineral deficiency on nodulated legumes it is important to know how the two partners — plant host and *Rhizobium* symbiont — are affected. The mineral nutrient status of a particular soil can affect *Rhizobium* at a number of different stages of nodule formation and function, some of the more important of which are: (a) survival and multiplication in the soil itself; (b) colonisation and multiplication in the rhizosphere; (c) infestation (in which calcium is clearly involved); and (d) nodule development and function (examples are requirements for iron for nitrogenase and leghaemoglobin production, and for molybdenum for nitrogenase synthesis).

It is important for our understanding of the way mineral nutrition affects the nitrogen fixation system of nodulated legumes to know which of these particular processes is affected, and if possible which of them is most important.

Once the nodulation process proceeds past the early steps of stage (c) the symbiotic rhizobia are completely enclosed by plant tissue and therefore completely dependent on a supply of mineral nutrient through the plant. Two situations exist in this supply system.

In the first, when the rhizobia are enclosed in the cellulose infection thread, they are dependent on mineral nutrients which are outside the plant cytoplasm and presumably associated with cell wall materials.

When the rhizobia are later released into cortical cells by a process of endocytosis, they are surrounded by a plant membrane which is initially derived from the plant plasmalemma. Because of this origin, the membrane surrounding the individual bacteroid (the peri-bacteroid membrane) is essentially 'inside-out' with respect to the plasmalemma. As far as the bacteroid is concerned, it is on the outside of the plasmalemma, a membrane which is designed to prevent the egress of substances the plant requires. For the bacteroid to receive supplies either of carbon compounds or of mineral nutrients, such substances must cross the peri-bacteroid membrane going in a direction which is not the natural one. The properties of the peri-bacteroid membrane are therefore important in deciding whether a mineral nutrient present in the plant cytoplasm is available in adequate quantities for the functioning of the enclosed bacteroids.

A further problem worth tackling is the assessment of the mineral nutrient status of the bacteroid inside the nodule. This can best be studied by establishing for laboratory-grown cultures parameters which indicate whether the cell is limited for a particular nutrient, and then determining how the bacteroid behaves for those parameters.

Establishing the requirements for particular mineral nutrients can be done in several ways, the first of which is simple measurement of the growth rate in cultures with varying concentrations of the nutrient in question. This approach is complicated by the depletion of the nutrient consequent on increase in bacterial cell mass; in practice this means that populations can only be followed at very low cell densities where depletion is not a serious problem. However, the cell densities must then be monitored by viable counting, which is tedious.

A second approach is to use a batch culture growth system in which nutrient depletion is countered by some mechanism replenishing used nutrients. An example of this approach is the use of phosphate absorbed onto iron oxides as a means of buffering low concentrations of phosphate in batch cultures, used by Cassman and others in their studies of the phosphate requirements of rhizobia. In this particular case, the iron oxide-phosphate was separated from the actual bacterial culture by a dialysis membrane, so that as phosphate was removed from the main culture compartment, replacement phosphate diffused from the dialysis bag and was replenished there

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by solution from the iron oxide complex. With this approach it has been possible to show that rhizobial strains differ in their growth response to low phosphate concentrations.

Another quite different approach is to use continuous cultures (chemostats) in which nutrient-containing medium is steadily fed into a culture vessel from which an equal volume of culture is pumped out. Given that the mineral nutrient being studied is the limiting nutrient, the cells will remove as much of the added nutrient as their transport systems will permit, and leave only a critical concentration behind. It follows that if the particular nutrient is indeed the limitation to growth, an increase in the amount of nutrient supplied must result in an increase in the equilibrium cell density achieved in the chemostat.

Studies on the mineral nutrition of rhizobia under continuous culture conditions allow the experimenter to:

(1) determine the mineral nutrient concentration remaining in solution when the culture is under mineral nutrient limitation, thus giving an indication of what soil concentrations of that nutrient may limit growth in the soil or in the rhizosphere;
(2) establish the physiological results of nutrient limitation under conditions where the cells are all in the same physiological state. Such parameters may include cellular concentrations of the nutrient in particular forms, or other qualitative changes in cell morphology or composition; and
(3) determine the physiological results of nutrient limitation on various enzymatic or other components of the cell, e.g. perisplasmic proteins.

Application to Phosphate and Cobalt

PHOSPHATE

In phosphate-limited chemostat culture of the fast-growing cowpea strain NGR 234, a number of changes can easily be recognised relative to the same strain grown under phosphate-excess conditions. Phosphate limitation results in a decrease in cellular polyphosphate and inorganic phosphate concentrations. There is a marked depression of the transport systems for both inorganic phosphate and glycerol-1-phosphate, and of the periplasmic enzyme alkaline phosphatase. In extracts of the periplasmic proteins from this strain, a number of proteins are specifically depressed in phosphate limitation, while others appear only to be induced under phosphate excess growth conditions. These parameters allow us to recognise the typical profiles for phosphate-limited or phosphate-excess cells.

When snake beans (*Vigna unguiculata* subsp. *sesquipedalis*) were grown in solution culture under phosphate-deficient and phosphate-normal conditions, growth was decreased to about 50% by phosphate deficiency. When bacteroids were isolated from nodules on both types of plants, the polyphosphate and inorganic phosphate concentrations in them were both at a level characteristic of phosphate-excess continuous cultures. Further, the phosphate and glycerol-1-phosphate transport systems were at a low level of activity characteristic of phosphate-excess cultures. While a low level of alkaline phosphatase activity was demonstrable, it was very much below the level found in depressed cells and was unrelated to plant phophate supply.

These results suggest that although a plant may be markedly phosphate-deficient in terms of growth, the bacteroids have access to adequate phosphate to meet their requirements.

COBALT

Cobalt deficiency presents an entirely different picture. In sweet lupins (*Lupinus angustifolius*) cobalt deficiency results in a dramatically altered nodulation pattern. The normal plant forms the bulk of its nodules on the top 10 cm of the root (crown nodulation) and only forms lateral root nodules at a late stage of plant growth. The cobalt-deficient plant forms very little crown nodule material but produces a ten-fold greater mass of lateral root nodules, mostly of very low nitrogen-fixing activity.

Cobalt does not exert effects on rhizobial multiplication in the soil or in the rhizosphere. The primary effect of deficiency is a lowering of the number of nodule initials and such nodules as develop have very much lowered concentrations of bacteroids. The low bacteroid number appears to be associated with defective synthesis of vitamin B_{12} and consequent effects on bacteroid multiplication.

However, analysis of the nodules shows that even in extreme deficiency less than 10% of the cobalt in the nodule is actually in the vitamin B_{12} form, while under cobalt-normal conditions this value falls to 1%. What this implies is that in deficiency 90% of the cobalt is unavailable to the bacteroids even though it is in the nodules. This behaviour is therefore markedly different from the behaviour of phosphate, representing a situation where the cobalt does not apparently cross the peri-bacteroid membrane in sufficient quantities for proper bacteroid multiplication.

By studying the responses of rhizobia to mineral nutrient deficiency and comparing these to the situation for bacteroids from normal and nutrient-deficient plants it is therefore possible to pinpoint where a particular mineral nutrient is likely to affect the overall performance of the legume-*Rhizobium* system.

Australian Experience in Diagnosis of Nutrient Deficiencies in Legumes

J.F. Loneragan*

In their virgin condition, most Australian soils were severely deficient in phosphorus and nitrogen for the growth of crops and pastures. These deficiencies have been overcome in the southern, well-watered regions by sowing pasture legumes such as subterranean clover and medics with superphosphate fertilisers. Additional problems have arisen where the legume has failed to nodulate and where other nutrient deficiencies have limited nitrogen fixation or plant growth. Full accounts of these developments have been given elsewhere (Stephens and Donald 1958; Loneragan 1971; Robson and Loneragan 1978).

In the diagnosis of nutrient deficiencies several approaches have been used and new ones are being developed:

Symptoms

Symptoms have been particularly useful to Australian agronomists after the likely deficiencies for crops and soils of a particular district have been defined. With new crops and on different soils they have sometimes also provided useful guides to nutrient deficiencies. But symptoms can also be very misleading. They should always be confirmed by plant response to application of sprays to leaves or fertilisers to the soil.

The use of symptoms for diagnosis of nutrient deficiencies suffers from the fact that plant yield may be seriously affected before symptoms appear. Cases are known of nutrient deficiencies seriously depressing seed yields in crops which showed no leaf symptoms.

Fertiliser Response

Field trials have been extensively used and are the standard against which all other techniques must be assessed. Unfortunately they are slow and require a large effort. Difficulties have frequently been encountered in Australia because of the occurrence of soils with multiple nutrient deficiencies. In this situation, each nutrient response can only be properly assessed when all other deficiencies have been corrected: addition of fertilisers singly to separate plots may fail to reveal any response. Use of factorial designs may also prove unrewarding.

For clarification of multi-element deficiencies, the 'omission trial,' in which nutrients are omitted singly from a complex mix of nutrients, has proved very effective.

Glasshouse experiments have been used extensively in association with field trials. They have proved very valuable for defining the likelihood of deficiencies occurring in the field. Omission-type designs have again been particularly useful for surveys of soil deficiencies. However, glasshouse trials sometimes give responses which do not occur in the field — either because water or other factors limit growth in the field or because availability of nutrients in the field is different to that in pots. Glasshouse trials may also fail to reveal deficiencies because of differences in availability or because of contamination from the water supply or glasshouse surroundings.

Soil Analysis

Analysis of soils which permitted prediction of crop response to fertiliser applications would provide an ideal diagnostic procedure. But in Australian experience, soil analyses have seldom provided good diagnostic advice. Soil analysis played no part in the early clarification of nutrient deficiencies in Australian soils. However, soil analysis is now being used to help in recommendations for phosphorus and potassium fertiliser applications. It is not generally used for other elements, and experience with them, particularly the trace elements, has been discouraging.

Plant Tests

Plant tests have not been widely used but are rapidly gaining in popularity.

Laboratory analyses for many elements and crops are now done by most departments of agriculture on the request of district agronomists. Emphasis is being put on the use of specific plant

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parts rather than the whole tops. Emphasis is also given to the need for the data to be interpreted by competent agronomists.

Field tests have recently been developed for deficiencies of several elements in subterranean clover permitting the agricultural adviser to make an 'on the spot' assessment for a farmer. The tests include ones for: (i) phosphorus — acid extraction of inorganic P from fresh leaves (Bouma and Dowling 1982); (ii) Potassium — colour test on expressed plant sap (Spencer and Govaars 1982); and (iii) copper — simple assay for ascorbate oxidase (Delhaize et al 1983).

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