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Peanut Improvement: A Case Study in Indonesia

Proceedings of an ACIAR/AARD/QDPI collaborative review meeting held at Malang, East Java, Indonesia, 19–23 August, 1991

Editors: G.C. Wright and K.J. Middleton

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Foreword

In the early 1980s, with the goal of self-sufficiency in rice realised, the Indonesian Agency for Agricultural Research and Development (AARD) turned its attention to improved production of the palawija (non-rice) crops. Peanuts are one such crop, important in the local diet and as a source of highly concentrated protein for animal feed, of which Indonesia made significant imports. The Indonesian Government requested ACIAR to provide help with improvement of the crop. Goals were improved yields from traditional production areas, and expansion into non-traditional areas.

After exploratory visits, the Queensland Department of Primary Industries (QDPI) was contracted to assist the Research Institutes for Food Crops investigate the causes of low peanut productivity in Indonesia and the potential difficulties in cultivation of peanuts under a wider range of conditions.

Reinforcing the common maxim that science is truly an international activity, the identification and resolution of the constraints identified proved to be most productive when appropriate assistance from other countries and institutions was utilised as necessary. The research activities eventually involved scientists from ICRISAT, the Netherlands, USA, Thailand, The Philippines and China, University of Queensland and the Australian National University as well as AARD and QDPI.

These proceedings present a necessarily brief summary of the activities and results of six years of collaboration between Indonesia and Australia under the ACIAR project Peanut Improvement in Indonesia. Greater detail can be found in the many of the published papers arising from this interaction, or by contacting the scientists involved directly.

G.H.L. Rothschild
Director, ACIAR

Introduction

PEANUT is a major food legume in Indonesia, and is produced and used almost entirely for direct human consumption. The kernels are roasted, boiled, fried, crushed, ground and mixed with sugar or made into cakes. Oil extraction is negligible. Annual production is estimated at approximately 0.5 million t of nuts in shell harvested from more than 0.5 million ha, with an average yield being 1.0 t/ha.

The major production areas are in Java (particularly in east and central Java) and South Sulawesi, with smaller areas in Bali, Lombok, Sumatra, Kalimantan, Irian Jaya and islands in the Nusa Tengara region. In Java, approximately one-third of production is from lowland areas as a rotation crop following rice or sugarcane, generally sown in April–May and grown on residual soil moisture. Upland (non-paddy) cultivation accounts for about two-thirds, with sowings in October for a wet-season crop and a second sowing in February–March. The crop occupies a diversity of ecological niches, and is cultured as both a monocrop and intercrop. Its usage in Indonesian cropping systems is relatively complex.

Despite the importance of peanut in the Indonesian diet, production over the past several years has not met demand, and importation of up to 30 000 t/year has been necessary. Indeed, the Indonesian Government forecasts that annual peanut production by the year 2000 will have to increase to 1.8 million t to meet demand, representing an increase of 250% over current production.

There are two approaches which may increase peanut production in Indonesia. The first involves an intensification program designed to increase productivity and cropping intensity in Java in the major production areas, which are largely based on latosols. The second involves an expansion program aimed to develop the crop in new areas outside Java, including newly opened farmlands, largely on podzolic soils in Sumatra, Kalimantan, Sulawesi and Irian Jaya. Although current commercial yields are relatively low (< 1.0 t/ha), experimental plot yields demonstrate potential pod yield in excess of 3 t/ha, provided adequate fertilizer, water and fungicide are supplied. The large gap between farmer and experimental yields indicate the scope for peanut improvement in Indonesia. There is, however, a common farmer perception of the crop as a low yielding and low return proposition, which is therefore given relatively low inputs and marginal cultural conditions. This perception does not reflect the high crop value (up to 2500 Rp/kg, or $A1.75/kg) and potential for high profits.

These Proceedings report a collaborative research program conducted by scientists from the Indonesian Agency for Agricultural Research and Development (AARD) and the Queensland Department of Primary Industries (QDPI) aimed at understanding the major constraints to peanut production. Initially, studies to identify the major constraints to peanut yield in a number of production systems were conducted. These studies are reported in the first paper of these Proceedings. Subsequent to these constraint identification studies, specific research programs were implemented to solve these constraints. The remaining papers report the research findings and their implications for increased peanut production in Indonesia.

Finally, it is worth noting that many of the limitations to increased peanut productivity are common to peanut producing regions throughout South and Southeast Asia, as well as Australia. Many of the findings from this research program are therefore directly relevant and applicable to these regions.

G.C. Wright and K.J. Middleton

Identification of Disease, Agronomic and Eco-physiological Factors Limiting Peanut Yields

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THE research strategy adopted during the project and reported in these Proceedings was to identify the major constraints to peanut production in Indonesia. Disease surveys and field omission trials were used to assess the importance of the main pathological and agronomic constraints at a range of locations representative of traditional production areas.

Another major objective was to understand better the role of environmental factors such as temperature, photoperiod, irradiance and water deficits in peanut cultivar performance across environments. Improved understanding of the factors affecting cultivar adaptation potentially contributes to improved efficiency in both national breeding programs and international germplasm exchange by identifying characteristics desirable in cultivars selected for particular target environments.

The final objective was to begin developing a dynamic growth and development model, utilising the research results. It was considered this model would facilitate extrapolation of results beyond the cultivars, environments and agronomic systems used in the Indonesian and Australian studies.

Disease Survey

A common set of Indonesian and exotic peanut cultivars was sown during the 1985 wet season at six research station sites: Bontobili (South Sulawesi), Jambegede and Muneng (East Java), Jakenan (Central Java), Cikemeuh and Tamanbogo (South Sumatra). Disease symptoms were assessed regularly throughout the growing season. These activities resulted in a number of diseases — all of major importance in limiting peanut productivity — being identified. The diseases are bacterial wilt, peanut stripe virus and the fungal foliage diseases (leafspot and rust).

Bacterial wilt

Historically, bacterial wilt was viewed as a constraint not only to peanut production but also to peanut research. It was believed that all exotic germplasm introduced into Indonesia for experimental purposes would be destroyed by *Pseudomonas solonacearum*. While the survey demonstrated the seriousness of bacterial wilt in Indonesian peanuts, it also demonstrated the possibilities of using introduced germplasm for research purposes. (Table 1). Data in the areas of agronomy and water use have been obtained by the use of such germplasm, but bacterial wilt has also limited to a significant degree the value of these data. In some situations, introduced germplasm was rapidly killed by bacterial wilt, but, in other circumstances, disease incidence has been negligible.

The disease survey indicated that further research on bacterial wilt was justified. In particular, investigations into its epidemiology, and research into those factors which, through appropriate manipulation, could lead to the development of cultural control practices to support genetic resistance were needed. For the results of this research see the papers by Machmud and Hayward and Subandiyah and Hayward, these Proceedings.

Peanut stripe virus (PStV)

This virus is undoubtedly the most widespread and damaging in peanuts throughout Indonesia. The farmers' field surveys detected significant infection by, and loss due to, PStV throughout Java, in South and West Sumatra, and in South Sulawesi (Table 2).

Resistance is seen as the most effective, long-term solution to seed-borne virus diseases in food crops, particularly in smallholder farming communities. Previous attempts to find resistance to PStV in Thailand and China, while thoroughly carried out, failed. It is believed the reason for this failure was the relatively small sets of germplasm screened.

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Table 1. Bacterial wilt severity (0–100 scale), as affected by cultivar and site.

	Jambegede	Jakenan	Muneng	Tamanbogo	Cikemeuh	Bontobili
Indonesian cultivars						
Kidang	0.0	0.2	0.4	0.3	11.8	0.1
Pelanduk	0.0	0.0	1.1	0.0	15.8	0.1
Gajah	0.2	0.5	0.4	0.0	11.5	0.7
Tapir	0.0	0.2	0.2	0.0	10.9	1.0
Tupai	0.0	0.0	1.3	0.0	12.1	0.1
No. 467	0.5	5.8	0.7	0.3	80.7	1.6
No. 469	0.0	5.4	0.8	0.2	78.0	0.3
Introduced germplasm						
A27-146	0.0	5.8	1.3	0.0	70.4	22.6
Tifton-8	0.4	6.0	1.3	10.5	69.8	13.7
RS 119	0.0	0.0	1.7	10.0	90.0	49.2
Chico	0.0	0.2	2.2	7.4	88.7	32.5
A32-20	0.5	6.5	1.5	0.8	78.6	12.1
Mani Pintar	0.6	5.1	0.4	0.0	70.5	1.7
Early Bunch	0.0	6.5	0.7	4.3	88.2	9.9

Table 2. Peanut stripe virus severity (0–100 scale), as affected by cultivar and site.

	Jambegede	Jakenan	Muneng	Tamanbogo	Cikemeuh	Bontobili
Indonesian cultivars						
Kidang	21.9	17.4	31.1	10.2	20.2	0.2
Pelanduk	30.4	18.3	34.0	21.4	17.3	0.2
Gajah	18.2	15.1	30.3	16.4	23.1	4.1
Tapir	14.1	15.8	31.9	19.4	21.1	3.6
Tupai	29.3	19.2	31.7	17.5	15.5	3.4
No. 467	21.4	10.0	32.3	18.5	14.9	0.9
No. 469	14.6	18.8	30.6	22.4	12.7	1.4
Introduced germplasm						
A27-146	29.9	22.5	38.3	15.8	5.6	15.7
Tifton-8	30.7	22.9	38.1	16.5	2.6	4.7
RS 119	24.1	19.2	31.5	7.7	*	6.0
Chico	20.3	19.7	24.9	7.4	*	0.6
A32-20	18.6	20.1	33.3	16.3	14.2	9.6
Mani Pintar	18.0	19.6	33.3	11.3	16.0	0.6
Early Bunch	22.6	27.1	32.9	6.2	*	9.8

* Not determined, due to destruction of plants by bacterial wilt.

In the current investigations, it was decided to substantially increase the number of entries, and expose them to the virus under field conditions even though this increased the risk of some susceptible material escaping infection. Alongside the resistance studies, other research aimed to quantify the extent of yield loss resulting from PStV infection at different times of growth (see Saleh et al. these Proceedings).

Fungal foliage diseases

The peanut leafspots (*Cercospora arachidicola* and *Cercosporidium personatum*) and rust (*Puccinia arachidis*) were also identified in the disease surveys as causing significant foliage damage in some situations (Tables 3 and 4). In part because of worldwide inputs into control of these diseases by genetic and chemical means, and in part because of the severity detected in the surveys, the need for local research in this area is considered to be less than for bacterial wilt and PStV. However, it is preferable to use an integrated package of controls appropriate to the Indonesian farmer, and some research inputs are considered necessary.

The sole use of fungicides in cropping systems such as those employed in Indonesia must be considered as a temporary measure only. When cultivars resistant to these diseases are developed, fungicide may be required to supplement the control provided by host-plant resistance. Considerable progress worldwide has been made on the genetic control of these pathogens, and the Indonesian peanut-breeding programs are making some use of that information.

However, until resistant cultivars become widely adopted, growers must be provided with the information necessary to ensure the best and most economical use of fungicides. To this end, the economic injury level studies for these diseases being carried out in Queensland have been conducted to provide the information required to make sound economic decisions (see Middleton, these Proceedings).

Table 3. Leafspot severity (0–100 scale), as affected by cultivar and site.

	Jambegede	Jakenan	Muneng	Tamanbogo	Cikemeuh	Bontobili
Indonesian cultivars						
Kidang	31.2	16.9	50.3	17.6	6.3	0.2
Pelanduk	48.4	16.3	47.0	13.6	23.1	3.5
Gajah	46.8	16.4	48.8	12.3	24.2	2.7
Tapir	31.5	17.8	51.0	12.8	21.3	2.3
Tupai	34.2	18.7	46.6	13.2	20.8	2.0
No. 467	19.9	11.1	41.8	3.9	15.4	0.0
No. 469	21.0	10.6	47.5	4.0	19.3	0.4
Introduced germplasm						
A27-146	25.9	19.4	45.1	4.0	8.8	1.7
Tifton-8	30.5	18.7	37.4	2.8	2.5	1.7
RS 119	32.4	15.0	48.3	4.2	*	1.0
Chico	25.2		13.4	47.5	2.8	0.5
A32-20	23.0	20.0	38.8	3.4	8.9	0.3
Mani Pintar	24.8	18.5	53.3	1.5	16.1	1.5
Early Bunch	33.4	22.6	51.1	3.6	*	0.4

* Not determined, due to destruction of plants by bacterial wilt.

Table 4. Rust severity (0–100 scale), as affected by cultivar and site

	Jambegede	Jakenan	Muneng	Tamanbogo	Cikemeuh	Bontobili
Indonesian cultivars						
Kidang	42.3	25.9	46.5	48.2	20.5	22.6
Pelanduk	47.7	24.2	48.1	41.9	22.0	23.3
Gajah	35.4	14.5	49.4	35.3	19.5	19.5
Tapir	40.1	23.1	50.6	47.0	19.0	19.4
Tupai	37.0	24.9	47.8	46.5	17.5	18.7
No. 467	27.5	20.2	47.7	46.6	16.7	24.8
No. 469	34.5	19.0	54.9	43.4	15.2	30.5
Introduced germplasm						
A27-146	27.3	16.8	43.8	33.4	7.0	13.1
Tifton-8	38.9	16.4	49.2	32.2	0.4	14.0
RS 119	42.6	16.8	47.4	39.5	*	17.2
Chico	40.7	19.3	46.5	43.7	*	20.1
A32-20	25.9	13.9	38.7	29.1	3.4	12.2
Mani Pintar	29.5	11.5	53.1	30.6	15.2	15.3
Early Bunch	46.4	20.2	53.8	25.7	*	23.0

* Not determined, due to destruction of plants by bacterial wilt.

Agronomic Constraints

The omission trial approach was used to determine primary yield limitations in different cropping systems and locations throughout Indonesia. These studies identified four major agronomic factors limiting peanut yield: nutritional deficiencies, acid soil, plant population, and irrigation management.

Nutritional deficiencies

The red-yellow podzolics, comprising a significant proportion of the major peanut-producing areas of central Java, were shown to be highly infertile. An omission trial designed to assess the relative importance of N, P, Ca, K and S, a mixture of micronutrients, and the effectiveness of the native *Rhizobium* strains was conducted in the Jakenan region of central Java. Dry matter production at the beginning of the pod-fill period (50 days after planting) and maturity are shown in Table 5.

This study clearly indicated that there was a strong response to K fertilizer for maximum growth, pod yield and quality. The experiment was conducted on a research station where the regular use of P and N fertilizers may have resulted in the lack of response to these elements in this study. Other omission experiments also found that there was little response to fertilizer N, and suggested that symbiotic N fixation was providing adequate nitrogen for normal crop growth. More detailed nutritional experiments were subsequently conducted to investigate the P and K response in farmers' fields, as well as examining the need for N fertilizer in a range of peanut-cropping systems. The results of these experiments are reported by Poerboyo and co-workers, these Proceedings.

Acid soil

Large areas of acid soils occur throughout Indonesia, with the largest in Sumatra, Kalimantan, Sulawesi and Irian Jaya. Gani and co-workers (these Proceedings) report results of research aimed at assessing the influence of dolomitic limestone on soil characteristics and peanut growth, as well as assessing whether cultivars tolerant to acid soils can be identified from peanut germplasm from the national program and international agencies such as ICRISAT.

Plant population

Currently recommended plant populations for peanut throughout Indonesia are in the vicinity of 250 000 plants/ha for the typically short-season Spanish cultivars, with research reports of pod yield increases up to 1 million plants/ha (B. Sutton, pers. com). This contrasts sharply with both subtropical monsoonal areas of Australia, where maximum yields of Spanish cultivars are achieved at plant populations of less than 100 000 plants/ha (dryland) and 100 000–125 000 plants/ha (irrigated).

Preliminary studies were begun under irrigation in 1987 at Jambegede research station (East Java) during the early dry season. The recently released

Table 5. Yield of tops 50 days after sowing, and yield of pods and kernel characteristics at maturity of cv. Gajah sown at Jakenan in April 1987.

	Yield (kg/ha)		Quality		
	Tops (50 days) after sowing)	Pods (maturity)	Kernel %[a] (full pods only)	Germination %	Number of empty pods[b]
1. Nil	385.9	653.6	64.6	79.8	55.0
2. Complete[c]	750.6	1266.3	68.0	93.8	89.8
3. Complete — P	603.0	1446.6	68.3	83.5	79.5
4. Complete — K	574.7	910.6	65.1	88.8	81.8
5. Complete — gypsum	742.7	1337.7	66.3	86.5	86.8
6. Complete — N	568.6	1199.1	67.9	88.0	89.0
7. Complete — N + *Rhizobium*	714.5	1167.9	70.3	93.8	73.3
8. Complete — trace elements	675.0	1424.1	65.1	80.8	115.8
LSD (P<0.05)	168.0	230.2	3.4	10.1	32.6

[a] Laboratory tests on 4 × 100 seed, harvested from each plot.

[b] 7.5 m^2 quadrat.

[c] Basal fertilizer for the 'COMPLETE' treatment contained 150 kg/ha N (urea), 60 kg/ha P (triple super phosphate), 50 kg/ha K (KCl), 500 kg/ha gypsum and 15 kg/ha trace element mix containing 2 kg Zn, 2 kg Cu, 3.5 kg B and 0.6 kg Mo. The inoculum added to treatment 7 was cowpea strain of *Rhizobium* sp.

Indonesian cv. Kelinci was sown at plant densities ranging from 62 500 to 333 000 plants/ha with differing plant rectangularities. Yield and quality data from this trial are shown in Table 6.

The data show that, although pod yield increased significantly in response to increasing plant density up to 167 500 plants/ha, there was no significant pod-yield benefit to higher plant density. The effects of reducing inter-row spacing to 30 cm did not produce differing yield to plant density relationships, and there was no suggestions of any benefit from 1:1 spatial ratios.

Accurate information on optimal plant densities for peanut grown in different cropping systems and climatic zones is essential in light of the high seed costs associated with high seeding rates. The possibility that water stress interacts with plant density to change the optimum plant population observed under fully irrigated conditions has not been studied in peanut. Detailed studies of the response of peanut to plant density under a range of water stress treatments were therefore conducted to allow accurate plant population recommendations to be made (see Adisarwanto et al., these Proceedings).

Irrigation management

Peanuts are grown under a variety of cropping systems throughout Indonesia. Under the sawah (lowland) cropping system rice may be grown once, twice, or even three times, following the start of the wet season, depending on rainfall and the availability of irrigation water. When water supplies are insufficient to support continued rice production, palawija (non-rice) crops are grown. The choice of crop depends on the expected water supply during the dry season and peanuts are usually grown where water supply is insufficient to support the more drought-susceptible palawija crops such as maize and soybean. Under the sawah system, therefore, peanuts are often sown where the soil profile is fully charged, but where the probability of rainfall during the growing season is very low. Terminal water stress is typical of this situation, where crops rely solely on stored moisture for their water requirements. Figure 1a illustrates this type of terminal drought, with evaporation minus rainfall data for a typical May-sown crop at Maros, South Sulawesi.

Under tegal (upland) cropping systems, peanuts are often included in the rotation either early or late in the wet season. Many of Indonesia's eastern islands which comprise the Nusa Tenggara region (e.g. Flores and Timor), as well as parts of Java, are typical tegal production areas. Here peanuts can suffer intermittent stress, which can occur at any time and with varying intensities between emergence and maturity. Figure 1b illustrates this type of intermittent drought with evaporation minus rainfall data for a typical April-sown crop at Genteng, East Java.

Irrigation can be used to ameliorate the effects of drought in both types of stress situation. The drought research program initiated during this project has aimed to gather more information on peanut growth and yield response to water deficits applied at different stages of growth. In particular, little information exists on peanut production in a post-paddy rice situation, and whether root growth and subsequent water extraction are limited by hardpans which develop as a result of puddling rice paddies. A water-use experiment conducted at Maros in South Sulawesi investigated the effects of varying irrigation frequency during the pre- and post-early pod-filling stages on growth, yield and water use of peanut grown under a post-paddy situation. The present cropping system in this area consists of wet

Table 6. Effects of plant population on yield and quality characteristics of cv. Kelinci during the dry season in East Java.

Plant density	Spatial arrangement (inter-row spacing × intra-row spacing, cm)	Pod yield (kg/ha)	Total kernels (%)	Mature kernels (%)	Full pods (%)
62 500	40 × 40 (1:1)	775	71.6	80.1	81.8
83 000	40 × 30 (1:1.33)	782	71.8	87.7	76.3
111 000	30 × 30 (1:1)	978	72.8	84.8	74.2
125 000	40 × 20 (1:2)	1328	73.8	87.6	78.2
167 500	30 × 20 (1:1.5)	1598	72.2	83.7	77.5
167 500	40 × 15 (1:2.67)	1615	75.4	88.2	84.7
250 000	40 × 10 (1:4)	1942	74.6	84.6	82.9
250 000	20 × 20 (1:1)	1799	72.2	83.3	68.4
333 000	40 × 7.5 (1:5.33)	2090	77.4	88.0	82.8
	LSD ($P<0.05$)	505	6.5 n.s.	7.2 n.s.	12.4 n.s.

season rice, with very little palawija production in the dry season. However potential exists for more widespread palawija production in the dry season considering post-wet season rainfall is reasonable and plentiful supplies of good quality groundwater are easily accessible throughout much of the region.

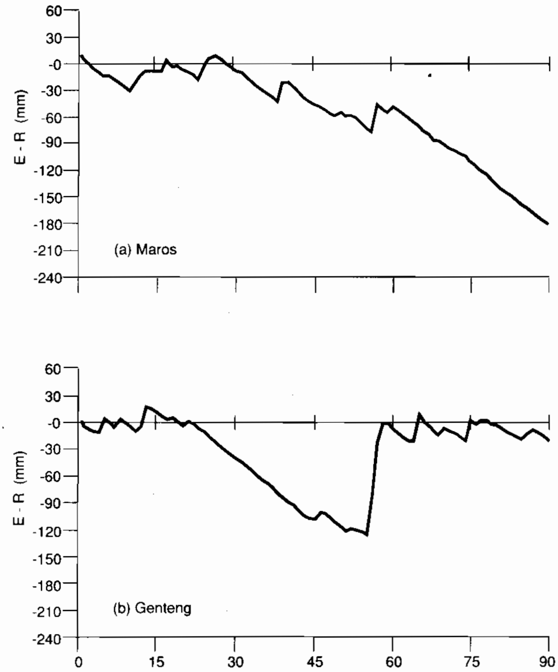

Figure 1. Evaporation (E) minus rainfall (R) deficit for a hypothetical crop sown on 15 May at Maros, South Sulawesi (a) and on 1 April at Genteng, East Java (b).

Results from this initial experiment indicated that delaying irrigation either during the vegetative and/or reproductive stage had only minor effects on pod yield compared to a fully irrigated treatment. Soil water content measurements before and after irrigations indicated a restriction, or choke, in the soil profile was inhibiting water movement to lower depths in the profile. This effect became more pronounced as the season progressed, indicating that there may be a problem with infiltration of irrigation water in peanuts grown in post-rice situations in this region. More detailed studies have subsequently been conducted to determine the source and methods of ameliorating this limitation. Prastowo et al. (these Proceedings) report the results of this research.

Cultivar Adaptation to Environmental Stresses

A primary objective of this project has been to understand better the influence of environmental factors such as temperature, photoperiod, irradiance and moisture availability (both singly and in interaction) on cultivar performance across environments. Information gathered on factors affecting cultivar adaptation can contribute to improved efficiency in both national breeding programs and international germplasm exchange by identifying characteristics desirable in cultivars selected for particular target environments.

Research activities have been grouped into:

(a) investigating non-manipulable environmental factors (i.e. temperature, photoperiod and irradiance), and

(b) investigating manipulable environmental factors (i.e. water stress).

Photoperiod, irradiance and temperature

Photoperiod. Although peanuts have been shown to be photoperiod-insensitive with respect to time of the first flower, short days (< 13 h) have been shown to enhance subsequent flower and fruit production, and the species can be described as a quantitative short day plant. Controlled environment studies showed that 12-hour photoperiods double flower and peg numbers compared with 16-hour photoperiods, while pod numbers increased 3- to 12-fold with short days for a range of peanut cultivars. Photoperiodically induced changes in flower and fruit numbers were independent of plant dry weight, although for individual plants, flower and fruit numbers were always highly correlated with plant dry weight.

The apparent anomaly between the strong photoperiod sensitivity exhibited by cultivars in the phytotron studies (and in field trials at ICRISAT Centre) and the high yielding, high harvest index characteristics associated with those same cultivars in the low latitude, long photoperiod subtropics was extensively investigated in field trials at Kingaroy. Using daylength extension in the field with incandescent lights, in combination with shading or varying temperature regimes created by different sowing dates, the possibility of an interaction between temperature and photoperiod sensitivity was raised. A subsequent glasshouse study has confirmed this interaction, with photoperiod sensitivity being much reduced with lower night temperatures. The Kingaroy environment is characterised by quite low night temperatures during the growing season (generally below 17 °C), which probably explains the lack of negative yield response to daylength extension in field trials and also high-yield, high-harvest index characteristics of photoperiod-sensitive cultivars in an essentially long photoperiod environment. Details of this research, as well as an examination of the relevance of selecting for photoperiod insensitivity in peanut cultivars for specific production environments, are reported by Bell, these Proceedings.

Irradiance. Irradiance has been shown to be a major determinant of peanut yield after flowering commences because it influences both flower and fruit numbers as well as plant dry weight. Dry matter accumulation was shown to be less sensitive to irradiance level than flower or fruit number. This can result in quite marked changes in harvest index (due to reduced fruit number) in peanut grown under low irradiance conditions. Such effects have been demonstrated in both short-term experiments in the phytotron and field trials under various grades of shade cloth. In these studies harvest index decreased with decreasing incident irradiance. Such observations are consistent with the low harvest indices exhibited by known cultivars when grown under low irradiance tropical conditions in Indonesia.

Field studies at Kingaroy show differences in sensitivity to irradiance both between botanical types (e.g. Spanish cultivars less sensitive to low irradiance than Virginia types) and among cultivars within a botanical type (see Bell et al., these Proceedings).

Temperature. Temperature has been shown to be of overriding importance to peanut growth and development, especially during early growth stages. Both leaf and flower production are shown to be temperature-dependent, with an optimal temperature of 30 °C or higher. At sub-optimal temperatures the linear thermal time model adequately describes first flower appearance, although subsequent flower production was shown to be affected by other environmental components.

Temperature effects on growth for both phytotron and glasshouse studies suggest that responses may be due to either temperature effects on assimilation rate as such (optima above 22 °C), or via feedback inhibition of photosynthesis at night temperatures of less than 20 °C (approx). The latter phenomenon may be of special significance in subtropical environments (or tropical environments at higher altitudes) with light-use efficiency being reduced by approximately 25% with night temperatures of 18 °C, compared to night temperatures of 23 °C (see Bell et al., these Proceedings).

Sowing date studies

To gain information on peanut growth and development under Indonesian environmental conditions, as well as relating the growth and phenology of Indonesian germplasm to that of known Australian cultivars, field studies were sown in both Indonesia and Australia. Indonesian studies were conducted at Jambegede Research Station (East Java), and consisted of four sowings at regular intervals during a 12-month period (March, May, August and January), using four Indonesian and four Australian cultivars. Comparison of growth, development and final yield was made within and among the sowing dates, and the performances of both local and introduced cultivars were related to those in other tropical and subtropical environments.

Total dry matter production of all cultivars was not dissimilar to that of McCubbin (the commercial standard Spanish type grown in Queensland) and varied little with sowing date (Fig. 2a). There were suggestions that reproductive yield of local cultivars under Indonesian conditions was at least as high as that of the introduced Virginia or Spanish cultivars (Fig. 2b).

Comparison of vegetative and reproductive growth of common cultivars sown under similar, non-limiting conditions in tropical, sub-tropical and semi-arid tropical conditions is shown in Figures 3a and 3b. An outstanding feature of the data was the very poor reproductive growth of all cultivars under Indonesian conditions across all sowing dates. The reduction in reproductive yield was largely due to much lower pod numbers (Fig. 3c). The data indicate that cultivar adaptation to Indonesian growing conditions may be quite poor, with yield potential lowered because of poor reproductive development. Possible solutions to this problem of low pod-yield could lie with agronomic solutions such as increasing pod number by increasing plant population. However, results of this work have proved negative, with yield potentials not increased significantly by high plant populations. Other reasons for these yield differences appear to lie in the nature of the East Java environment.

Photoperiods are generally short under Indonesian conditions, and are not likely to limit peanut yield as the crop is generally daylength neutral or short-day in response type. Irradiance is quite low compared to subtropical and dry tropical environments, and controlled studies in Australia show this may limit reproductive development. Similarly, temperatures are quite high and, while ensuring dry matter accumulation is not restricted, they also ensure that phenological development is rapid (note the more rapid maturing in the Jambegede studies). The latter two factors are likely to hold the key to low-yield ceilings under Indonesian conditions.

Rapid progress though the vegetative stage to flowering and the beginning of reproductive development ensures small plants, few branches, and few nodes for pod development on each plant. While more nodes may develop subsequently, and even produce flowers and pods, they are of little significance

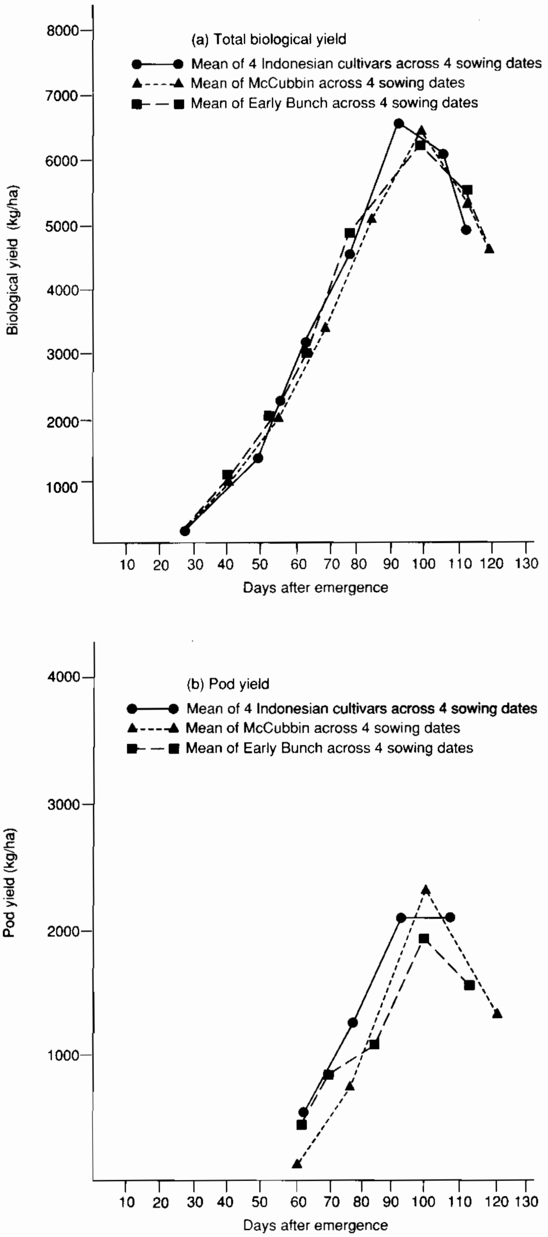

Figure 2. Development of total biological yield (a) and pod yield (b) of introduced and local peanut cultivars at four sowing dates in East Java.

for final yield. Coupled with this effect of rapid phenological development is the effect of low irradiance causing reduced pod and kernel development. Together these factors would severely limit the yield potential of Indonesian peanuts, as is suggested by the Jambegede studies. Possible ways of overcoming these environmental limits include identifying cultivars which are less temperature sensitive (and hence were phenologically rapid in their development) and also less sensitive to low incident irradiance. These aspects are discussed in more detail by Bell et al. (these Proceedings).

Water stress physiology

Both terminal and/or intermittent droughts are likely to occur in peanut production areas in different regions of Indonesia, while the predominant drought pattern in Australian production areas is of the intermittent type (see Figs 1a and 1b). The water stress physiology component of this project has the broad aim of improving peanut yield under water-limited conditions under both types of drought situation. Useful information can be obtained only through detailed studies aimed at quantifying the effects of drought on peanut growth, development, yield and water use, and studying how these effects are influenced by cultivar selection and agronomic management. Once a sound understanding of the various mechanisms peanut uses to cope with and yield under different drought situations is achieved, appropriate breeding selection criteria can be formulated.

The broad framework used to study peanut yield performance under water limited conditions is provided by the following identity:—

$$\text{Pod yield} = \frac{\text{water}}{\text{transpired}} \times \frac{\text{water-use}}{\text{efficiency}} \times \frac{\text{harvest}}{\text{index}}$$

This simple framework helps focus on a wide range of physiological and morphological attributes of possible significance to drought tolerance.

Experiments in this project therefore attempted to investigate the relative importance of these attributes in conferring yield advantage in a range of peanut genotypes.

Water transpired. A number of field experiments investigating the influence of water deficits at different stages of growth on a range of peanut cultivars demonstrate large cultivar differences in water extraction capability. Some cultivars extracted more than 50 mm more soil water than others in a severe end-of-season drought. This extra water was extracted at depths below 1.1 m, indicating superior rooting characteristics in some cultivars under drought conditions. Simple screening techniques are currently being assessed, hopefully to enable selection for this character in breeding programs.

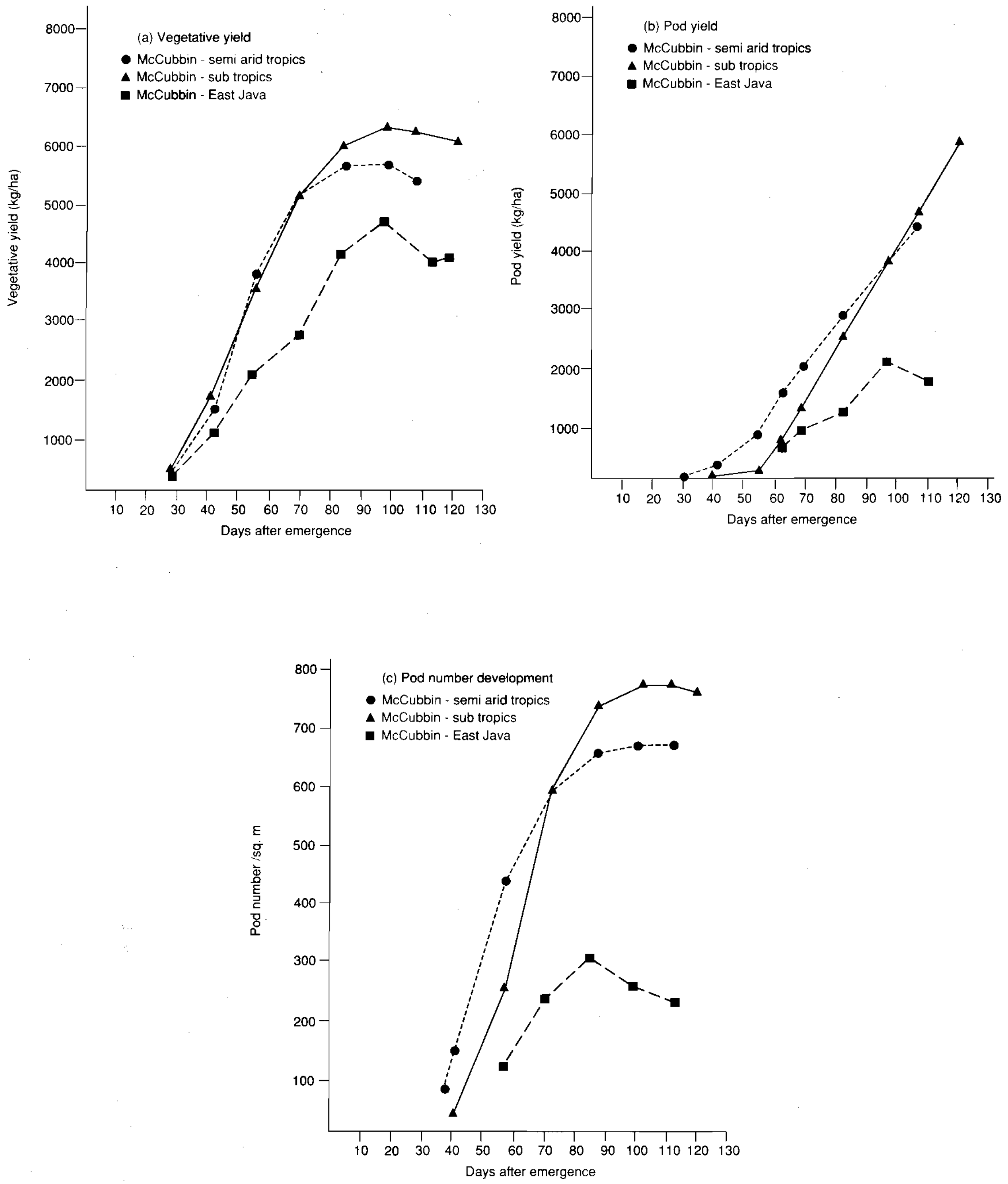

Figure 3. Effect of location on vegetative yield (a), pod yield (b), and pod number development (c) of the spanish cultivar McCubbin.

Water-use efficiency (WUE)

Improvement in WUE, defined as the ratio of dry matter production to water use, may help increase yield when water resources are limited. Genetic variation in WUE in peanut cultivars has been shown in pots and, more recently, in plants grown in minilysimeters placed in small canopies in the field. For example, Tifton-8, a Virginia cultivar from USA, has a WUE of 3.71 g/kg compared to 2.46 g/kg for the Indonesian local cultivar Rangkasbitung. Clearly, significant variation in WUE is present in peanut cultivars, and is potentially selectable to improve peanut drought tolerance. This project has been collaborating with scientists from the Australian National University in Canberra to assess the potential of a rapid screening technique to select for WUE in peanut cultivars. The ratio of ^{13}C:^{12}C (Δ) has recently been shown by theoretical analysis to reflect how efficiently a plant uses water in the production of biomass. Leaf samples from the glasshouse and field drought experiments have been analysed for Δ and regressed against the measured plant WUE. In all the glasshouse and field experiments conducted to date in this project, good correlations between Δ and WUE have been found, indicating that this technique may have considerable application in breeding programs to screen for high WUE.

Harvest index (HI)

Field and pot studies show that there is considerable variation in HI under well-watered and drought conditions. For instance, in a field study where four cultivars were severely droughted during pod-filling, differences in HI from 23% to 47% were measured in the poorest and best-yielding cultivars. Pod yield was a function of the rate of pod addition and subsequent filling in response to plant water deficits. Its ease of measurement and relatively high heritability suggest that rapid progress in breeding programs should be possible. Details of the range of experiments conducted on peanut water stress physiology are reported by Wright et al. (these Proceedings).

Peanut Growth Model Development

The development of a peanut crop growth model to enable integration of information from the adaptation and water stress studies in Indonesia and Australia was a primary objective of this project. It was hoped the model could assist to focus research and develop appropriate production systems for peanuts in Indonesia. Extrapolation of results beyond the cultivars, environments and agronomic systems used in the field studies would be possible.

Initially, some evaluation of the University of Florida PNUTGRO model was made by calibrating growth and yield data sets from previous field studies at Kingaroy. This model was found, however, to be unnecessarily detailed and cumbersome for the purposes of this project, and a much simpler, less detailed model utilising fewer coefficients was developed in collaboration with Dr Tom Sinclair of USDA, Florida. Hammer et al. (these Proceedings) report on the development of this model using data sets derived from the agronomic and adaptation studies in Australia and Indonesia. Their paper also discusses potential uses of the model in agronomic management and genetic improvement contexts. Once thorough calibration and general confidence in the predictive capability of the model has been achieved, it is planned to use the model as a predictive tool. For instance, long-term climatic data from a range of sites throughout Indonesia will be entered to enable risk analysis of a number of agronomic management variables, including sowing times, row spacing and irrigation timing. Also in a genetic improvement context, simulation runs which vary the length of the various developmental phases will enable optimum maturity ranges in specific environments to be assessed. Such information will be of great benefit to guide and focus peanut breeding programs in specific areas.

Genetic and Cultural Control of Peanut Bacterial Wilt

M. Machmud* and A.C. Hayward†

DISEASES are one of the most important constraints in peanut production. However, bacterial wilt caused by *Pseudomonas solanacearum* is the only important bacterial disease. It was first observed on peanut by a Dutch scientist, van Breda de Haan, in the Cirebon area of West Java in 1905. Bacterial wilt has been reported since to be widespread and causing serious damage to peanut in various parts of Indonesia. Yield losses due to the disease range from 15–35% on resistant cultivars and 60–90% on susceptible ones.

Research on bacterial wilt conducted by Dutch scientists since the first decade of the twentieth century includes ecology of the pathogen, screening for peanut resistance, and cultural as well as chemical control. These studies continued until World War II. However, the disease is still a problem in the field.

In 1985 collaborative research between AARD (Indonesia) and ACIAR (Australia) on peanut improvement in Indonesia was initiated. Field surveys using disease trap nurseries were conducted at six sites throughout Indonesia and indicated that bacterial wilt was present in all fields; in some areas the disease was still potentially damaging. As a result, research on bacterial wilt of peanut was one topic selected for attention in the project.

During the first three-year period of the project, research on bacterial wilt included:

- field surveys and diseased plant collections;
- identification of strains and biovars of the pathogen;
- a comparison of the methods of inoculation, suitable for screening resistance of peanut germplasm; and
- evaluation of peanut cultivars and germplasm for resistance to bacterial wilt.

In the second three-year period, besides continuing the work of the first period, further studies in Indonesia included:

- host range of the bacterium;
- the effect of some environmental conditions on the disease;
- the effect of organic matter amendments on disease development;
- disease control through crop rotation, and
- the inheritance of resistance to bacterial wilt of peanut.

The following is an overview of the results of this research, particularly those related to genetic and cultural control of the disease. Other areas worthy of further research have been identified.

Research Highlights

Disease distribution, economic importance and symptoms

In the 1984–85 wet season, disease trap nurseries were set up at locations representing the major peanut-growing areas in Indonesia. In each location, a number of peanut cultivars including three resistant (Gajah, Pelanduk and Tupai) and two known susceptible cultivars (Mani Pintar and Early Bunch) were grown in small plots. During crop growth all diseases present in the crops, including the bacterial wilt, were recorded regularly. Following the trial, field surveys and diseased plant collections were made annually in different parts of Indonesia, including Sumatra, Java, Bali, South Sulawesi and Irian Jaya. Results of the surveys indicated that bacterial wilt is widespread in various peanut-growing areas of Indonesia.

Disease intensity in the field varies with locality and cultivar. High disease intensities were found in West Sumatra, West Java, parts of Central and East Java, Bali, and South Sulawesi. Some of the major peanut areas with severe bacterial wilt infestations were Pasaman (West Sumatra), Northern Lampung (Lampung), Serang, Tangerang, Bogor, Subang, and Pangalengan (West Java), Pati, Jepara, Kebumen (Central Java), Jambegede (East Java), and Bontobili (South Sulawesi). Although disease intensity in

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the field varied, in many areas the disease was potentially damaging to peanut production, particularly if susceptible cultivars are grown. Disease intensities can range 5–35% on resistant cultivars such as Gajah, Kidang, Pelanduk and Tupai, and 60–100% on susceptible cultivars such as Kelinci, No. 469 and many local cultivars.

The bacterium attacks peanut at different plant ages. In the field, wilted plants may be observed as early as two weeks after sowing. Infection in young plants results in sudden wilting of stems and foliage, with leaves of dead plants remaining green. When infections occur in older plants, wilting proceeds gradually, usually starting with the lateral branches, frequently enabling the plants to mature and produce pods and seeds. Sometimes the infected plants did not show significant wilting symptoms but a gradual decline and yellowing of the leaves. The root systems of the infected plants showed obvious discoloration and rot. These conditions were also found frequently on funiculi and pods of mature plants. The diagnostic characteristics of the disease are the dark brown discoloration in the xylem and pith, and the streaming of bacterial exudate from cut ends of stems and roots when placed in water.

Strain, variability and host range

At present, isolates of *P. solanacearum* have been grouped into five races based on their host ranges, and into five biovars based on their biochemical characteristics. Identification of race and biovar of *P. solanacearum* has not been made previously in Indonesia. Therefore an attempt was made to identify the race and biovar of the isolates collected during the field surveys of various peanut-growing areas. More than 250 isolates have been evaluated since 1985. The host range studies have been done by inoculating peanut, tomato, eggplant and potato plant with each isolate. Race 1 attacks peanut and the solanaceous plants, while race 3 only attacks solanaceous plants. Biovar identification was made using the technique of Hayward (1964).

Table 1 shows race and biovar of some representative isolates from different hosts and localities. Almost all isolates obtained from peanut were of race 1 and biovar 3, except for one isolate from Manokwari, Irian Java, which was of race 1, biovar 1. Some of the tomato and potato isolates from areas of altitude greater than 1000 m, such as Segunung, Lembang, and Pangalengan (West Java) and

Table 1. Some of the representatives of race and biovars of *Pseudomonas solanacearum* collected from different localities in Indonesia, from 1985 to 1991.

Isolate No.	Host	Origin	Altitude (m.a.s.l.)	Race/biovar
BO1-BO5	Peanut	Bogor, W. Java	250	1/3
PS 9101	Peanut	Sukabumi, W. Java	350	1/3
PS 8970	Peanut	Tangerang, W. Java	50	1/3
PS 8963	Peanut	Kuningan, W. Java	400	1/3
PS 9102	Eggplant	Cirebon, W. Java	20	1/3
PS 8520	Peanut	Tegal, C. Java	20	1/3
PS 9031	Peanut	Pati, C. Java	50	1/3
PS 9032	Peanut	Jepara, C. Java	40	1/3
PS 9103	Peanut	Wonosari, Yogyakarta	200	1/3
BO79	Tobacco	Kutoarjo, C. Java	35	1/3
PS 9110	Peanut	Kebumen, C. Java	10	1/3
PS 9125	Peanut	Malang, E. Java	180	1/3
BO16	Peanut	Jambegede, E. Java	335	1/3
PS 9126	Peanut	Biltar, E. Java	200	1/3
BO98	*Croton hirtus*	Sulusuban, Lampung	20	1/3
PS 9130	Peanut	Tamanbogo, Lampung	40	1/3
PS 8945	Peanut	Pasaman, W. Sumatra	75	
PS 8946	*Croton hirtus*	Pasaman, W. Sumatra	75	1/3
PS 8721	Peanut	Maros, S. Sulawesi	120	1/3
6722	Peanut	Bontobili, S. Sulawesi	100	1/3
PS 8974	Peanut	Manokwari, Irian Jaya	50	1/4

Sumberbrantas (East Java), were of race 3, biovar 2, and a few of biovar 4. One peanut isolate from Pangalengan was race 1 and biovar 3 although it came from a high altitude area.

There is evidence of differences in virulence among strains of *P. solanacearum* on peanut, such as the reports from China (Boshou and Yujun pers comm.). To further clarify this aspect, a study was carried out to measure the extent of variation in virulence among peanut isolates from Indonesia. In two separate trials, a number of Indonesian peanut isolates were tested on cv. Chico and Kelinci, both susceptible to bacterial wilt. Plants were inoculated in the glasshouse at two weeks of age using the leaf axil injection technique. Parameters observed included incubation period, wilt intensity, and the effect of inoculum dilution on disease development. Table 2 shows the virulence ranking of the peanut isolates on cv. Kelinci based on the wilt intensity after inoculation with different dilutions of the inocula.

It was indicated that isolate PS 9019 from Ngale, East Java, was the most virulent peanut isolate, followed by isolates from Cikeumeuh (Bogor), Malang, and Manokwari (Irian Jaya).

The more virulent isolates also initiated symptoms more rapidly than the less virulent ones. For example, the most virulent isolate (PS 9019) initiated visible symptoms within nine days of inoculation, while the least virulent (PS 9060) required 15 days to produce symptoms.

Weeds are commonly found in peanut-growing lands. These weeds not only compete with peanut crops for nutrition, but they may act as hosts for many pathogens including *P. solanacearum*. Failure to control bacterial wilt by crop rotation in the past could be due to poor field sanitation, with weed control being neglected. During the field surveys some weeds showing symptoms of wilt were also collected to check for the presence of the pathogen. Host-range tests were also done by growing weeds collected from peanut fields and inoculating them artificially with a peanut isolate of the bacterium in the glasshouse.

Some weeds which commonly grow in peanut fields were susceptible to bacterial wilt, while a few were resistant (Table 3). There have been reports on latent infection in weeds and speculation that some non-host plants could harbour the bacterium; these aspects have not been studied.

Seed infection and transmission of the bacterium

Due to lack of experimental evidence there has been controversy in the past on peanut seed infection and the role of infected seed in transmission of the pathogen. Palm (1922) was the first to report seed transmission in peanut. He had successfully isolated from parts of seeds, including the funiculus, pod or shell, and seed coat, but not from the embryo.

In the 1987–88 wet season, pods of eight cultivars with differing levels of resistance to bacterial wilt were collected from plants grown at Cikemeuh Experimental Farm, an area known to be heavily infested with wilt bacterium. Pods were collected from wilted plants and also from healthy ones. Isolation of the pathogen from different parts of pods and seeds was done in the laboratory. The bacterium could be isolated from any part of the pod and seed, including funiculus, pod shell, seed coat and embryo. One hundred seeds from wilted plants of each cultivar were then grown in pots containing sterilised soil to observe transmission to the new plants. Wilted plants were produced by 5–8% of the seeds (Table 4). These results, therefore, confirm the report of Palm (1992), show that the infection can reach as far as the embryo, and that an infected seed may grow into a diseased plant and serve as source of inoculum in previously clean fields.

Table 2. Virulence ranking of *P. solanacearum* isolates on peanut cv. Kelinci, two weeks after inoculation.

Isolate No.	Origin	Wilt intensity (%)*
PS 9019	Peanut isolate from Ngale, E. Java	86.00 d
PS 8954	Peanut isolate from Cikeumeuh, W. Java	50.67 c
PS 9060	Peanut isolate from Malang, E. Java	38.67 bc
PS 9027	Peanut isolate from Muara, W. Java	36.00 bc
PS 8974	Peanut isolate from Manokwari, Irian Jaya	38.17 bc
PS 9006	Peanut isolate from Cikeumeuh, W. Java	32.00 ab
PS 9028	Peanut isolate from Muara, W. Java	30.67 ab
PS 9026	Pepper isolate, Sumedang, W. Java	21.33 a
PS 8962	Potato isolate, Segunung, W. Java	20.00 a
PS 9023	Potato isolate, Lembang, W. Java	20.00 a

* Numbers followed by a common letter are not significantly different at 5% level of DMRT.

Table 3. Some of the weed species commonly found on peanut-growing lands and known to be hosts of bacterial wilt.

Family/species	Common name	Relative susceptibility to bacterial wilt
Amaranthaceae		
Amaranthus spinosus	bayam duri	R
Asteraceae		
Ageratum conyzoides	goatweed, babadotan	R
Bidens pilosa	Spanish needle	
Crassocephalum crepidioides	thickhead	S
Sphilantes paniculata	jotang	S
Euphorbiaceae		
Croton hirtus		S
Phyllanthus spp.	meniran	S
Physalis angulata	ceplukan	S
Leguminosae		
Crotalaria juncea	crotalaria	S
Sesbania rostrata	sesbania	S

R = resistant; S = susceptible.

Table 4. Percentage of wilted plants from peanut seeds harvested from peanut plants of eight cultivars infected with the wilt bacterium.

Cultivar	Wilt intensity in the field (%)		Wilted seedlings from 100 seeds
	30 das	100 das	
Gajah	8	12	5
Pelanduk	12	18	5
Kidang	10	16	6
Macan	6	16	5
Tupai	12	20	7
Kelinc	40	60	8
GH 467	18	42	7
GH 469	24	48	8

* 100 seeds of each cultivar were sampled from bulk of seeds harvested from wilted plants. The seeds were grown in plastic trays containing sterilised Cikeumeuh soil. Observations were made two and three weeks after sowing to record the incidence of wilt.

Genetic control

Bacterial wilt is difficult to control by any single means. Integrated control, combining resistant cultivars, crop rotation and crop sanitation is a more appropriate way to control the disease.

The use of resistant cultivars is one of the most effective and economical ways to control a disease. In Indonesia, control of bacterial wilt using resistant varieties was initiated in 1910 when Dutch scientists found cultivar Raja. However, the resistance of this cultivar was not effective for very long. Another resistant cultivar (Schwarz 21) was then found by Schwarz and Hartley in the 1920s. Again the resistance of this cultivar was broken down within a 15-year period. Schwarz 21 was then replaced by cv. Gajah which was considered more resistant to bacterial wilt. Other cultivars such as Kidang, Pelanduk, Tupai, Banteng, and Marcan were subsequently developed in Indonesia. However, these cultivars were susceptible to other diseases so their productivity is still low. There has also been an indication that the resistance of peanut cultivars has tended to be degraded over a period of time. Therefore there is a need to continuously develop cultivars with effective resistance in order to effectively maintain disease control.

Since the 1985–86 wet season until the 1990–91 wet season, a few thousand lines of peanut germplasm, including local collections from Indonesia and international collections from ICRISAT, were evaluated for their resistance to bacterial wilt under both field and controlled environmental conditions in the glasshouse. Some of the germplasm lines resistant to the disease under both sets of conditions are listed in Table 5. Only a few were from ICRISAT, while most were either local cultivars from Indonesia or introductions from other countries. One ICRISAT line resistant to bacterial wilt is also reputed to have resistance to *Fusarium* spp. and *Aspergillus flavus*. These resistant lines could be used either as sources of resistance in breeding programs or directly as cultivars in peanut production.

Table 5. Some peanut cultivars and germplasm resistant and moderately resistant to bacterial wilt under natural and artificial conditions.

Genotype/identity	Country of origin	Genotype/identity	Country of origin
NC X-4	USA	Brudul	Indonesia
Giza Spread	Egypt	Lokal Tuban	Indonesia
Bola Blanco	Brazil	Lokal Tasikmalaya	Indonesia
Vera Cruz	Mexico	Lokal Muneng	Indonesia
Cocalmete	Spain	Deli Serdang	Indonesia
Cocalmete do grand palmas	Spain	Kacang Brudul	Indonesia
Chiba	Japan	Presi	Indonesia
Jaba 13	Japan	White Spanish	Indonesia
Tachinasaki	Japan	Macan	Indonesia
Tainan No. 7	Taiwan	Banteng	Indonesia
Tainung	Taiwan	Kidang	Indonesia
Argentina	Argentina	Ah 5/875/B-2-2	Indonesia
Mo Ket	Vietnam	Ah 5/875/38-8	Indonesia
E.G. Bunchag	India	790-61/26-36-B1-2	Indonesia
P I19647	West Africa	PI 268653	Indonesia
NC Ac17130	ICRISAT India	RR6	Indonesia
ICG 7502	ICRISAT India	RR6/875-673-1875	Indonesia
FESR 1	USA	GH32/NC Ac17090-4B-1	Indonesia
FESR 5	USA	Tupai	Indonesia
McCubbin	Australia	Tapir	Indonesia
Virginia Bunch	Australia	Pelanduk	Indonesia
Holland St. Runner EGPN 18		Landak	Indonesia
Chico (S Check)	Australia	Gajah (R Check)	Indonesia

* Under natural or field conditions, peanut seeds were grown in heavily infested soil at Cikeumeuh Experimental Farm. Under artificial conditions peanut plant were inoculated using the leaf axil injection in the glasshouse.

Crop rotation

In the past, research results on the effectiveness of crop rotation to control bacterial wilt were controversial. This is partly due to the fact that *P. solanacearum* is capable of attacking many plant species. Despite this fact, many reports suggest that crop rotation be considered in a bacterial wilt management program. During the second period of the project, two crop rotation trials were conducted. One trial was on upland conditions at Cikemeuh Experimental Farm near Bogor, the other was on irrigated land at Muara Experimental Farm. Prior to the trial, the susceptible peanut cv. Kelinci was grown in the field to assess wilt intensity and uniformity in the site. Subsequently, the rotation was started for the duration of one to three years. In each year two crops were grown in each plot. The crops used in the rotation were peanut (cv. Kelinci), rice (cv. Cisadane), maize (cv. Ariuna), soybean (cv. Orba) and sweet potato (cv. Borobudur). After each cycle of rotation, susceptible crops of peanut cv. Kelinci and tomato cv. Gondol Hijau were grown in each plot to assess wilt intensity after rotation. Table 6 shows wilt intensity on the check plants after one and two year rotations, because the third year rotation is still in progress. Data indicated that wilt intensities were reduced in each plot after rotation of peanut with other crops. Rotation with irrigated corn gave the best reduction in wilt intensity in the field.

Effect of soil type and organic manures on bacterial population and wilt intensity

Previously published reports indicate that bacterial wilt intensity in the field may be affected by soil type and organic matter amendments. In the 1989–90 wet season, an experiment in the glasshouse investigated the development of *P. solanacearum* populations and wilt intensities on peanut cv. Kelinci in four different soil types as affected by the addition of four organic manures.

The soil types were organosol, red-yellow podsolic, red latosol and grey latosol, and the organic manures

Table 6. Effect of crop rotation and duration on incidence* of bacterial wilt.

Year 1		Year 2		Year 3		Wilt Intensity	
WS88-89	DS89	WS89-90	DS90	WS90-91	DS91	Peanut	Tomato
Peanut (base level)						64	80
Peanut	Corn					48	68
Peanut	Corn	Peanut	Corn			40	56
Peanut	Corn	Peanut	Corn	Peanut	Corn	**	**
Corn	Peanut					56	70
Corn	Peanut	Corn	Peanut			44	56
Corn	Peanut	Corn	Peanut	Corn	Peanut	**	**
Rice	Rice					33	45
Rice	Rice	Rice	Rice			20	35
Rice	Rice	Rice	Rice	Rice	Rice	**	**
Corn	Soy					44	62
Corn	Soy	Corn	Soy			31	46
Corn	Soy	Corn	Soy	Corn	Soy	**	**
S.pot	S.pot					58	71
S.pot	S.pot	S.pot	S.pot			47	60
S.pot	S.pot	S.pot	S.pot	S.pot	S.pot	**	**

* The susceptible checks peanut cv. Kelinci and tomato cv. Gondol Hijua were grown in each plot just after each rotation.
** Data on wilt intensity after three-year rotation not available; experiment still in progress.

were chicken manure, goat manure, cattle manure, and compost. Table 7 shows bacterial wilt intensities on cv. Kelinci three weeks after sowing the peanut seeds. There were significant effects of soil type and organic manures on bacterial wilt intensity. Generally the bacterial wilt intensity on cv. Kelinci was the lowest when grown on red-yellow podsolic soil, compared to those on organosol or latosols. The use of organic manures generally reduced bacterial wilt intensity. In this trial, compost was the best manure to reduce bacterial wilt intensity in the soil.

Table 7. Effect of soil types and organic manures on bacterial wilt intensities on peanut cv. Kelinci, three weeks after sowing in the glasshouse.

Treatment	Wilt intensity (%)
Main plot (soil type)	
Organosolic soil	35.4 b
Red-yellow podsolic	26.2 a
Red latosolic	35.0 b
Grey latosolic	33.8 b
Sub plot (organic manure*)	
Without manure (control)	41.0 c
Chicken manure	27.2 b
Cattle manure	40.8 c
Goat manure	31.0 b
Compost	22.8 a

* In all treatments the organic manures were mixed with the soil three weeks prior to sowing the peanut seeds. Values followed by a similar letter are not significantly different.

Data on the bacterial population development in the soil was not conclusive due to technical difficulties in isolating the pathogen from the soil.

Implications for peanut production and future research in Indonesia

After a lag period of more than 25 years, research on bacterial wilt of peanut in Indonesia has been rejuvenated. It is without doubt that the collaborative research work has been fruitful and beneficial to the improvement of peanut production in Indonesia. During phase I of the collaboration, the disease trap nursery trial was shown to be an excellent method of evaluating the status of peanut diseases in the country. With data obtained from the surveys we were able to confirm that bacterial wilt of peanut was still widespread and potentially dangerous to peanut production. Following the surveys we also undertook studies on various aspects of the disease and its pathogen. However, the three-year period of phase I was too short to study various aspects of the disease.

Within phase II of the project, more research has been done. Some aspects relating to control of the disease were studied. Further sources of resistance to bacterial wilt were identified. Seed infection and transmissibility of the bacterium through peanut seed were confirmed. However, the inheritance of resistance to bacterial wilt in peanut has not been studied.

Although basic information has been obtained, more aspects need to be researched if the disease is to be controlled effectively, to enhance the improvement of peanut production in Indonesia. Some aspects of bacterial wilt needing further investigation include:

- studies on host range and aggressiveness of strains and their geographical distribution;
- significance of weed hosts, including those latently infected, on distribution of the pathogen;
- the process of infection of peanut plants by the bacterium.
- further studies on seed transmission of the bacterium;
- interactions between the pathogen and other soil microorganisms;
- relationships between soil biological factors and disease severity;
- relationships between cropping systems and disease severity;
- relationships between agroclimatic factors and disease severity.

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The Influence of some Environmental Factors and Isolate Variability on the Development of Peanut Bacterial Wilt Caused by *Pseudomonas solanacearum*

S. Subandiyah* and A.C. Hayward†

BACTERIAL wilt disease caused by *Pseudomonas solanacearum* is the only significant bacterial disease of peanut. Although the disease on other crops like potato, tomato, eggplant, chilli and ginger is worldwide in distribution, peanut bacterial wilt occurs only in isolated areas. At present, it is of importance only in Indonesia, China and Uganda. In some countries the status of the disease on peanut is uncertain. Peanut bacterial wilt in North Carolina, USA was once considered important but is now considered a minor disease.

It is not known whether the sporadic occurrence of peanut bacterial wilt is a reflection of restricted distribution of specific strains of high virulence, or whether the determining factors are environmental. The distribution of distinct pathotypes in relation to ecology and etiology of peanut bacterial wilt needs more investigation.

Resistant cultivars have been used in Indonesia to reduce yield loss of peanut caused by *P. solanacearum*. It has been suggested that the stability and durability of genetic resistance to bacterial wilt may be under threat due to possible genetic variability of the pathogen. Some resistant cultivars were not resistant (or they had variable resistance) when tested in different production areas, while some resistant cultivars show different reactions when tested in other localities in the same country. For example, cultivars 467 and 469 from Indonesia were resistant when tested in Jakenan (Central Java) but susceptible when tested at Cikemeuh (West Java) and in glasshouse trials.

The source of the bacterial isolates is an important variable affecting the susceptibility of peanut cultivars to bacterial wilt. Some isolates of *P. solanacearum* from crop plants other than peanut and weeds such as *Crassocephalum crepidioides* were as virulent for susceptible peanut cultivars as the most virulent isolates from peanut. Some isolates from potato were not virulent following axillary inoculation. Nothing is known about the relative virulence of different strains of *P. solanacearum* using the most critical technique of infectivity titration.

This paper presents results of a study at The University of Queensland investigating the influence of diurnal temperature variation and nitrogen nutrition on disease expression. It also reports comparison of the virulence for peanut of strains of *P. solanacearum* from different hosts, originating from different localities in Indonesia and Australia (see Tables 1–3). No direct comparison of strains of *P. solanacearum* was made in these experiments because of quarantine restrictions and because the risk of escape of a non-indigenous strain of *P. solanacearum* could not be contemplated. However, DNA was extracted (using the modified method of Samadpour et al., 1988) from Indonesian isolates and imported into Australia for direct comparison with the DNA of Australian isolates.

Research Highlights

Experiments on the influence of temperature

All isolates caused more severe symptoms at high temperature regimes (30°/25°C and 35°/30°C day/night temperatures) than at low temperatures

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Table 1. List of isolates used in virulence screening experiments in Australia from 15 March to 25 April, 1989.

Isolate	Host plant	Locality	Biovar
001	Tomato	Redland Bay, Qld	3
0234	*Pultenaea villosa*	Nambour, Qld	3
0171	*Solanum melongena*	Nambour, Qld	3
0190	*Xanthium pungens*	Nambour, Qld	3
0369A	Tomato	Banora Point, NSW	3
01017S	*Solanum nigrum*	Maroota, NSW	3
0732	Tomato	Darwin, NT	Ab. 2
0672	Zinnia	St Lucia, Qld	3
01023S	*Strelitzia reginae*	Somersby, NSW	3

Table 2. List of *P. solanacearum* isolates used in virulence screening experiments in Australia from 20 September to 31 October, 1989.

Isolate	Host plant	Locality	Biovar
001	Tomato	Redland Bay, Qld	3
0234	*Pultenaea villosa*	Nambour, Qld	3
0171	*Solanum melongena*	Nambour, Qld	3
0190	*Xanthium pungens*	Nambour, Qld	3
0369A	Tomato	Banora Point, NSW	3
01017S	*Solanum nigrum*	Maroota, NSW	3
0672	Zinnia	St Lucia, Qld	3
01023S	*Strelitzia reginae*	Somersby, NSW	3
0732	Tomato	Darwin, NT	Ab. 2
0405	Tomato cv. Pirate	Bundaberg, Qld	3
0905	Tomato cv. Rochdale	Bundaberg, Qld	3
0505	Potato	Gatton, Qld	2
2456c	Tomato	Bundaberg, Qld	3
2456g	Tomato	Bundaberg, Qld	3
2456l	Tomato	Bundaberg, Qld	3
2456m	Tomato	Bundaberg, Qld	3
2456t	Tomato	Bundaberg, Qld	3

Table 3. List of *P. solanacearum* isolates used in virulence screening experiments in Indonesia, 20 January to 25 February, 1990.

Isolate	Host plant	Locality	Biovar
1005 Mr	Peanut	Maros, South Sulawesi	3
1105 B	Peanut	Bogor, West Java	3
1405 WS	Peanut	Pasaman, West Sumatra	3
EW 0290	Peanut	Tangerang, West Java	3
1605 WS	*Pogostemon* sp.	Pasaman, West Sumatra	3
1705 WS	Eggplant	Pasaman, West Sumatra	3
T 435	Chilli pepper	Wates, Central Java	3
T 440	*Curcuma longa*	Bogor, West Java	3
2305 L	Tomato	Lembang, West Java	2
S718	Potato	Jambegede, East Java	4

(20°/15°C and 25°/20°C). At high temperatures, most isolates produced maximum disease indices of 3–3.67, on a 1–5 scale (although isolate 01017S produced a disease index of 4.3 at 35°/30°C). At low temperature regimes most isolates produced slight or no symptoms, although isolates 001, 0234, and 0171 produced disease indices of 2–3.3 at six weeks after inoculation.

There were no significant differences between disease indices produced by each isolate at 20°/15°C and at 25°/20°C, or between the disease indices at 30°/25°C and those at 35°/30°C, except for isolate 001 which produced a significantly higher disease index at 35/30°C than at 30°/25°C. Mean symptom scores of infected peanut plants six weeks after inoculation at different temperature regimes are shown in Figures 1 and 2.

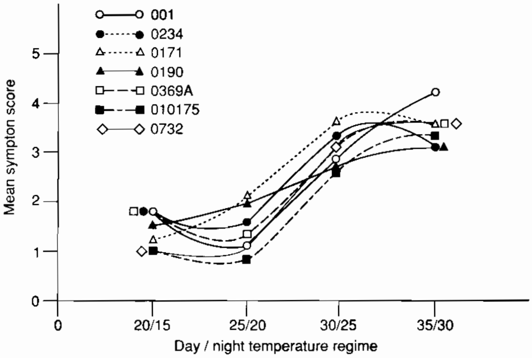

Figure 1. Mean (derived from 3 inoculum levels and 2 replicates) symptom scores of infected peanut plants six weeks after inoculation at different temperature regimes.

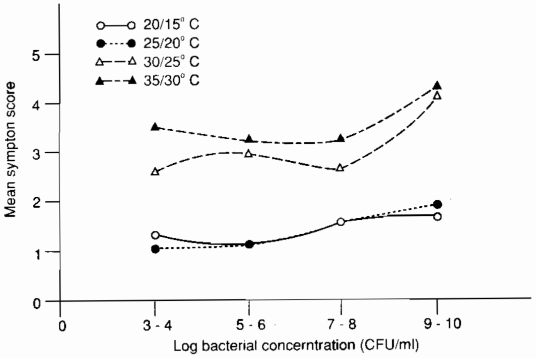

Figure 2. Mean (derived from 7 isolates and 2 replicates) symptom scores of infected peanut plants six weeks after inoculation at different temperature levels.

Experiments on nitrogen nutrition

Experiments on the influence of N fertilizer conducted in both Australia and Indonesia suggest that most isolates produced more severe symptoms on peanut after low N treatment (20 kg N/ha) than after high N treatments (either 20 kg N/ha + *Bradyrhizobium* inoculum, or 200 kg N/ha). However, high nitrogen treatments do not consistently reduce the severity of disease; sometimes particular isolates produce more severe symptoms under high N levels, or N level does not influence disease symptoms. The use of *Bradyrhizobium* inoculum does not seem to have a specific interaction with the development of bacterial wilt. Mean symptom scores of infected peanut plants at different nitrogen treatments are shown in Figures 3 and 4.

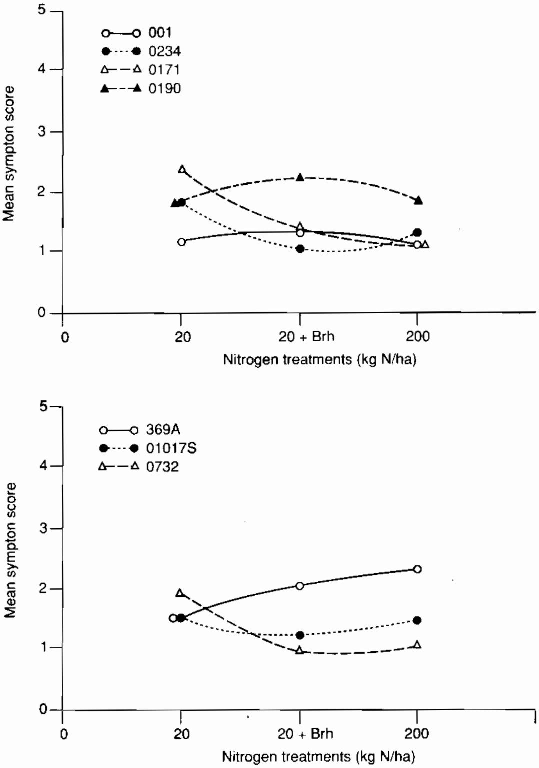

Figure 3. Mean (derived from 3 inoculum levels and 3 replicates) symptom scores in Australia of infected plants six weeks after inoculation at different N levels.

Virulence screening

The virulence screening experiments in Australia (see Fig. 5) showed that all tested biovar 3 isolates could infect peanut, although with different levels of severity. The biovar 3 isolates used in Australia could

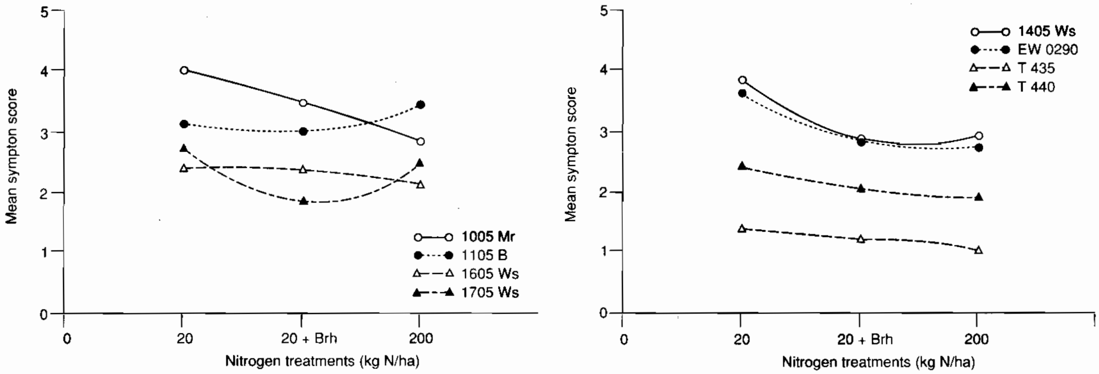

Figure 4. Mean (derived from 3 inoculum levels and 3 replicates) symptom scores in Indonesia of infected peanut plants six weeks after inoculation at different N levels.

be separated into three groups on the basis of virulence on peanut. One group, consisting of the isolates from wilt endemic areas in Queensland (Nambour and Bundaberg), produced mean symptom scores of 3 or more. A second group, consisting of isolates from different localities in Queensland, the Northern Territory and New South Wales, produced disease severities of less than 3 but greater than 2.5. Group 3 consisted of isolate 01023S which was least virulent on peanut. One isolate of biovar 2 (isolate 0505) did not infect peanut.

The results of the virulence experiment in Indonesia (Fig. 6) suggested that Indonesian isolates tested could be separated, on the basis of virulence, into two groups; a peanut isolate group and a non-peanut isolate group. Peanut isolates were much more virulent than non-peanut isolates and produced acute symptoms of wilt especially at high inoculum concentrations. All biovar 3 isolates were virulent on peanut, whereas an isolate of biovar 2 (isolate 2405L) and an isolate of biovar 4 (isolate S718) were not virulent on peanut.

In the experiments in both Australia and Indonesia the percentage of peanut plants killed by the non-peanut isolates was low, and none of them killed 50% or more of the plants at all inoculum levels. On the other hand, peanut isolates were able to kill up to 100% of the inoculated plants.

Restriction Enzyme Analysis of the DNA

The DNA fragment patterns resulting from *Bam* HI or *Sal* I digestion were similar for all biovar 3 isolates. All isolates of biovar 3 originating in Australia had identical DNA banding patterns, whereas 3 isolates of biovar 3 originating in Indonesia (2 peanut isolates and 1 non-peanut isolate) were slightly different in DNA fragment pattern. The isolate of biovar 2 (isolate 0505) and an isolate of aberrant biovar 2 (isolate 0732) had completely different DNA fragment patterns from each other and from those of biovar 3 isolates.

The similarity coefficients between isolates were calculated on the basis of DNA banding patterns resulting from *Sal* I digestion. The similarity between the isolates of biovar 3 and the isolate of biovar 2 ranged from 40.6 to 50.0%, and between the biovar 3 isolates and the aberrant biovar 2 isolate, from 46.9 to 56.3%. The similarity between isolates of biovar 3 ranged from 81.3 to 96.9%. Similarity between the Indonesian peanut isolates (isolates EWO290 and 1905 Mr) was 84.4%.

Implications for production and research

The experiments on the influence of temperature regimes showed that high temperatures support the development of peanut bacterial wilt by non-adapted isolates of this pathogen. At low temperature regimes disease symptoms were slight or absent. Therefore it is suggested that high temperature regimes are very important and necessary for the development of peanut bacterial wilt. Li et al. (1981) reported that the optimum temperature for the development of peanut bacterial wilt in China was 28–33 °C.

Disease indices at high and low N levels were not significantly different. This could be because both NH_4-N and NO_3-N were applied in the experiment, and these may have opposite effects on the development of the disease. It is elsewhere reported that the application of NH_4-N decreased the severity of bacterial wilt on tobacco and tomato, whereas the disease was increased by NO_3-N application.

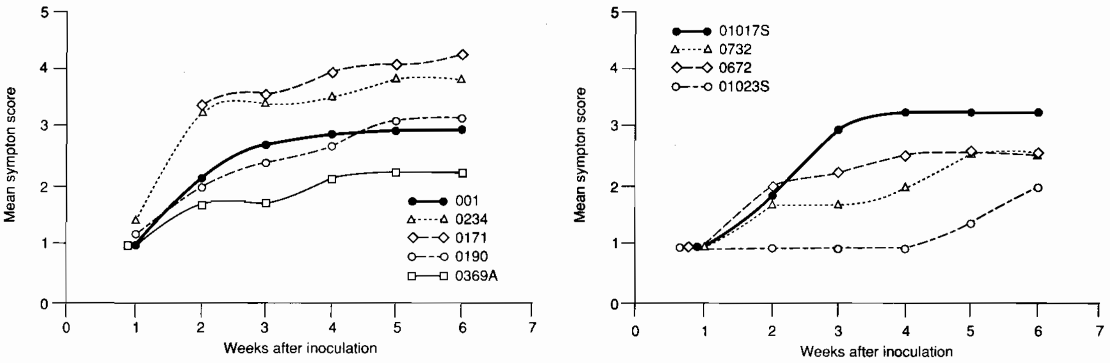

Figure 5. Disease progress curves of infected peanut plants from virulence screening experiments in Australia.

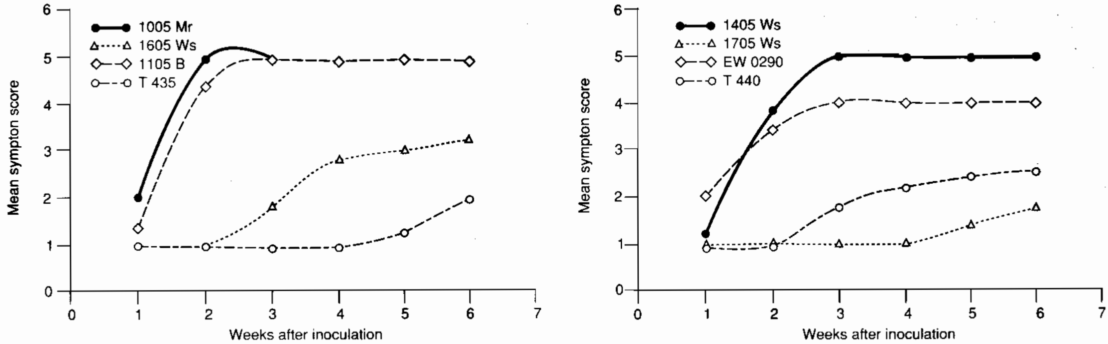

Figure 6. Disease progress curves of infected peanut plants from virulence screening experiments in Indonesia.

The results of the virulence screening experiments show that peanut isolates are much more virulent than non-peanut isolates. Non-peanut isolates originating from endemic areas (Nambour and Bundaberg) were more virulent than isolates from other areas in Australia. Non-peanut isolates could infect peanut but the development of the disease was slow. Therefore, it is suggested that highly virulent populations of *P. solanacearum* are required for the development of peanut bacterial wilt. Endemic areas, like Nambour and Bundaberg in Queensland, may have populations of high virulence.

Restriction enzyme analysis of the DNA show that there is a correlation between the DNA banding patterns and the geographical origin of the isolates rather than host plant of origin. The isolates of biovar 3 originating in Australia had identical DNA banding patterns, whereas the isolates of biovar 3 from Indonesia, including peanut isolates, were similar but not identical in DNA banding pattern. Therefore, populations of *P. solanacearum* affecting peanut may represent specific strains which have developed under the favourable environmental conditions (high temperature, low soil nitrogen levels) for disease development in Indonesia. Similar populations may develop in endemic areas in Australia.

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The Importance and Genetic Control of Peanut Stripe Virus

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IN Indonesia, peanut is the second most important legume crop, after soybean. In 1988, the total harvested area of peanut was 607 000 ha with an average yield of 0.97 t/ha. This yield is lower than the potential yield of the improved varieties, which can produce 2–2.5 t/ha. Virus diseases are one of the limiting factors in peanut production.

Among the virus diseases, peanut stripe virus (PStV) is the most important. The disease is present in almost all peanut growing areas throughout Indonesia, although the disease intensity varies among locations and seasons. Peanut crops planted in the second dry season usually exhibit heavy PStV infection and it has been estimated that yield losses are regularly up to 30–40%. Since PStV was considered economically important in the peanut production system, management of the disease was given priority.

Peanut stripe virus, which belongs to the potyvirus group, is transmitted by several aphid species in a non-persistent manner and through infected seeds. It is able to infect other leguminous crops, including soybean, cowpea and mungbean. For these reasons, the use of resistant varieties seemed to be the most effective way to manage it. Resistant varieties are usually compatible with other disease management approaches, require minimal crop management intervention and help preserve the environment. Moreover, the use of resistant varieties can be sufficient to minimise losses caused by this type of disease.

Research Highlights

Based on a survey of the distribution of PStV carried out by ICRISAT and ACIAR staff and others, it was concluded that PStV was infecting peanut crops in Indonesia, Malaysia, the Philippines, Japan, People's Republic of China, India and other East and South Asian countries, and the United States of America. PStV was considered an economically important peanut disease in many of these countries, although data on the yield losses of peanut caused by it was still lacking. Therefore, assessment of crop losses due to PStV was recommended during the first Coordinators' meeting on PStV in June 1987 at Malang.

Yield loss assessments

Experiments to assess peanut yield loss caused by PStV were carried out in three consecutive years (1988, 1989 and 1990) using different approaches. In 1988, experiments were carried out at the Muneng Experimental Farm, Probolinggo in the dry season (June–October) using natural infection, and at Jambegede Experimental Farm, Malang using different initial infection levels in September–December. The results showed (in Gajah variety) that the number of pods per plant and the dry pod weight from infected plants were lower than those from healthy plants. These effects were more pronounced for plants infected at an early age (Table 1). At Muneng, the yield reduction varied between 14 and 56%, while at Jambegede 7 to 24% loss was measured, again depending on the age at which the plants were infected.

In 1989–1990, further yield loss assessment experiments were carried out at Jambegede during the dry season (July–November) and the wet season (November 1989–March 1990). During the wet season, yield was assessed after artificial (mechanical) inoculation at different ages of peanut plants grown in screen cages, and compared to the yield of naturally infected plants grown outside the cages. The results showed no significant difference in plant height, pod number and dry pod weight per plant (see Table 2). However, in the dry season of 1989,

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* MARIF, Malang, East Java, Indonesia
† MORIF, Maros, South Sulawesi, Indonesia
‡ QDPI, Kingaroy, Queensland, Australia

Table 1. Yield loss of peanut infected by PStV at different times, Muneng and Jambegede, dry season 1988.

Location	Time of infection w.a.p.	No. pods/plant	Dry pod weight/plant (g)
Muneng	1	3.81	4.55
	2–5	6.76	6.99
	6–8	7.14	8.28
	9–10	8.16 n.s.	8.59 n.s.
	Healthy	5.59	10.39
Jambegede	1	13.48	13.98
	2	15.00	13.98
	4	14.93	14.50
	6	19.33 n.s.	17.68 n.s.
	8	17.77 n.s.	17.65 n.s.
	10	21.88 n.s.	19.22 n.s.
	Healthy	20.66	18.98

Notes: w.a.p. = weeks after planting; n.s. = not significantly different from healthy plants at 5% level.

Table 2. Yield loss of peanuts infected by PStV at different ages at Jambegede, during the dry season of 1989 and wet season of 1989–1990.

Mode of infection		Dry season		Wet season	
	w.a.p.	No. pods/plant	Pod weight (g)	No. pods/plant	Pod weight (g)
Artificial inoculation (caged)	1	12.0	12.7	5.6	5.1
	2	11.9	12.2	7.5	6.4
	3	16.9	16.6	8.9	7.9
	4	13.9	12.4	6.6	5.5
	5	9.3	7.7	7.2	5.7
	6	12.3	11.3	9.3	7.7
	7	13.1	10.6	7.2	5.6
	8	15.6	14.9	6.7	6.6
	9	13.8	10.7	5.5	4.7
	Healthy	13.8	10.7	7.8	7.7
Naturally infected (open field)	4	13.1b	13.2b	7.9	7.5
	5	10.0c	9.4de	6.8	6.5
	6	9.7c	9.0	8.0	7.6
	7	11.7bc	11.6bcd	8.0	7.6
	8	10.7c	10.2cde	6.6	6.3
	9	11.4bc	10.3cde	8.3	7.9
	10	13.0b	12.2bc	8.0	7.6
	Healthy	19.0a	17.9a	9.0	8.6

Notes: w.a.p. = weeks after planting; values followed by similar letters are not significantly different.

plants naturally infected at different ages showed significant differences in plant height and pod yield. Peanut plants infected by PStV at 10 weeks after planting or earlier grew shorter and produced lower yields than healthy plants. Pod number of infected plants was reduced by 30 to 49%, and dry pod weight per plant of infected plants was reduced by 26 to 50%.

This reduction is similar to that obtained in a yield loss assessment experiment conducted at Muneng in the dry season of 1988, but again at this location in the wet season 1989–1990, PStV infection did not significantly reduce the peanut yield.

Yield loss assessments conducted at Bontobili, South Sulawesi in the dry seasons of 1989 and 1990 also revealed that PStV infection consistently causes pod and dry weight reductions of up to 50% and 54–60% respectively, depending on when the plants were infected (Table 3). Further analysis showed that PStV infection also causes reduction in seed number per hill and seed weight.

In the 1990 dry season experiments at Jambegede, pod number and dry pod weight of peanut plants artificially inoculated at 10 days after planting, or naturally infected at different plant ages, were not significantly different from those of healthy plants. However, seed number and seed weight of plants infected at seven weeks after planting or earlier were significantly lower than those of healthy plants. Seed number per plant and seed weight reduction varied between 16–22% and 15–20% respectively.

These results indicate that peanut yield losses caused by PStV are much higher in the dry season than in the wet season. Plants infected during the early stages of growth will be more severely affected than plants infected later.

Sources of resistance

During the last four years (1987–1990) more than 10 000 entries from the world peanut germplasm collection held at ICRISAT have been evaluated under natural field conditions for resistance to PStV. These tests included almost the entire collection, except for a few lines where germination problems were experienced. Experiments were conducted at Muneng Experimental Farm at MARIF at Probolinggo (East Java), in South Sulawesi at Maros Experimental Farm of MORIF at Maros, and at Barru. Except in the 1987 experiments, some peanut germplasm was duplicated for sowing at both the Java and the Sulawesi locations. The results showed that, among the peanut germplasm tested, none was resistant to PStV infection. Some lines were observed to exhibit milder symptoms than other lines (Table 4).

Mechanical inoculation of some wild *Arachis* spp. in the glasshouse indicated that *Arachis duranensis* was resistant to PStV infection. These results show that no cultivated peanut cultivar with resistance to PStV is available.

Table 3. Yield loss of peanut infected by PStV at different time of infection at Bontobili. Dry season 1989 and 1990.

Time of infection	No. of pods per 2 plants		Dry pod weight per plant (g)	
w.a.p.	1989	1990	1989	1990
2	9.0a	—	8.4a	—
3	9.0a	7.5a	9.7a	7.9a
4	10.4a	8.5b	11.4ab	9.5b
5	11.0ab	9.8c	11.9b	10.9c
6	13.4bc	10.8d	15.0c	12.0d
7	15.5cd	12.0c	17.0cd	13.8e
8	15.9cd	13.0f	19.1d	14.7f
9	15.6cd	13.6f	17.8cd	15.3f
10	17.2d	13.9g	20.8d	15.6f
11	17.5d	14.7gh	21.0d	16.8g
12	17.2d	—	21.3d	—
Healthy	17.8d	15.2h	21.2d	17.1g

Notes: w.a.p. = weeks after planting; values followed by the same letter are not significantly different.

Table 4. Peanut germplasm lines showing mild symptoms of PStV infection, Muneng 1989–1990.

Year	Peanut germplasm			
1987	ICG 1560	ICG 2385	ICG 5428	ICG 6179
	ICG 7676	ICG 8483	ICG 9388	ICG 9896
	ICG 9910	ICG 10542	ICG 105993	PFDRGVT 36
	PFDRGVT 38			
1988	ICG 640	ICG 1975	ICG 3837	ICG 3844
	ICG 8379	ICG 9459	No. 1019	83/366-1
1989	ICGV 88259	ICGV 8806	85/166-4	85/172-1
	85/165-19	10/93-2		

Seed transmission

ELISA and grow-out tests confirmed that PStV is transmitted through infected peanut seeds. Seed transmission rates of plants inoculated at 10 days after planting and grown in the screenhouse varied between 1.4 and 3.3% depending on the peanut variety. However, the frequency of naturally infected plants in the fields was only 0.25 to 0.37%, depending on the time at which the plants became infected (Tables 5 and 6).

Table 5. PStV seed transmission in different peanut varieties.

Variety	Transmission rate*	%
Gajah	7/190	3.62
Kelinci	3/240	1.25
Rusa	2/140	1.43
Anoa	3/90	3.33
Kerantil	2/120	1.66

Note (*): number of seeds indexed as positive by ELISA/number of seeds tested.

Table 6. PStV seed transmission in Gajah variety infected at different ages.

Time of infection w.a.p.	Transmission rates*	%
2	19/5175	0.37
4	20/6460	0.31
6	18/7225	0.25
8	7/2700	0.26

Note: number of seeds indexed as positive by ELISA/number of seeds tested; PStV was detected in the cotyledons and embryo axis of the infected peanut seeds, but could not be detected in the testa tissues consistently.

Implications for production research in Indonesia

Yield loss assessment studies show that PStV infection markedly reduced peanut yield, especially when grown as the second crop in the dry season. Peanut crops planted in the first dry season usually exhibit less PStV infection. Some efforts have been made to control PStV on peanuts using insecticides to control the virus vectors, or cultural practices such as roguing of infected plants, hand weeding and interplanted maize as a barrier. However, they do not significantly reduce PStV incidence.

Resistant varieties and the use of virus-free seed appear to be the only ways to control PStV. Unfortunately, our results and other resistance screening carried out in China, USA, India and Thailand have not succeeded in finding cultivated peanut cultivars resistant to infection. Some wild *Arachis* spp. have been observed to have resistance, but transfer of these resistant genes to cultivated peanuts will not be easy, due to the incompatibility problems between *A. hypogaea* and some wild species. A biotechnological approach to transferring resistance into adapted cultivars has been proposed for collaborative research between Australian and Indonesian scientists. This proposal has been approved.

In the meantime, we propose looking for tolerant varieties, i.e. varieties which, although infected by PStV, only suffer small yield reduction. Another possible approach for control of PStV is non-seed transmission. Experiments on tolerance and non-seed transmission are continuing.

Management of Peanut Foliar Diseases

K.J. Middleton*

FOLIAR diseases caused by fungi are important in most areas where peanuts are grown, particularly where the crop is grown as a monocrop over large areas. Even where peanuts are grown as an intercrop, these diseases can cause significant destruction of foliage, and hence reduce yield. It is possible for total loss of yields to occur.

There are several diseases in this category. The most widespread are the two leafspot diseases, usually referred to as early leafspot (caused by *Cercospora arachidicola*) and late leafspot (*Cercosporidium personatum*). In the past decade, rust (*Puccinia arachidis*) has become more widespread, and is now a serious disease also. In addition to these three diseases, more than twenty other fungi can cause spots and blights of the foliage, although none of these justify any form of control beyond good cultural practices such as rotation and farm hygiene. The leafspot diseases and rust are the subjects of this report.

Probably as a result of cultural practices used, the leafspots and rust have caused serious losses for many years in the mechanised farming systems of developed countries and farmers have used fungicides to control them. As the economics of developing countries improve, and production stability assumes equal importance to that of production, as such, the use of fungicides to protect peanuts against the leafspots and rust in these countries is gaining acceptance.

In recent years genetic resistances to these diseases have been found, and the peanut-breeding programs of many countries have among their aims the production of disease-resistant varieties which are equivalent in all other respects to traditional susceptible cultivars. The reasons for this change include concerns about the environmental effects of pesticides, their costs, the need for repeated use and the likelihood of failure in particular situations. However, the development of well-adapted, highly disease-resistant varieties is not yet commonplace and alternative approaches to the minimisation of fungicide use are being explored.

To minimise the use of fungicides without sacrificing economic gain requires a sound knowledge of the biological spectrum of activity of the available fungicides, information about the activity of these chemicals against the disease, and the effects of the disease on crop yield.

Research Highlights

Several different experiments were conducted to assemble the information needed to make the necessary decisions for minimising the economic impact of peanut leafspots and peanut rust. These were:

- field-testing candidate fungicides in Indonesia to confirm their activity against the pathogens under local conditions;
- studying the mode of action of newer fungicides available to control these diseases, and
- quantifying the economic injury level of these diseases, to enable the farmer to decide whether fungicidal control was economically rewarding.

Testing of fungicides has been carried out largely with the support of the national program and the ATA 272 project, with inputs of information as required from ACIAR scientists.

The leafspot pathogens are controlled with varying levels of success by the fungicides benomyl, mancozeb, chlorothalonil, bitertanol, cyproconazole, and tebuconazole. The rust pathogen is controlled by all of these except benomyl.

The Australian national research program undertakes controlled investigations designed to provide information about the mode of action of fungicides which can be used against these diseases. This information is useful in choosing an appropriate

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fungicide, when chemical control is contemplated. For example, mancozeb and chlorothalonil are protectant fungicides, i.e. they can only prevent further infection taking place, and are incapable of controlling infections after fungal penetration of the leaf tissue has occurred. Benomyl has limited ability to penetrate leaf tissue, but very limited ability to control established infection.

Newer fungicides vary in their ability to control pre-existing and future infection. For example, cyproconazole (sold as Alto® in Australia) can both provide protection against future infections and eradicate infections which have occurred before application. The degree of control reduces as the interval between infection and application increases. These effects are shown in Figure 1, where negative time indicates eradication, and positive time indicates protection.

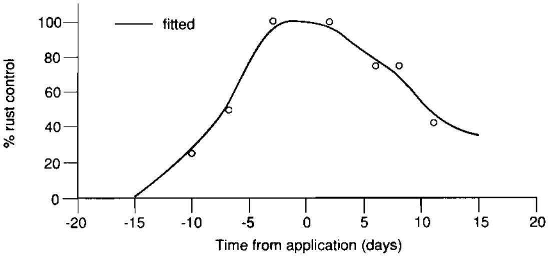

Figure 1. Cyproconazole against peanut rust.

Data for other fungicides and other pathogens are being accumulated and will be invaluable in disease control in all countries, for making appropriate decisions about the use of fungicides.

The most difficult decision facing a peanut farmer whose crop is infected by foliage diseases is whether the use of a fungicide will result in a greater profit from the crop. The farmer needs to know (a) the cost of the fungicides available, and capable of controlling the disease, and (b) whether the incidence of disease present will reduce yield by an amount greater than the cost of control.

Detailed field studies conducted in Australia attempt to provide an insight into this complex, dynamic system. Epidemics of the foliage diseases (leafspot and rust) have been manipulated, using inoculum, sprinkler irrigation and fungicides, to enable study of yield responses to varying disease levels at different crop ages.

Despite the promotion of 'leafspot advisories' and 'disease-forecasting' systems in other countries, attempts to define the interaction between crop age and disease intensity in terms of the effect on yield have shown that, under semi-tropical and tropical conditions and using cultivars with low partitioning characteristics, the relationships are not clear. The factors which control pod (seed) yield are complex, and the modelling exercise supported by this project will be needed to unravel them.

The effects of a foliage disease are to reduce the ability of the crop canopy to intercept radiation by reducing healthy leaf area and by causing leaf necrosis. Lowered radiation interception by the crop reduces the capacity of the canopy to produce assimilates for later conversion into harvestable yield. Diseases can also affect factors such as water-use efficiency, by interfering with normal stomatal function, and some pathogens can produce toxins which affect leaf function, but these effects are minor compared to the light responses. For these reasons, examination of the effects of disease involves a study of the remaining healthy tissue, not the diseased tissue.

Both the area of healthy leaf and the time the healthy leaf is available for assimilate production will influence the total assimilate supply, assuming no other factors are limiting. These parameters can be combined into a unit called 'healthy leaf duration' (HAD). An examination of HAD has failed, despite many attempts, to show a close relationship to yield (see Figure 2, as an example).

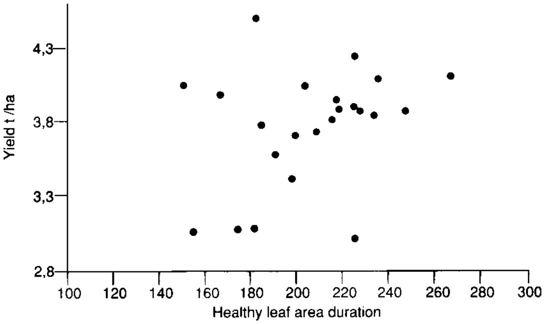

Figure 2. Effect of HAD on yield.

It must be conceded reluctantly that any attempt to precisely define a damaging level of disease at a particular crop age will fail. Peanut farmers should be encouraged to make decisions about the use of fungicides based on their experience of local epidemic development rates, always trying to avoid disease levels where healthy foliage cover falls below that needed for full light interception. In general terms, this suggests that the natural wish to keep crops close to free from foliage diseases will result in overuse of fungicides.

Implications for Peanut Production and Research in Indonesia

Peanut farmers in Indonesia should not be encouraged to use fungicides on their crops, and in fact many need to be actively discouraged from so doing. This does not mean that foliage diseases do not cause losses. Rather, it is an expression of concern that poor decisions about fungicides might be made, and cost farmers dearly. Farmers need to be taught how to choose whether or not to apply fungicides, and which fungicide to apply.

As most of the persuasion to apply fungicides will come from commercial interests, it is likely that the full choice may not be available to the farmer. It is also possible that farmers might be persuaded to buy fungicide when there is no benefit to the crop.

As many of these decisions, to be correct, demand an intimate knowledge of plant pathology and the social structure of the rural community, it is important that accurate information be made available to the extension services.

The peanut growth model might be used to gain a better understanding of when the use of fungicides to control foliage diseases is justified. Scientists in AARD institutions should maintain contact with scientists working in this area.

The Influence of Plant Population on Peanut Growth and Yield Under Variable Water Supply

T. Adisarwanto*, A. Rahmianna*, G.C. Wright† and M.J. Bell†

CURRENTLY, a blanket plant population (PP) recommendation in the vicinity of 250 000 or more plants/ha exists for the short-season Spanish cultivars grown under a range of wet and dry season cropping systems in Indonesia.

It appears this recommendation is based on limited research, as preliminary 'omission' experiments in phase I (Project No. 8419) demonstrated that high pod yields were achievable using PPs as low as 125 000 plants/ha. Similarly, Sumarno (pers. comm.) suggests that an optimal PP for newly released Indonesian cultivars may be around 167 000 plants/ha. Also, research in other crops (e.g. maize and soybeans) shows that drought stress can influence the PP response, such that optimal densities occur at lower and lower PP as the severity of drought increases. Research into this response has not been conducted for peanut in Indonesia, but seems warranted given that peanut is largely produced under water-limited conditions.

The high seeding rates needed to achieve high PPs represent a significant proportion (up to 40%) of the total variable costs of commercial peanut production. Therefore it is vitally important that information on factors affecting optimal peanut PP in Indonesia is collected.

The objective of this PP research report was therefore to define the optimal PP for peanut grown under a range of cropping systems throughout Indonesia and in Australia. The influence of soil water supply on peanut PP response was evaluated critically by using a simple mathematical model as a framework for analysis. The application of this model for the prediction of optimal PP under variable water supply was also attempted.

Research Highlights

Pod yield response under well-watered conditions

Increasing PP has been shown often to increase total dry matter production; however, yield of the economically important components (pod and kernel) is generally less responsive. Typically, yields of pods and kernels increase with increasing density until reaching a maximum yield, after which further density increases produce no additional effects. This 'flat-topped' PP response has given considerable latitude to irrigation producers in determining required seeding rates, with sowings at higher than optimal rates to ensure an adequate stand is obtained.

In cooler subtropical regions, such as Kingaroy in Queensland, studies show that optimum PP of the commercially grown Spanish and Virginia botanical types are around 88 000 plants/ha, with little pod yield response above this level (Fig. 1a). Similar results have been obtained in the semi-arid tropics at Kununurra in the Ord River Irrigation Area, Western Australia.

Under irrigated conditions in Indonesia, however, the dominant Spanish cultivars generally have optimum PP of 167 000–250 000 plants/ha. For example, a number of PP experiments conducted under well-watered conditions in East Java (Muneng and Jambegede) demonstrate this point (Figs 1b, c, d). Thus, optimum PP under Indonesian conditions is 2–3 times that observed in the subtropics. Experiments within this project outlined the role of environmental factors in affecting PP response.

In subtropical regions phenology is slowed by cooler temperatures, especially at night. This, combined with the typically high incidence of photosynthetic active radiation (PAR) during the relatively long, clear days, provides the basis for substantial branching and canopy development prior to the onset of reproductive growth (even at low densities). In the semi-arid tropics, excessively high temperatures also

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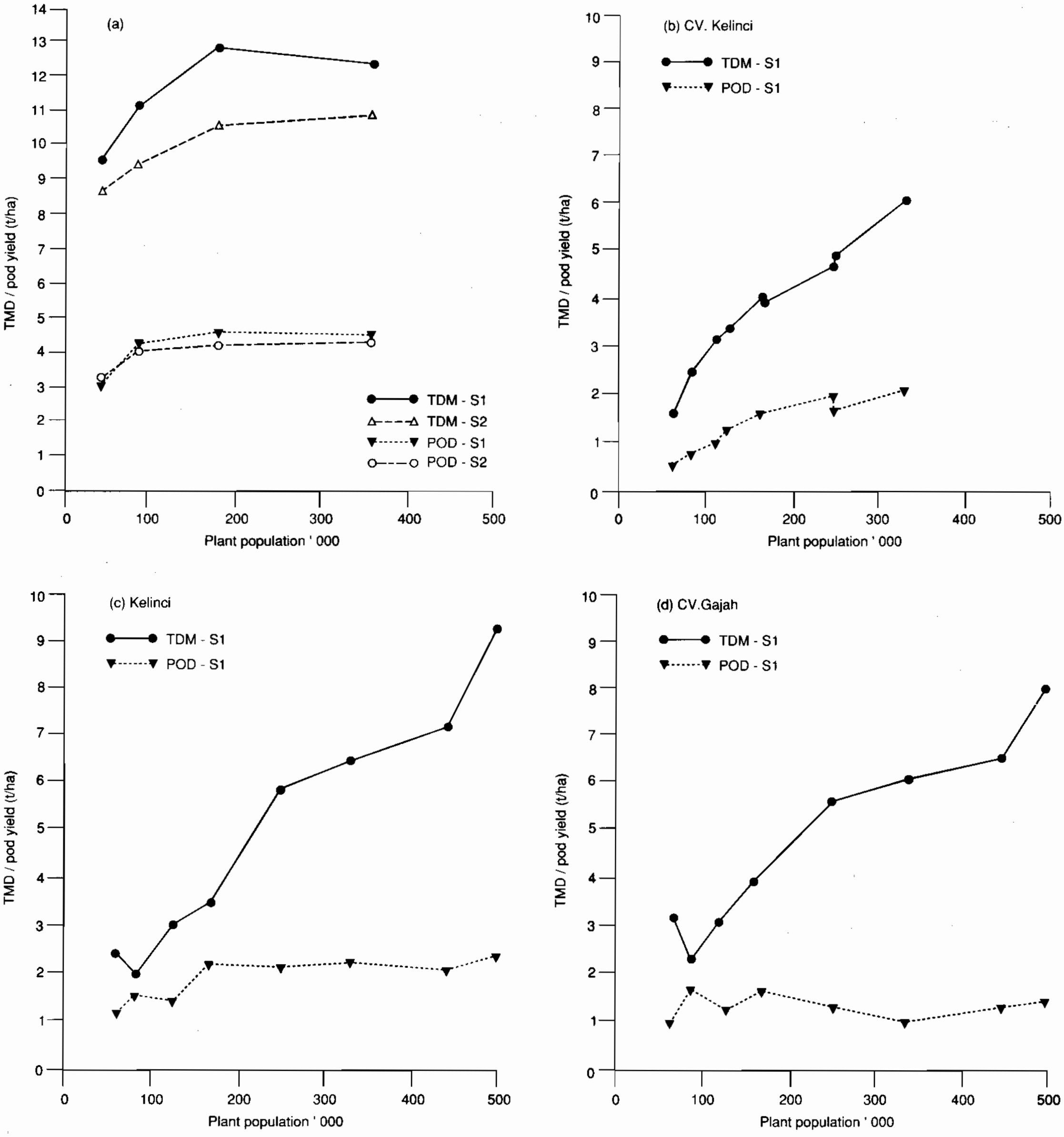

Figure 1. The effect of PP on total dry matter and pod yield under well-watered conditions for (a) two sowing times at Kingaroy, Queensland, cv. McCubbin; (b) cv. Kelinci at Jambegede, East Java, 1987 dry season; (c) Kelinci at Jambegede, East Java, 1988 dry season; (d) cv. Gajah at Jambegede, East Java, 1988 dry season.

slow rates of phenological development such that vegetative growth at low densities is sufficient to allow extensive branching and full canopy cover to be attained at, or near, early pod set. It is therefore not surprising that yield responses to increased density are not obtained.

In the wet tropics, however, temperatures are generally optimal for maximum rates of phenological development — days not excessively hot, nights warm — while daily incident PAR is relatively low due to short days and high cloud cover. The resulting growth of individual plants prior to reproductive growth is limited. The higher optimum PPs are therefore not surprising, both from the point of intercepting incident PAR and also providing sufficient reproductive nodes per unit area during early reproductive development to maximise yield. Interestingly, total dry matter is observed to increase linearly with increasing PP, whereas pod yield plateaus above approximately 250 000 plants/ha (Fig. 1b, c, d). This observation again suggests that the above-mentioned environmental conditions limit reproductive potential in Indonesia.

This phenomenon is discussed further in the modelling paper by Hammer et al. (these Proceedings). Also the simple PP model (discussed later) shows the differing PP responses between Indonesia and Australia can be related to the potential individual plant size achievable in the absence of competition.

Pod yield response to PP under water-limited conditions

Peanut is grown mainly under rainfed conditions in Indonesia where crop water deficits of varying duration and intensity limit pod yield. In post-rice dry season production, peanut is often planted into a fully moist soil profile, but declining rainfall availability later in the season means crops are solely dependent on soil water reserves. Similarly, when peanut is grown as a wet season crop, intermittent drought stress of unpredictable timing and duration limits productivity by forcing crops to rely on soil water reserves.

The optimum PP under variable water supply is shown to vary widely in a range of species. Broad recommendations of optimum PP have been based largely on observations of empirical relationships which have not attempted to study and understand the complex interactions occurring between PP, soil water availability and sensitivity of the crop to water deficits at different stages of growth.

The optimum PP under variable water supply will involve a delicate compromise between maximising water extraction and reducing soil evaporation, on the one hand, and conserving soil water for use during pod filling, on the other. Thus both the timing and severity of crop water deficits occurring in response to rainfall availability and distribution, and the soil water-holding capacity, will interact to determine the PP-yield response.

A number of experiments were conducted in both Indonesia and Australia to examine the influence of plant population on the growth, yield, soil water extraction and physiological responses of peanut grown under variable water supply. An experiment investigating the interaction between PP and water availability was conducted in the 1988 dry season at Muneng, East Java, where four levels of water availability (fully irrigated, I-I; irrigated until early podfill, then rainfed until maturity I-R; rainfed until early podfill, then irrigated until maturity; R-I; and rainfed from planting to maturity, R-R were superimposed on five PP (30 000, 60 000, 120 000, 240 000 and 480 000 plants/ha). No rain fell during the dry season, so crops relied on soil water reserves in the R-R treatment. The cultivar 'Gajah' was used. Figure 2(a,b,c,d) shows how total dry matter (TDM), vegetative dry matter (VDM), pod yield and harvest index (HI) responded to increasing PP under these four watering regimes. Interesting results include:

- TDM and VDM increased linearly with increasing PP, while pod yields tended to plateau (or decrease) with increasing PP. As observed in numerous other experiments throughout this project in Indonesia, HI was extremely low under well-watered conditions (about 25%). Water stress under the R-I, I-R and R-R treatments tended to reduce HI even further, with a severe decline with increasing PP observed under the RR treatment.
- The optimum PP for pod yield was shown to decline with increasing drought stress. Thus while the optimum PP under fully irrigated (I-I) conditions was around 240 000 plants/ha, it declined to around 120 000 plants/ha under the R-I and I-R water availability regimes, and down to 60 000 plants/ha under the terminal drought stress treatment (R-R) where crops were forced to rely solely on soil water reserves. Importantly, in the R-R treatment, increasing PP above 60 000 plants/ha led to a reduction in pod yield.

A similar range of PP experiments was conducted at Kingaroy using a Spanish cultivar McCubbin. Figure 3 shows TDM and pod yield response to increasing PP for similarly imposed watering treatments to those discussed earlier (viz. I-I, I-R, R-I and R-R). In these experiments rainout shelters were used to exclude all rainfall in the rainfed (R) treatments. Thus the R-R treatment was totally dependent on soil water reserves and simulated a post-rice drought stress condition. In general, the optimum PP for pod yield declined as the severity of drought stress increased. Thus, while optimum PP under I-I was around 100 000 plants/ha, it declined to 40 000 plants/ha (or less) under the I-R, R-I and R-R treatments. Pod yields declined in response to increasing PP in the R-R treatment, as observed under Indonesian conditions (Fig. 2c).

Detailed soil water extraction measurements taken throughout the season on the R-R crop indicated that the rate of water use was greater in high-density crops early in the season. Figure 4 demonstrates that the high-density crop (P5) had extracted significantly

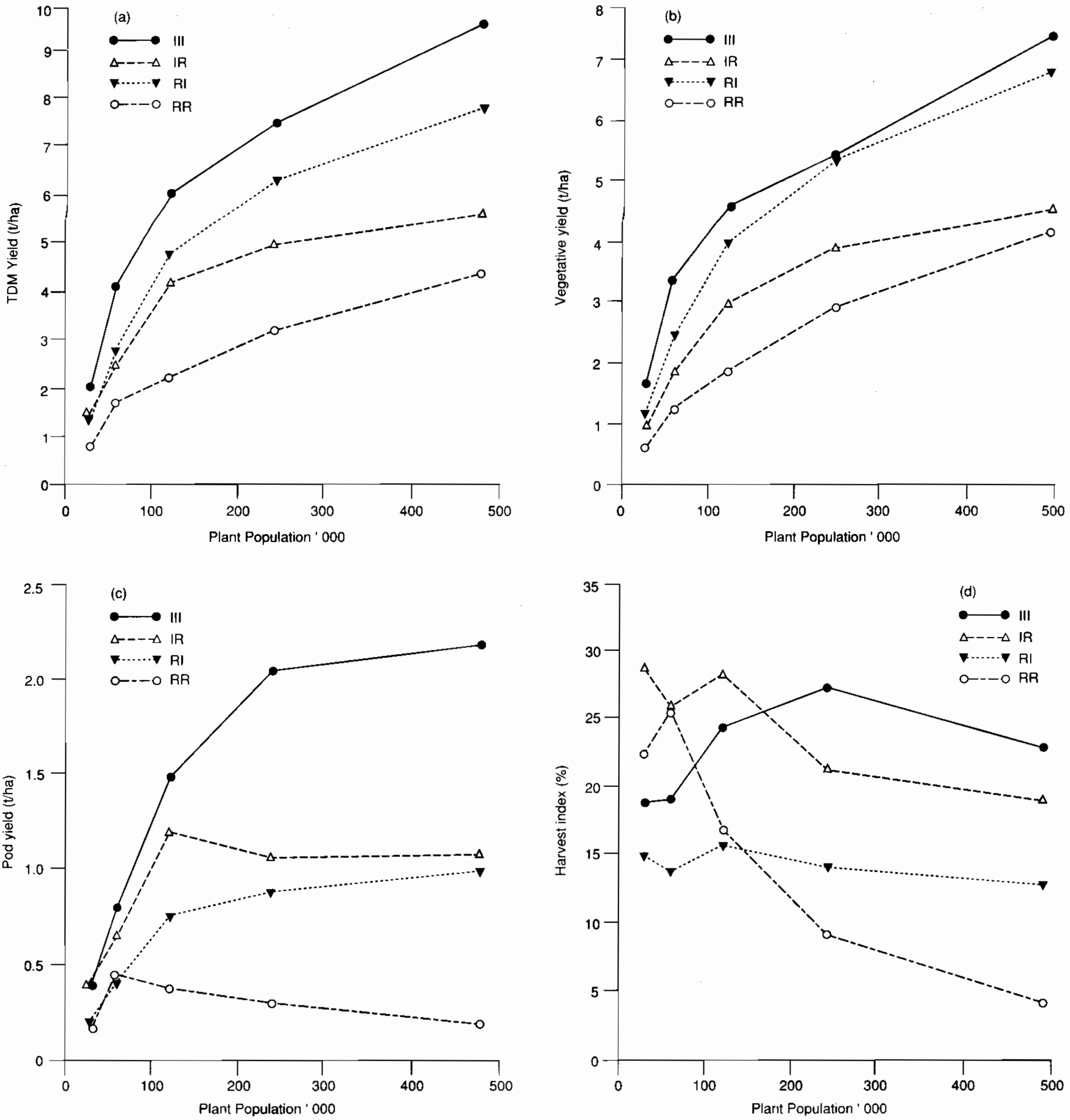

Figure 2. Effect of PP on (a) total dry matter, (b) vegetative yield, (c) pod yield, (d) harvest index for cv. Gajah grown under four different irrigation regimes (I-I, R-I, I-R, R-R) at Muneng, East Java, 1988 dry season.

greater amounts of soil water (about 25 mm) than the low-density crops (P1) at 38 and 58 days after planting (DAP). A dry matter sample measured at 70 DAP (Table 1) indicated that although there were no significant differences in TDM, the proportions of vegetative and pod dry matter in low and high-density crops were significantly different. While low-density crops produced only 309 kg/ha of pods, high-density crops produced 77 kg/ha, a nearly four-fold difference in pod yield potential.

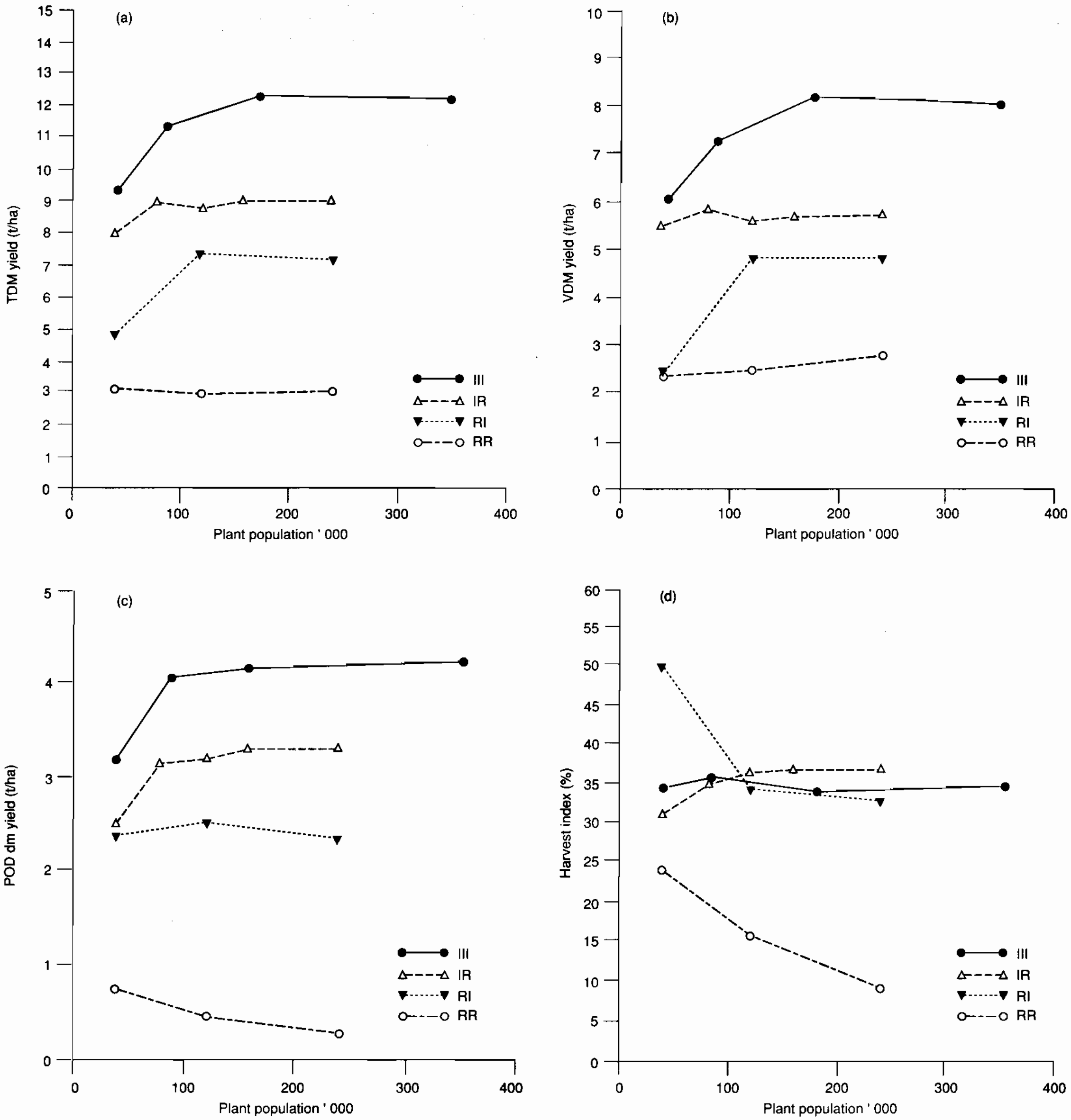

Figure 3. Effects of PP on (a) total dry matter, (b) vegetative yield, (c) pod yield, (d) harvest index for cv. McCubbin grown under differing irrigation regimes (I-I, I-R, R-I, R-R) at Kingaroy, Queensland.

Leaf water potential (ψ) measurements at around 60 DAP also showed low-density crops had better water status, with P1 crops having a midday ψ of -2.5 MPa compared to -4.0 MPa in high density crops. Similarly, leaf photosynthetic rate, leaf transpiration rate and stomatal conductance measured around midday were significantly higher in P1 compared to P5 crops (Wright and Bell 1991b).

The data presented here clearly show that PP strongly interacts with water availability to determine pod yield performance. In high population treatments (P5), water extraction from lower depths commenced sooner and was more rapid than in low population treatments (P1). Greater early water use was associated with more rapid leaf area development, as evidenced by higher leaf area index (LAI)

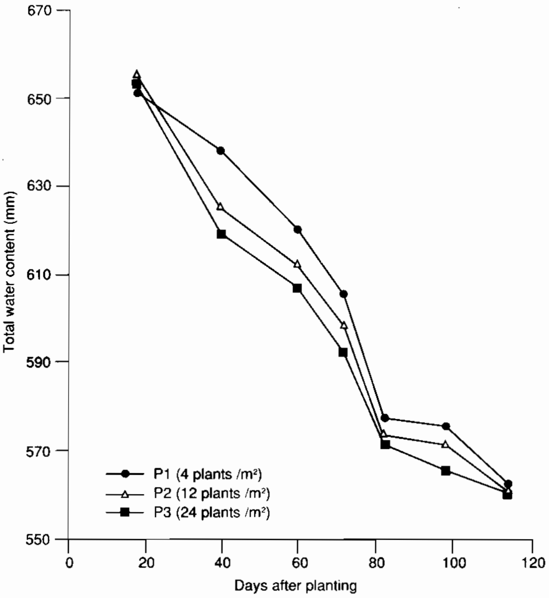

Figure 4. The change in total soil water content with time for differing PP of 40 000 (P1), 120 000 (P3) and 240 000 (P5) plants per hectare.

values at 70 DAP (Table 1). Crop water deficits during the pegging and early podding periods (40–70 DAP) were substantially lower in the low-density crops as evidenced by the lower ψ, and higher leaf photosynthetic activity. It is likely that peg and pod development in high-density crops are inhibited by lowered assimilate availability associated with these greater crop water deficits.

Application of PP research

In large areas of East Java, farmers are known to 'opportunity crop' in the June to August period. This practice is dependent on unseasonal rainfall following the harvest of the first palawija crop (late February to early June). The risk of crop failure in this opportunity crop is high, so the level of inputs are generally low.

Following on the findings of the population work, it was thought that manipulating PP to alter ground cover and adjust crop demand to water supply may be appropriate for peanut grown under rainfed conditions as an opportunity crop. Experiments were therefore conducted at Muneng in East Java and Maros, in South Sulawesi, where PP was varied (30 000 to 480 000 plants/ha) in crops planted in early June. Figure 5 shows pod yield response to PP, measured in each of these experiments. A general parabolic response was observed in each experiment, with optimum PP for pod yield being between 60 000 and about 120 000 plants/ha, with yields tending to decline above 160 000 plants/ha.

The results from this experiment confirm the earlier population studies, in that optimum PP under severe drought stress is significantly below the currently recommended 250 000 plants/ha. Indeed, pod yields have been shown to decline at PPs above the optimal level. The general pod yield level achieved in the Muneng experiment was low, due to a combination of severe drought and high stripe virus infection. We are confident, however, that the general PP response was representative and useful for future PP recommendations under low rainfall conditions.

Development and application of a simple PP model

Gardner and Gardner (1983) proposed a useful framework for defining optimum PP for a crop grown in environments with varying degrees of water limitation. The model uses parameters derived from the PP response under well-watered conditions. Detailed description and theory of the model are presented in recent publications (Bell et al. 1991, Wright and Bell 1992a). Briefly, seven parameters are derived from the pod yield – total dry matter data across a range of PPs for each cultivar – treatment. These parameters include TDM, the maximum total dry matter production achieved at optimal PP; P_h, the PP at half TDM; d_m, the theoretical maximum plant size achievable in the absence of competition; d_o, the hypothetical minimum plant size which is

Table 1. Effect of plant population (PP) on total, vegetative and pod dry matter production, peg number, pod number, and leaf area index (LAI) 70 days after planting (DAP) for cv. McCubbin.

Plant population (plants/ha)	Total dry matter (kg/ha)	Vegetative dry matter (kg/ha)	Pod dry matter (kg/ha)	Peg No. (per m²)	Pod No.	LAI (per m²)
P1, 40 000	2231	1923	309	339	150	1.62
P3, 120 000	2123	1916	207	323	148	1.61
P5, 240 000	2381	2304	77	233	83	2.10
l.s.d. (P = 0.05)	n.s.	150	88	n.s.	35	0.40

capable of producing pods; 'a' is the increase in pod yield per unit increase in total dry weight per plant, or effectively a dry matter partitioning index; and W_f is the relative water availability factor calculated as the seasonal water usage for a particular crop as a fraction of that required for maximum TDM under water non-limiting conditions.

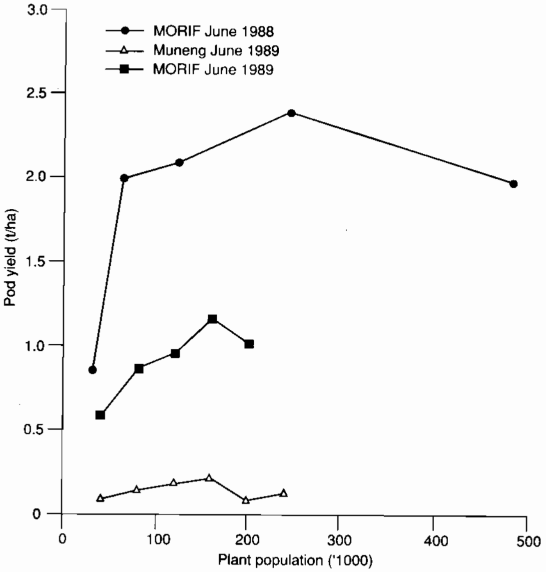

Figure 5. The effect of PP on pod yield of peanut planted in the late dry season at MORIF and Muneng. The MORIF (1988) crop received unusually high rainfall during the season.

The first six parameters are easily derived from measurements of total and pod dry matter. However W_f requires reasonable estimates of the total water balance of a crop (including irrigation, rainfall, and the change in soil water storage between sowing and maturity). Substantial resources are therefore required to accurately measure W_f.

Model parameters were derived from data collected for a range of PP experiments conducted under variable water supply at Kingaroy, where detailed soil water measurements were taken. Table 2 shows the coefficients derived for the Spanish cultivar McCubbin under well-watered conditions, while Figure 6(a,b) illustrates the observed and predicted TDM and pod dry matter achieved, indicating the model was capable of predicting dry matter response to PP under well-watered conditions.

The model was then run using these 'irrigated' coefficients on data collected in the I-R and R-R experiments reported earlier. Values for W_f were calculated as 0.70 and 0.26 for R-I and R-R experiments respectively (see Wright and Bell 1992a, for details). Agreement between measured and predicted values of TDM were good, though pod dry matter prediction was poor. This indicated that the partitioning value 'a' was not constant, as proposed by the model, but varied with severity of drought stress. The value of 'a' was then calculated from dry matter data as being 0.33 and 0.21 for I-R and R-R experiments, compared to the irrigated value of 0.41. Figure 6(b) shows that when the revised 'a' values

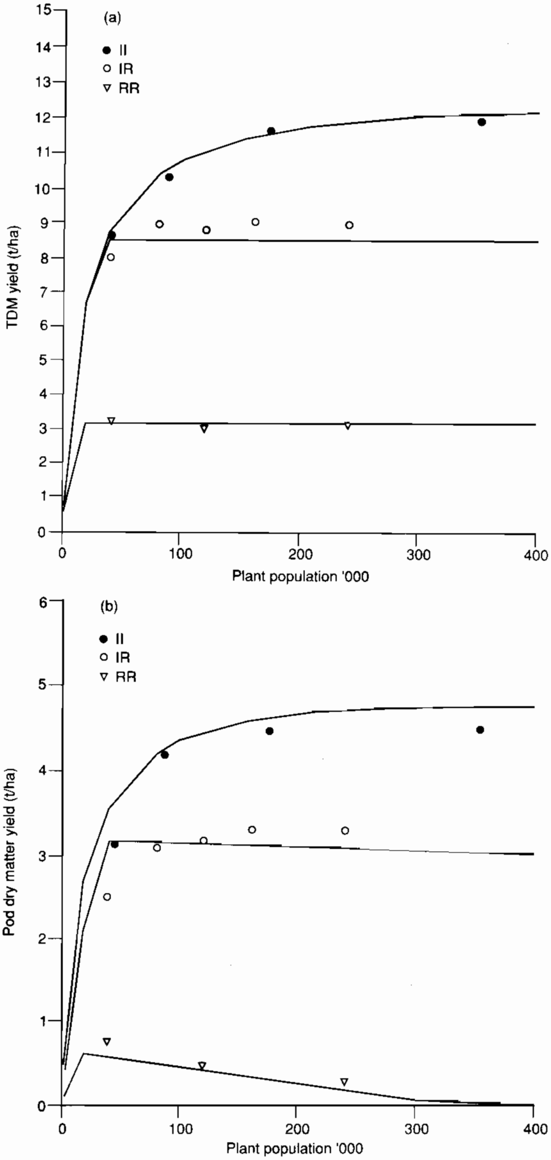

Figure 6. Measured values (shown by symbols) versus predicted values (shown by lines) for (a) total dry matter and (b) pod yield for the I-I, I-R and R-R crops at Kingaroy, Queensland.

were put into the model, good agreement between measured and predicted values of pod dry matter was achieved.

The PP model presented here may be useful in characterising the PP pod yield response under well-watered and water-limited conditions. The assumption that partitioning of dry matter to pods is a cultivar-specific constant, irrespective of crop water deficits experienced, was an over-simplification. The model may have application in defining optimum PP under varying levels of water availability on a relative rather than on an absolute basis.

Although measurements of crop water use were not made in the PP experiment conducted at Muneng in 1988, an attempt was made to derive the various coefficients from dry matter data presented in Figure 2a. Values for W_f were assumed to be a function of the fraction of TDM achieved under water-limited conditions relative to the well-watered control crops. The other difficulty with the data concerned the lack of a plateau TDM response at high PP (Fig. 2a). The main assumption of the model is that the yield PP response reaches a plateau at high PP, so that, for the purposes of this exercise, maximum TDM was extrapolated (from Fig. 2a) to be 12 000 kg/ha, which occurred at a P_h of 175 000 plants/ha. Using these assumptions, Table 2 shows the coefficients derived from the Indonesian data set (cv. Gajah).

Figure 7(a,b) shows the measured and predicted values of TDM and pod dry matter for I-I, I-R, R-I and R-R treatments respectively. Reasonable agreement was achieved for TDM (Fig. 7a) using these assumptions, though the model tended to overpredict TDM at low PP. As observed in the Kingaroy data set under water-limited conditions, there was poor agreement between predicted and observed values of pod yield. Again, the partitioning index 'a' was shown not to be constant, but to decline with increasing water stress. Thus, I-R, R-I and R-R crops had 'a' values of 0.2, 0.2 and 0.15 respectively, compared to the well-watered value of 0.3 for Gajah. Using these revised values, reasonable agreement between measured and predicted pod yields was achieved (Fig. 7b). The two data sets from Australia and Indonesia clearly demonstrate that the model has value in predicting pod yield–PP response, provided an

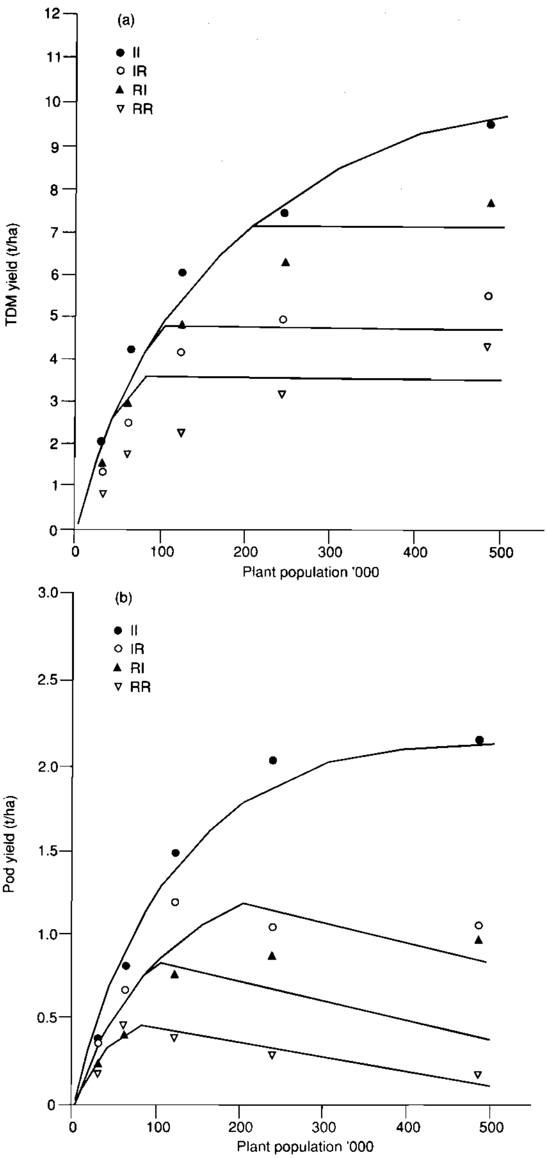

Figure 7. Measured values (shown by symbols) versus predicted values (shown by lines) for (a) total dry matter and (b) pod yield for the I-I, I-R, R-I and R-R crops at Muneng, East Java, 1988 season.

Table 2. Model coefficients derived under well-watered conditions for McCubbin in the Australian (Kingaroy) study, and for Gajah in the Indonesian (Muneng) study.

	Australia	Indonesia
Max. TDM (kg/ha)	12 150	12 000
Max. plant size, d_m (kg)	0.69	0.077
Population at 0.5 × max. TDM, P_h (plants/ha)	18 500	175 000
Partitioning index, 'a'	0.41	0.3
Minimum plant size for pod yield d_0 (kg)	0.0015	0.0055

assessment of water stress effects on partitioning (harvest index) is available. As a first step in this process, we developed a relationship between 'a' (relative to each cultivar under well-watered conditions) and the relative water availability factor W_f. Figure 8 shows that a highly significant negative correlation exists between relative 'a' and W_f. This relationship is used later to develop pod yield contours to PP under varying W_f.

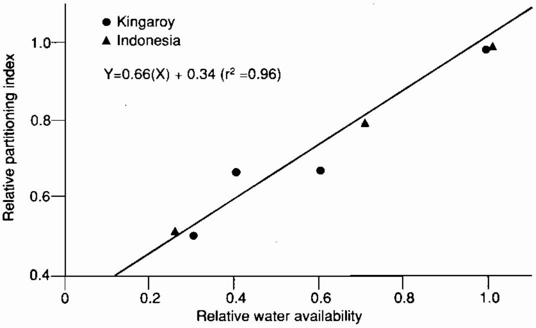

Figure 8. Relationship between relative partitioning index and relative water availability for data derived from the Kingaroy, Queensland and Muneng, East Java data sets.

Some interesting differences in the physiologically meaningful coefficients derived from the model are apparent. For instance the maximum plant size d_m was dramatically different between Australia and Indonesia, with McCubbin achieving a value of 690 g compared to Gajah at only 77 g, a nearly ten-fold difference. This value represents the theoretical maximum plant size achievable in the absence of any plant competition. Clearly, environmental conditions in Indonesia do not allow the development of large plants, despite the absence of competition. This finding accounts for the requirement for significantly higher PPs to achieve maximum pod yield in Indonesia than in Australia (e.g. 250 000 compared to only 88 000). This effect is also highlighted in the model, where the difference in P_h, the PP at half the maximum TDM, is extremely large (175 000 compared to 18 500 plants/ha in Indonesia and Australia, respectively).

We hypothesise the large difference in d_m may occur because of the interaction of temperature and radiation on peanut crop growth and development. In Indonesia radiation is low while temperatures are high. These environmental conditions favour rapid phenological development with relatively low dry matter production at each developmental stage due to low radiation (i.e. a small plant with low TDM). By contrast, in Australia radiation is high, while temperatures are low. These conditions favour slow phenological development with high levels of dry matter production (i.e. large plants with high TDM). The modelling paper discusses this phenomenon in more detail.

Although the model has been shown to contain many assumptions, it has been useful in characterising the pod yield–PP response under non-limiting and limiting water conditions. It was concluded that the model may have application in defining optimum PP on a relative rather than an absolute basis. To demonstrate the potential usefulness of the model in predicting optimum PP under variable water supply, Figure 9(a,b) shows a plot of relative pod yield as a function of PP, for a range of levels of water availability, in both Indonesia and Australia (using the 'a' versus W_f relationship derived in Fig. 8).

Such a graph is useful in determining PP recommendations for peanuts grown under different water availability regimes. For instance, in an Indonesian post-rice cropping system, a peanut crop may be known to exploit only 200 mm of water (rain + soil water) during a season. From irrigation studies, total water requirements for a fully irrigated crop may be found to be 500 mm. Thus, the W_f for this cropping system would be in the order of 200/500, which equals 0.4. From Figure 9a, the optimum PP would be expected to be about 100 000 plants/ha. A listing of the PP model (in GWBASIC) is given in Appendix I.

Implications for the Future

The PP research conducted throughout Indonesia provides significant information for future recommendations.

- The optimal PP for Spanish-type peanuts under water non-limiting conditions in Indonesia is between 200 000 and 250 000 plants/ha. This number contrasts sharply with Australian production, where around 90 000 plants/ha for Spanish cultivars is optimal. The reasons for the difference appear to be associated with peanut growth and developmental response to radiation and temperature, which vary significantly between Indonesia and Australia.
- Drought stress of varying timing and duration can modify substantially the PP pod yield response compared to that observed under well-watered conditions. In all cases, the optimum PP for pod yield was lower under reduced water availability.

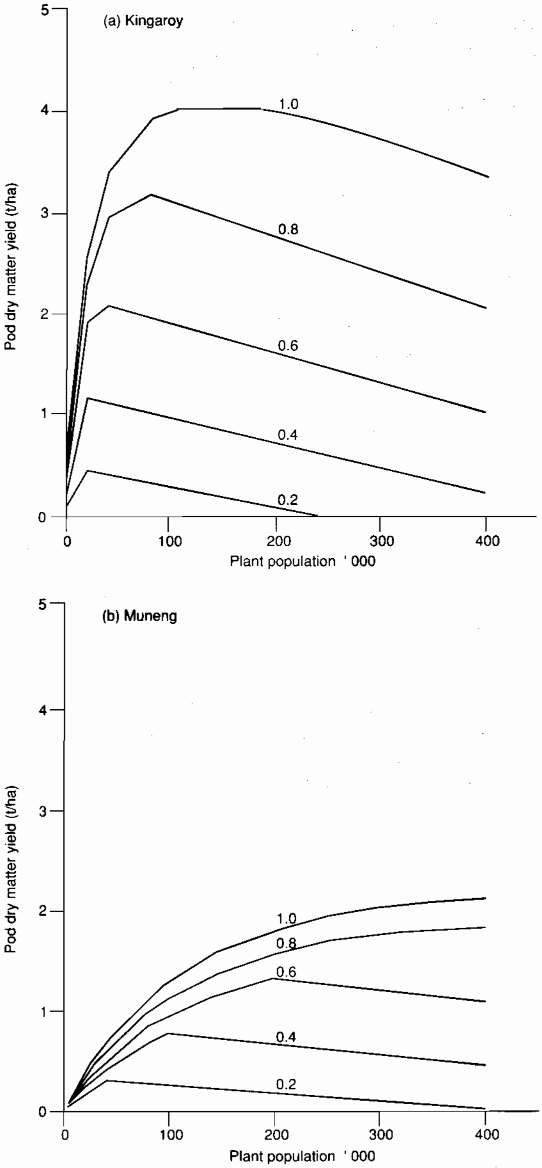

Figure 9. Model predictions of the relationship between PP and pod yield under varying levels of relative water availability using coefficients derived from studies at (a) Kingaroy, Queensland and (b) Muneng, East Java. The figures on each graph refer to the relative water availability factor.

The choice of PP involves a compromise between maximising soil water extraction and conserving soil water for maximum pod development and filling. In dense stands, rapid early water use results in more severe crop water deficits, which in turn reduce pod set and reproductive potential.

- These findings have significant implications for future PP recommendations for peanuts grown under drought conditions in Indonesia. Future recommendations will depend on the likely severity of drought encountered under particular cropping systems. The experiments reported here showed that as the severity of drought increased, so did the PP decline in order to achieve maximum pod yield. Under severe drought conditions, such as experienced during terminal stress in a post-rice cropping system, pod yields were even reduced as PP increased. Clearly, the current recommendation of 250 000 plants/ha for peanuts produced in all cropping systems in Indonesia is in need of change. Increased profitability could be achieved by significant savings in seed costs, and by increasing pod yields when PP is reduced in terminal drought situations.
- A simple PP model is useful in describing peanut PP response under variable water supply. It may be a useful tool to provide information on future PP recommendations appropriate for peanuts grown in a variety of cropping systems where soil water availability is limited. Future research into the testing and applicability of the model in Indonesia clearly is warranted.

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Appendix I

Program listing of plant population model developed by Gardner and Gardner (1983) and revised by Bell et al. (1991) and Wright and Bell (1992a) — in GWBASIC:—

```
 10  DIM1 (12), TDM (12), GYLD (12)
 20  CLS: PRINT “Gardner and Gardner Population Model”: PRINT: PRINT
 30  PRINT “Enter data: ”: PRINT
 40  INPUT“MAX TDM/HA’; MTDM:LPRINT“MTDM= ”;MTDM
 50  INPUT“MAX PLANT SIZE ”;DM:LPRINT “MAX PLANT SIZE= ”;DM
 60  INPUT“PLANT POP 1/2 MAX DM ”;PH:LPRINT “ POP 1/2 MAX DM= ”;PH
 70  INPUT“HI ”;HI:LPRINT “HI ”; HI
 80  INPUT“MIN PLANT SIZE ”; DO:LPRINT “ MIN PLANT SIZE = ”;DO
 90  INPUT“WATER AVAIL FACTOR ”; WA:LPRINT “ WATER AVAIL= ”;WA
100  LPRINT“ POPLN       TDM       GLYD ”
105  ‘*** FUNCTION TO REDUCE HARVEST INDEX IN RESPONSE TO WATER DEFICIT ***
110  RHI=(.66*WA) + .34
120  HI=RHI*HI
130  FOR I=1 TO 12
140  READ P(I)
150  DATA 10000, 20000, 40000, 80000, 100000, 150000, 200000, 250000, 300000, 350000, 400000, 500000
160  TDM(I)=P(I)*(DM*PH/(P(I)+PH))
170  IF TDM(I) < MTDM*WA THEN TDM (I)=MTDM*WA
180  D=TDM(I)/P(I)
190  GYLD(I)=P(I)*HI*(D-DO))
200  LPRINT USING “###### ##### ##### ”;P(I),TDM(I),GLYD(I)
210  NEXT I
220  INPUT “Do you want to save the output? Y/N”;Y$
230  IF Y$=“N” PR Y$=“n” GOTO 300
240  INPUT “Enter the filename”; FILE$
250  OPEN “O”,#1, FILES$
260  FOR I=1 TO 11
270  WRITE #,P(I), TDM(I), GYLD(I)
280  NEXT
290  CLOSE
300  INPUT “Another run? ”;Y$
310  IF Y$=“n” OR Y$=“N” GOTO 320 ELSE RESTORE:GOTO 20
320  END
```

Optimal Irrigation Strategies for Peanut Using Scarce Supplies of Supplementary Irrigation

B. Prastowo*, I. Firmansyah*, A. Prabowo* and G.C. Wright†

THE present cropping system throughout much of South Sulawesi consists of wet season (paddy) rice, with very little dry season production of palawija (non-rice) crops such as peanut. The major reason for the lack of crop production is water limitation, both rainfall and irrigation, during the dry season.

Recent investigations reveal large areas of good quality and easily accessible groundwater available for pumping throughout many of the lowland areas of South Sulawesi. The potential therefore exists for more widespread field crop production using supplementary irrigation, and highlights the need for research aimed at improving the efficiency of irrigation water application for optimal dry season crop production.

A number of irrigation experiments have been conducted to investigate the effects of varying irrigation frequency on growth and yield of peanut in a post-rice situation. In particular, information was needed on optimal irrigation timing, as the current belief in the area was that peanut needed frequent watering to optimise pod yield. The ability of roots to penetrate and extract soil water at and below the hard pans which develop as a result of puddling rice paddies also needed investigation. Indications were that restricted infiltration of irrigation water through the puddled zone was limiting soil water recharge and subsequent soil water availability. Experiments on the influence of practices such as deep tillage and alternative irrigation methods aimed at improving soil water recharge were therefore conducted to overcome this limitation.

Research Highlights

Influence of irrigation frequency on peanut yield

The initial peanut water-use experiment (conducted during the 1987 dry season at Maros, South Sulawesi) investigated the effects of varying irrigation frequency during the pre- and post-early podfill stages on growth, yield and water extraction of peanut grown in a post-rice situation.

Pod and seed yields were not reduced significantly below that of fully irrigated (F-F) crops if irrigation (sprinkler) was delayed to an evaporation deficit of 70 mm throughout the season (I-I), and either during the vegetative (I-F) or reproductive (F-I) stages (Table 1).

Table 1. Total pod and seed yields at maturity and components for each irrigation treatment. Frequent (F) and infrequent (I) irrigations were applied when evaporation deficits reached 35 and 70 mm respectively.

Irrigation treatment	Total dry matter (kg/ha)	Pod dry matter (kg/ha)	Seed dry matter (kg/ha)	Pods/m^2	Harvest index (%)
F-F	6400	2400	1500	270	38
F-I	6100	2200	1300	250	36
I-F	5800	2400	1500	290	41
I-I	6200	2100	1200	290	34
Rainfed	2900	530	250	55	19
l.s.d. ($P = 0.05$)	1850	850	545	125	9

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The broad conclusion from the pod yield data presented is that optimum yield can be achieved using less than full irrigation. In fact, there was no yield advantage from irrigating throughout the season at an evaporation deficit of 35 mm (12 irrigations) compared to 70 mm (6 irrigations).

This initial conclusion may be misleading in the light of additional plant and soil water data collected during the experiment. It was apparent from the data that poor structural stability of the surface 20 cm of soil was limiting infiltration, internal drainage, and redistribution of soil water. For example, Figure 1 shows how the applied irrigation water failed to replenish soil water content at each depth to levels approaching the drained upper limit (approx. 38% volumetric water content) at an irrigation at 74 DAP (and similarly at 47 DAP). Although 70 mm of irrigation water was applied, only 14 mm was recovered one day after an irrigation; this represents an irrigation efficiency of only 20%. It is hypothesised that the structure of the surface soil was destroyed by puddling in the rice phase. The finely dispersed material filled pores in the soil and resulted in a surface seal and reduced infiltration rates. The influence of deep tillage to improve water penetration through the compaction layer was suggested as a possible management practice to overcome this limitation. Results from these experiments are discussed later.

Pod yield under the rainfed treatment was extremely low, despite the ability of the crop to extract significant amounts of soil water at depths to and beyond 1.2 m (Fig. 1), and produce reasonable total dry matter (approximately 2.9 t/ha). Apparently, severe water stress during reproductive development reduced pod numbers (Table 1) and hence pod and seed yields. Further assessment of peanut cultivar variation in pod yield performance under the post-rice terminal drought stress situation is clearly warranted in order to improve harvest index. Results presented by Wright et al. (these Proceedings) on the drought physiology research indicate there is considerable scope to achieve this objective. In addition, a reduction in plant population, aimed at limiting leaf area and rate of water extraction, may delay the onset of severe crop water deficits until after the critical early pod set stage (Adisarwanto et al., these Proceedings). Importantly, if improved reproductive efficiency and harvest index could be increased to around 0.4 under this terminal drought condition, pod yield could increase to approximately 1.1 t/ha. Further results are reported by Prabowo et al. (1990).

A follow-up experiment to validate further the data collected was conducted during the 1988 dry season. Four irrigation frequencies were applied throughout the season; very frequent (VF) applied at an evaporation deficit of 20 mm; frequent (F) at a deficit of 35 mm; infrequent (I) at a deficit of 70 mm and rainfed (R). Rainfall during the season was exceptionally high (175 mm) compared to typical seasons where negligible rain occurs during the dry season.

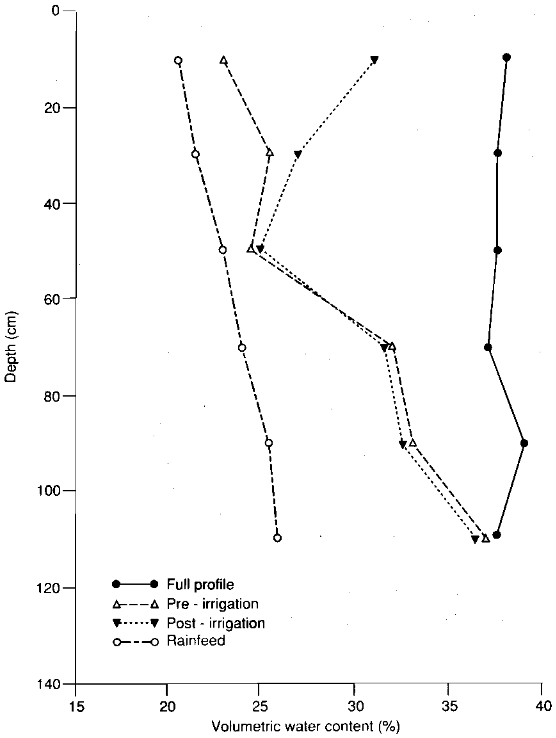

Figure 1. The change in the volumetric water content with depth prior to irrigation at 74 DAP (△) and post-irrigation at 76 DAP (▼) for peanut (local cv.) grown under infrequent irrigation. The initial water content profile at planting (•) indicates field capacity, and final water content profile at maturity (o) for a rainfed crop indicates potential available water content.

As observed in the earlier irrigation frequency experiment, high pod yields were achieved using less frequent irrigation (Table 2). There was a slight pod yield advantage by irrigating very frequently (VF, every 3–4 days) compared to infrequent irrigation (I, every 15–20 days). The extra cost and labour requirement needed could hardly be justified in terms of pod yield return.

The rainfed crop produced similar TDM to the I treatment, yet produced significantly less pod yield (2.0 cf. 1.4 t/ha), which led to a severe reduction in harvest index (35 compared to 24%). Interestingly the R crops had significantly fewer kernels/m^2 and

Table 2. Total dry matter and pod yield and components for each treatment.

Irrigation treatment	Total dry matter (kg/ha)	Pod yield (kg/ha)	Kernels/m^2	Empty pod (%)	Harvest index (%)
VF	6390	2476	640	32.5	38.7
F	7232	2362	697	30.7	32.7
I	5719	2021	592	40.2	35.3
R	5765	1401	411	49.2	24.3
l.s.d. ($P = 0.05$)	680	335	98	11.2	7.3

also higher percentages of empty pods. These data suggest that dry surface soil conditions at the time of pegging and podset may have limited subsequent reproductive development under R conditions. Similar reports of this response are reported and discussed in the review paper on drought physiology (Wright et al., these Proceedings). The data again highlight the potential importance of surface soil dryness and hardness in determining podset and subsequent partitioning of dry matter to pods for peanut grown during the dry season.

Influence of deep tillage and irrigation frequency

An experiment investigating the effect of depth of tillage, as a method of improving the infiltration and subsequent redistribution of applied irrigation water and rainfall, was conducted at MORIF during the 1988 dry season. Previous work had shown that a restriction, or choke, in the soil profile at about 20 cm was inhibiting water movement to lower depths in the profile. Two levels of tillage (to depths of 20 or 40 cm) in combination with four levels of irrigation frequency were applied throughout the season: very frequent (VF) applied at an evaporation deficit of 20 mm; frequent (F) at a deficit of 35 mm; infrequent (I) at a deficit of 70 mm; and rainfed. Rainfall during the dry season was unusually high (175 mm) and meant that most treatments were not severely water-stressed throughout the season. Intensive soil water and growth measurements made throughout the experiment indicated significant effects of tillage within the different irrigation frequency treatments. Major findings from this experiment include the following points.

- Figure 2 shows penetrometer resistance profiles made prior to and following the tillage operations. The profiles clearly show that tillage dramatically reduced soil strength to around 0.5 kPa to depths of about 25 and 45 cm compared to the initial post-rice condition where soil resistances were high (>3.6 kPa) from 7.5 cm to 45 cm.
- Gravimetric soil water content (GWC) profiles measured the day after heavy rain (31 mm) at 45 days after planting (DAP) are shown for the deep (T_{40}) and shallow tillage (T_{20}) treatments under I and rainfed conditions. The data (Fig. 3) show the T_{40} plots were wetter throughout the profile, indicating deep tillage had improved water infiltration and redistribution throughout the profile. Interestingly, under the I irrigation treatment, GWC in the T_{20} was higher than in T_{40}

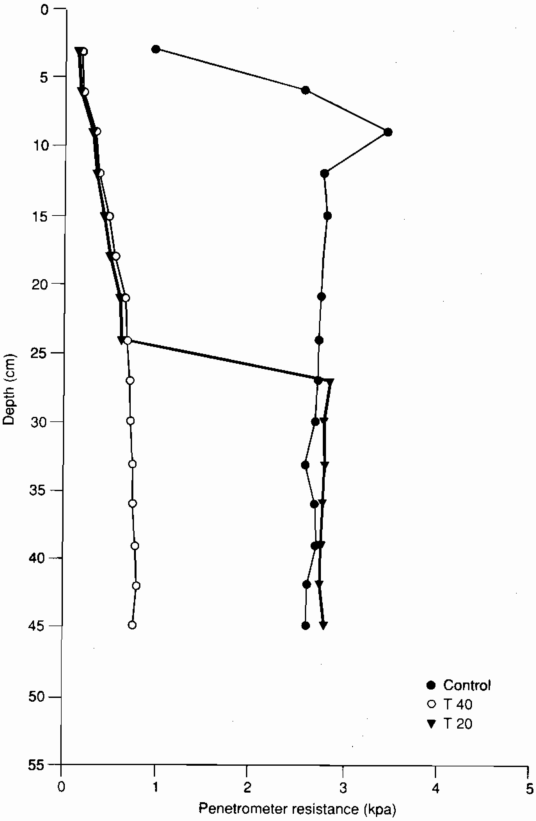

Figure 2. The change in penetrometer resistance with depth prior to planting (•) and following tillage, to 20 cm depth (▼) and 40 cm depth (o).

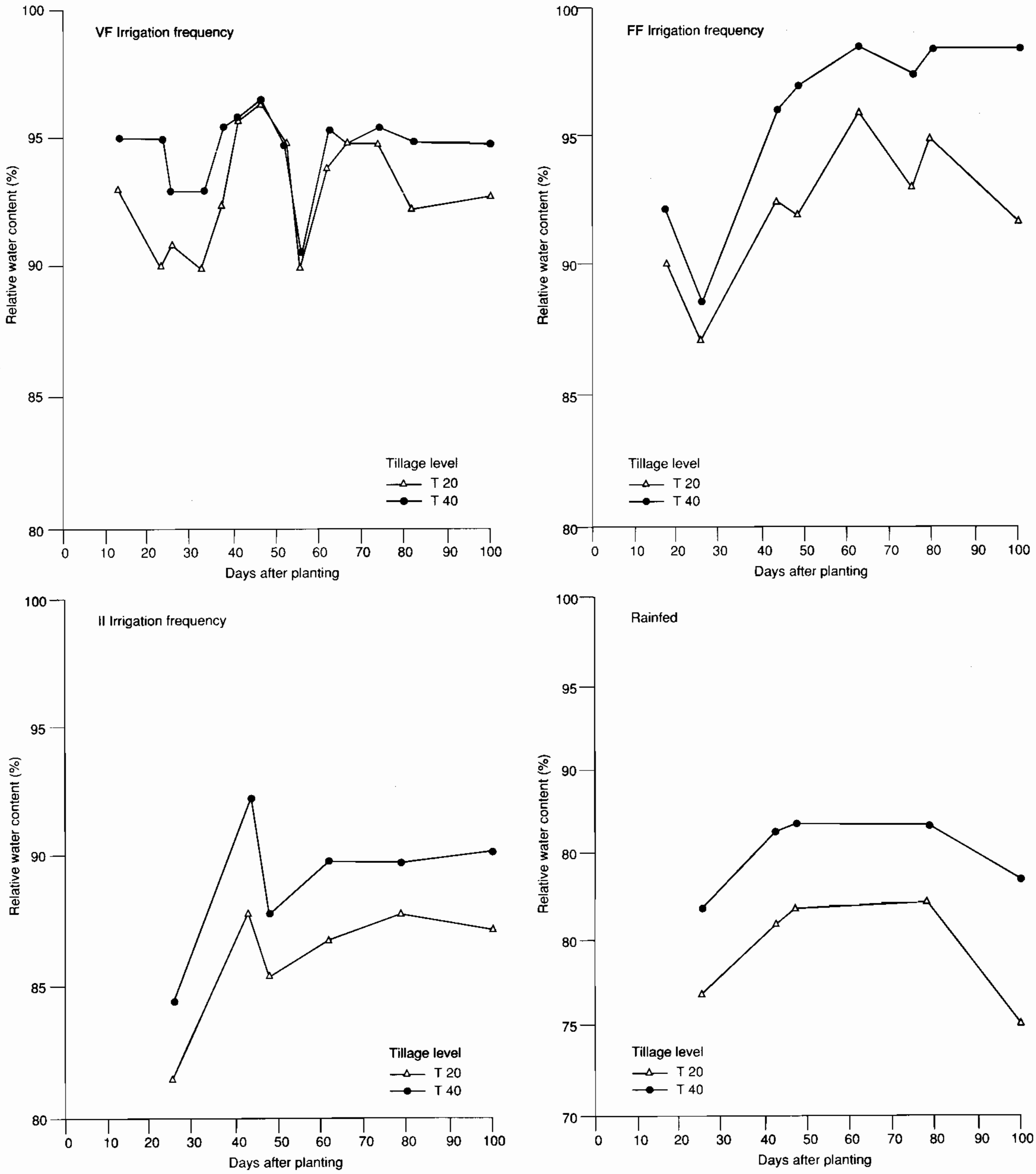

Figure 3. The change in leaf relative water content with time for crops under tillage treatments to 20 and 40 cm, under V-F, F-F, I-I and R-R irrigation levels.

treatments in the surface 30 cm, below this depth the reverse effect was apparent. This data may provide evidence for the existence of a choke at or around 20 cm in the T_{20} treatment. This choke would tend to cause the surface layers to become waterlogged, and limit subsequent infiltration down the profile following rainfall or irrigation. The T_{40} treatment, on the other hand, apparently allowed free movement of water to lower depths in the profile. Similar soil water profiles following heavy rainfall were measured on four other occasions during the season (data not included).

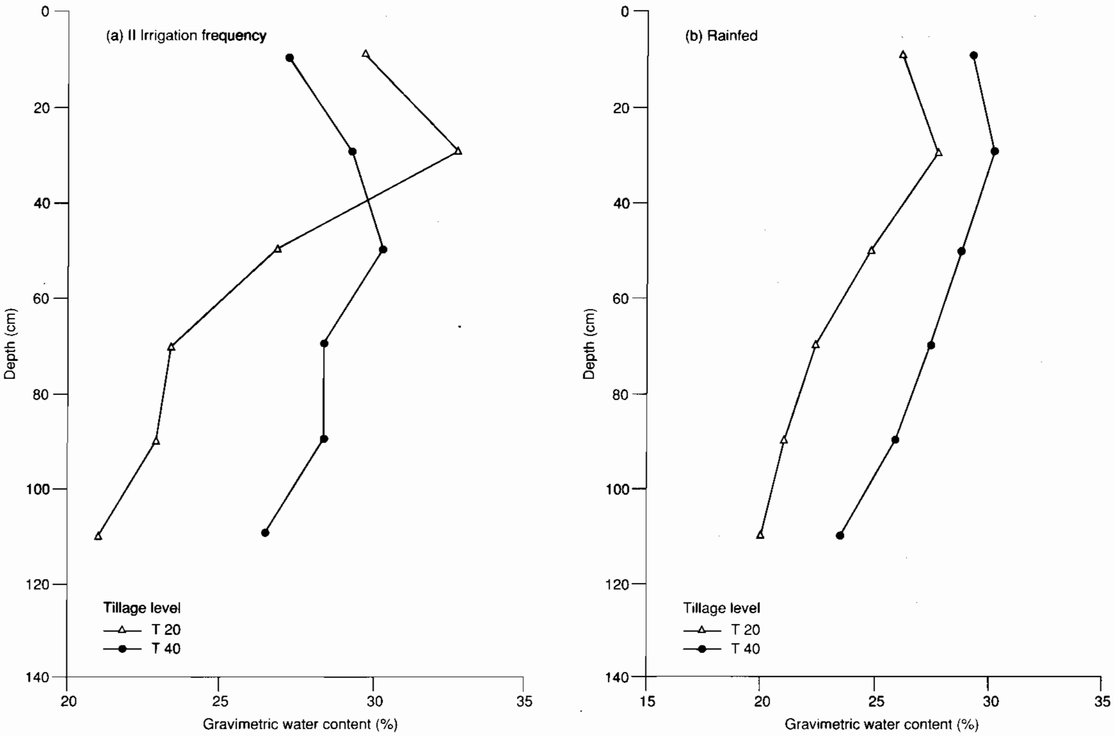

Figure 4. The change in gravimetric water content with depth for tillage treatments to 20 and 40 cm, under I-I irrigation (a) and rainfed conditions (b) at 45 days after planting.

- Leaf relative water content (RWC), which indicates the water status of the crop, was measured under each irrigation treatment for T_{20} and T_{40} tillage treatments at intervals throughout the season (Fig. 4). Under the VF irrigation treatment, RWC in crops remained high throughout the season, with little difference between T_{20} and T_{40} tillage. Under the less frequent irrigation treatments (F and I), RWC remained high; however, there was a trend for the T_{40} tillage treatment to have higher RWCs compared to T_{20} crops. This response indicates consistently better water status under deep tillage. Under rainfed conditions, where no irrigation was applied, highly significant ($P<0.05$) differences in RWC were apparent, with T_{40} crops having RWCs up to 5% higher than T_{20} crops throughout the season. Clearly, T_{40} crops were better hydrated than T_{20} crops, which is indicative of better soil water availability in the root zone. The soil water content profiles measured under rainfed conditions (Fig. 3b) indicate that this was the case.
- There was a significant irrigation × tillage interaction for total dry matter production (TDM), which occurred because, while tillage had no effect on TDM under VF and F irrigation, there were significant responses to deep tillage under I and R conditions (about 800 kg/ha) (Table 3). This interaction was not evident for pod yield, although a significant increase in yield (350 kg/ha) was recorded with deep tillage under rainfed conditions.

Table 3. Total dry matter and pod yield of peanut as affected by irrigation and tillage treatment.

Irrigation treatment	Tillage treatment (cm)	Total dry matter (kg/ha)	Pod yield (kg/ha)
VF	T_{20}	6237	2497
	T_{40}	6542	2454
F	T_{20}	7176	2386
	T_{40}	7287	2338
I	T_{20}	5227	1951
	T_{40}	6211	2091
R	T_{20}	5411	1220
	T_{40}	6119	1573
l.s.d. ($P=0.05$)		680	335

The data presented suggest there were definite yield responses to deep tillage as water availability decreased. The RWC data presented earlier support this result in that crops grown under deep tillage with less frequent watering were better hydrated (Fig. 4), largely as a result of better water penetration and soil storage capacity following rainfall and irrigation (Fig. 3). The response to deep tillage in a 'normal' dry season would be expected to be even greater based on these results. Unusually high rainfall during this experiment would have minimised severe crop water deficits, and not allowed the full expression of the better crop water status which deep tillage obviously caused.

In the following season (1989 dry season) the effect of tillage was again investigated to determine whether deep tillage was improving peanut yield performance. An experiment assessing deep and shallow tillage on peanut grown at three times of sowing (late May, mid-June and mid-July) under rainfed conditions was established to ensure reasonable water stress occurred. Table 4 presents TDM and seed yield for each time of sowing and tillage treatment.

Table 4. Total dry matter and seed yield of peanut as affected by time of sowing (rainfed) and tillage.

Time of sowing	Tillage treatment (cm)	Total dry matter (kg/ha)	Seed yield (kg/ha)
30 May	T_{20}	5020	1838
	T_{40}	7560	2091
12 June	T_{20}	4454	1558
	T_{40}	4589	1703
17 July	T_{20}	1703	336
	T_{40}	3427	263

Rainfall during each time of sowing treatment was again unseasonally high (129, 141 and 189 mm for May, June and July, respectively); however, severe water deficits developed in each crop. Unfortunately, peanut stripe virus (PStV) incidence was severe during each time of sowing, and was particularly bad in the July sowing. As a result of PStV infection, these results need to be interpreted with some caution. For example, although rainfall increased with later-sowings, TDM and seed yields declined with later-sown crops. These data clearly illustrate the devastating influence of this virus on peanut yield potential.

With these PStV virus concerns in mind, it was apparent that TDM at maturity was substantially higher under deep compared to shallow tillage (for example, in the May sowing, crops produced 7.5 compared to 5.0 t/ha under deep and shallow tillage). The seed yield response to tillage was small at each time of sowing (200 kg/ha). The lack of seed yield response, compared to TDM response to tillage may be associated with PStV infection, as other work in this project has shown the virus severely affects podset and subsequent partitioning.

In general, the data confirms the earlier experiment in that there was a positive growth response to deep tillage under water-limited conditions. Water infiltration and subsequent soil water availability may therefore have been improved by deeper tillage.

Implications for Production and Research in Indonesia

The irrigation management work conducted throughout the peanut project provides significant information for future recommendations and research activities in the South Sulawesi region. It includes the following points.

- The large potential for widespread field crop production in the South Sulawesi region, using easily accessible but limited supplies of groundwater, highlights the need to utilise irrigation water as efficiently as possible for dry season crop production. The results of the research conducted for peanut clearly demonstrate that high yields (>2 t/ha) can be achieved by using less frequent irrigation than previously thought by farmers and extension officers. Irrigating at a cumulative evaporation deficit of 70 mm (approximately every 15 days) produced similar pod yields to crops irrigated on a deficit of 20 or 35 mm (at four to seven day intervals). The soil water and crop physiological data collected clearly demonstrate that peanut is capable of extracting soil water to depths of 1.0 m and more. Thus the soil profile acts as a buffer to supply the water requirements of the crop between irrigations. The reduction in frequency of irrigation will significantly reduce labour and fuel costs associated with irrigation. Also, where crops are operating under a certain level of soil water deficit, any unseasonal rainfall will be able to be stored in the soil, rather than running off. Thus overall efficiency of rainfall utilisation will be optimised.
- Soil water sampling immediately after irrigations on certain treatments revealed that infiltration of irrigation water was restricted to about 20 cm, a response which resulted in poor soil water replenishment and low irrigation efficiency. It is well documented that the structure of surface soil in the paddy phase is often destroyed by puddling and reduces subsequent infiltration in the dry

season crop. The effect of deep tillage in overcoming the infiltration problem was investigated in a number of experiments under conditions of variable water supply. The results showed that deep tillage (40 cm depth) improved penetration of irrigation water and rainfall, increased soil water-holding capacity, and improved crop water status throughout the season, when compared to conventionally tilled (20 cm depth) soil. The effect of deep tillage on total dry matter production was more pronounced than for pod yield, especially as soil water deficits increased with reduced irrigation frequency. On the basis of the results to date, however, it appears that the benefit of deep tillage in terms of pod yield is of marginal value, particularly in light of the large labour requirement needed.

Further experimentation to assess pod yield in response to tillage is required before firm recommendations can be made. Our experiments were confounded in the first year by unseasonably high rainfall, and in the second by severe PStV incidence. The use of calcium ameliorants such as gypsum to improve surface soil structure and subsequent infiltration also needs to be investigated.

- Soil water extraction profiles measured in irrigated and rainfed crops showed that peanut was capable of extracting significant amounts of water to and below a depth of 1.2 m. It therefore seems soil compaction around the paddy layer was not limiting root penetration at and below this zone. Rather, the data presented here suggest that poor structural stability of the surface soil (associated with puddling) limits infiltration and redistribution of irrigation water and rainfall. These findings may have implications for future research in the post-rice cropping system, where the current perception is that the compact puddled zone limits yield by restricting root penetration and subsequent soil water extraction.
- Pod yields under rainfed conditions were shown to be extremely low in relation to the total dry matter produced by peanut crops (i.e. harvest index was extremely low). It is suggested that surface soil dryness (and associated hardness) may be limiting peg entry, podsetting, and subsequent pod and kernel development. Other research in this project shows significant cultivar variation in ability to penetrate dry and hard soils. The potential for increased yield under rainfed conditions is enormous if genotypes capable of pegging and podding into dry and hard soils can be identified. For example, in one experiment TDM produced under rainfed conditions was 2.9 t/ha, while pod yield was only 0.5 t/ha. If harvest index could be improved to around 0.4, pod yield would increase to around 1.1 t/ha.

Reference

Prastowo, B., Prabowo, A. and Wright, G.C. 1990. Growth, yield and soil water extraction of irrigated and dryland peanuts in South Sulawesi. Irrigation Science, 11, 63–68.

The Role of Macronutrient Deficiencies (N,P,K) in Limiting Peanut Yields in Java

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CONSTRAINT identification studies indicated nutritional deficiencies were apparent in a number of major peanut production areas — especially in East and Central Java. While K was implicated in at least one location in Central Java, symptoms consistent with P and/or K deficiency were reported from other areas. At the same time, no studies conducted during the first phase were able to show positive responses to N fertilizer applications, and prolific (and apparently functional) nodulation was evident in most plants.

Currently there exists a national fertilizer recommendation for peanuts in Indonesia. It calls for 50 kg N, 20 kg P and 25 kg K per ha. The objectives of this aspect of project 8834 were (i) to demonstrate that fertilizer efficiency could be improved by establishing basic relationships between soil test P and/or K and crop yield; and (ii) to investigate further N_2-fixation in peanut grown in lowland cropping areas (rice-rice-palawija or rice-palawija-palawija), and hence to determine the need for N fertilizer applications).

An additional yield limitation apparent in the Kuningan–Majalengka regions (the main peanut-producing provinces of West Java) during project 8419, was due to infestations of leaf miner *Aphroareama modicella*. Small-scale investigations into the extent and severity of this problem and the likely benefits from chemical control were also studied during the project.

Research Highlights

P and K studies — Jakenan (Central Java)

Studies were undertaken in the Jakenan region of Central Java, on red-yellow podzolic soils typical of the district. Previous experiments on the CRIFC research station at Jakenan had suggested a strong likelihood of K responses in farmers' fields, and in addition, possible roles of P and micronutrient deficiencies in limiting yield. Experiments were conducted at five locations in 1989 and 1990, with five or six treatments (consisting of a control, and various combinations of N, P and K, along with foliar-applied trace elements) at each location, with three replicates. Individual field sizes in this locality were so small as to necessitate placing each replicate at each location in a different field with a differing crop history. Therefore replicates were treated as additional locations, and soil test to yield relationships were derived from individual 'replicate' data.

Serious problems were encountered in obtaining reliable soil analytical data from laboratories in Indonesia, at least for the 1989 season. Soils were analysed at the Jember laboratories, while duplicate samples from two replicates of each location (10 samples) were returned (with appropriate quarantine restrictions) to Australia for comparative analysis. Results of analyses from the 10 samples are shown in Table 1, highlighting the problems encountered in data interpretation.

During a subsequent six-month technical visit by Mr Arief Harsono (Agronomist, MARIF) to QDPI in 1990, considerable emphasis was placed on appropriate methodology for soil chemical analysis. In addition, a number of soil samples with known chemical characteristics were returned to Indonesia by the laboratory as reference samples or standards for future analysis. Unfortunately, at the time of this report, soil analytical data from the 1990 locations were not yet available. However, it is hoped some of the problems encountered in 1989 have been overcome.

Plant tissue samples were also taken from uppermost fully expanded leaves during early podding in both 1989 and 1990, with samples analysed in Australia. Values for tissue P and K concentrations

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Table 1. Chemical analysis of Jakenan soils conducted in Australia (0–20 cm) from the 1989 nutritional experiments. Analytical data from Jember laboratory in parenthesis where applicable. Similar extraction methods used, unless indicated (*).

Soil parameter	Location 1		Location 2		Location 3		Location 4		Location 5	
(replicate)	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
pH (1:5, water)	5.4	5.3	5.4	6.4	5.1	5.4	6.8	5.3	6.3	4.8
	(6.8)	(6.7)	(6.6)	(6.4)	(5.6)	(5.6)	(6.5)	(6.6)	(6.7)	(6.1)
Organic carbon (%)	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.6	0.4	0.5
	(0.29)	(0.36)	(0.32)	(0.24)	(0.23)	(0.32)	(0.17)	(0.28)	(0.26)	(0.42)
Total N (%)	0.02	0.02	0.03	0.02	0.02	0.01	0.02	0.04	0.03	0.04
	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
Exchangeable Ca	3.9	2.6	2.8	4.0	4.5	3.5	12.0	5.8	8.8	3.5
(meq/100 g)*	(12.9)	(14.3)	(13.2)	(17.1)	(3.8)	(4.9)	(6.3)	(6.9)	(10.2)	(3.3)
Exchangeable Na	0.11	0.12	0.15	0.27	0.07	0.07	0.16	0.11	0.13	0.09
(meq/100 g)*	(0.41)	(0.46)	(0.10)	(0.41)	(0.15)	(0.08)	(0.20)	(0.12)	(0.34)	(0.15)
Exchangeable K	0.07	0.05	0.05	0.08	0.07	0.07	0.14	0.15	0.11	0.13
(meq/100 g)*	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Exchangeable Mg	0.6	0.3	0.4	0.5	0.6	0.5	1.6	0.9	1.2	0.6
(meq/100 g)*	(1.6)	(1.7)	(0.8)	(2.1)	(0.8)	(0.6)	(1.2)	(0.9)	(1.2)	(0.6)
Exchangeable Al^{3+} (meq/100 g)	0.2	0.3	0.7	0	1.0	0.3	0	0.4	0	0.9
Bicarbonate	13	12	37	22	5	5	4	22	7	18
extractable P (ppm)	(10)	(15)	(27)	(10)	(12)	(18)	(4)	(10)	(12)	(20)
SO_4-S (ppm)	6	5	8	8	9	7	5	20	5	13
	(10)	(10)	(13)	(8)	(10)	(26)	(9)	(9)	(10)	(8)
DTPA Cu (ppm)	1.3	0.9	1.1	0.6	1.5	0.9	0.5	1.5	0.9	1.4
DTPA Zn (ppm)	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.8	0.2	0.8
DTPA Fe (ppm)	84	71	166	45	37	36	17	169	31	151
DTPA Mn (ppm)	8	5	14	6	36	13	9	39	12	16

(*) Extracts of exchangeable cations in Australia undertaken using ammonium chloride method (pH 7.0), while Jember analyses were done using ammonium acetate (pH 7.0) method. Both methods should produce fairly similar results.

are shown in Table 2 and suggest that at least five of the 15 sites in 1989 and all nine sites tested in 1990 were experiencing severe K deficiency (i.e. leaf K concentration <1.0%). All sites in 1989 showed tissue P levels of 0.21–0.4%, which suggested that limitations from P deficiency were less likely (values <0.2% are considered critical). However there were suggestions of P deficiency at one location in 1990, with tissue P concentration at 0.15%.

All sites were non-irrigated, and suffered extreme water stress during the 1989 season. Yields were consequently very low (200–700 kg/ha pods), and relationships between soil test P and K (or tissue P or K) and yield were very poor (Figs 1a,b). There was, however, a trend to increased yield with increasing soil K, as expected from soil analytical data. In fact, although 12 out of the 15 locations tested in 1989 showed yield increases of 25% or better with a complete fertilizer application (N, P, K and trace elements), only four showed a response of 20% or greater in the absence of K (Table 3).

Table 2. Tissue P and K concentrations during early seed-fill stage in uppermost fully expanded leaves of peanuts grown at locations around Jakenan (Central Java) in 1989 and 1990. Values are shown as means for each location (with the range across replicates in parentheses) for the unfertilised control plots.

	P concentration (%; crit. = 0.2%)	K concentration (%; crit. = 1.5%)
	1989	
L1	0.35 (0.34–0.37)	0.94 (0.66–1.45)
L2	0.30 (0.28–0.33)	1.42 (1.32–1.48)
L3	0.30 (0.21–0.36)	1.69 (1.49–1.85)
L4	0.32 (0.26–0.38)	1.19 (0.84–1.50)
L5	0.41 (0.40–0.43)	1.09 (0.75–1.44)
	1990	
L1	0.21 (0.20–0.23)	0.76 (0.68–0.90)
L2	0.18 (0.15–0.21)	0.54 (0.51–0.56)
L3	0.22 (0.20–0.23)	0.59 (0.51–0.64)

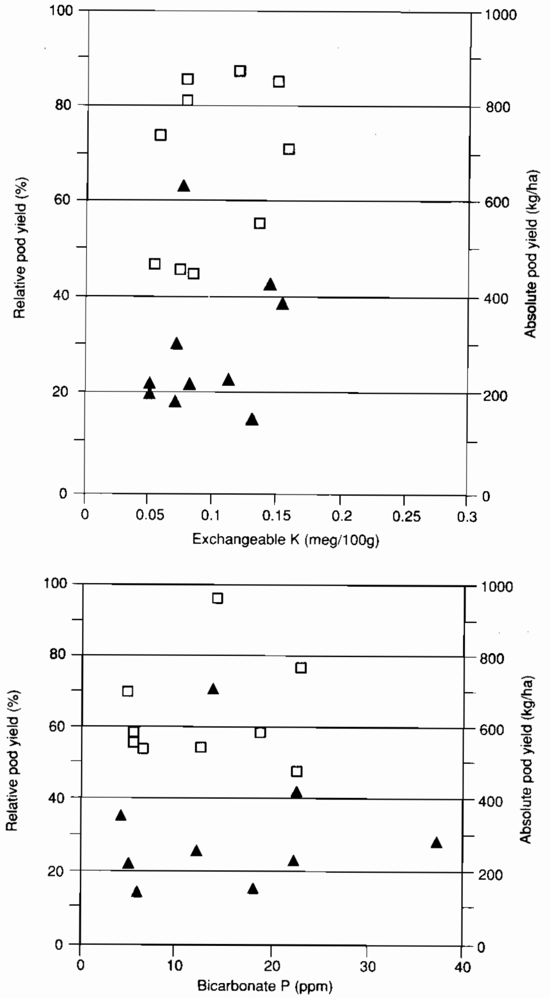

Figure 1. Soil test to yield relationships for (a) K and (b) P from Jakenan, 1989 dry season. Yields are expressed either as absolute yields (▲, kg/ha) or relative yields (☐, % of yields with complete fertilizer).

Similar stress periods were experienced in 1990, resulting in the decision to abandon the two most severely stressed locations as yields were almost non-existent. All three remaining locations (means of individual replicates) produced similar fertilizer responses and, indeed, similar yields (Table 4). All locations produced yields with (P + K) fertilizer of approximately 150% of the unfertilised control. However, at all three locations there appeared to be strong P-K interactions. Yield in the absence of K ranged from 67 (L1) - 77% (L2) of the yield with (P + K), while yields in the absence of P ranged from 75% (L1) to 87% (L2) of yields with (P + K). While responses to K were generally stronger than to P, results indicated both elements were deficient at these locations. It is also worth nothing that the cultivar SHM1509 significantly ($P<0.05$) outyielded both Gajah and the local check at each location, although fertilizer responses were similar.

It is hoped that, once soil test data for each replicate at each location is obtained, these (combined with data from 1989) may establish a clearer picture of the soil test-yield response for these soils. What is clear so far is that K deficiency in particular, and P deficiency to a lesser extent, severely limit peanut productivity on red-yellow podzolic soils in Central Java.

Tuban (East Java)

Studies were undertaken in both Blitar and Tuban provinces in 1989, but further work in Blitar was

Table 3. Relative yields (compared to unfertilised controls) of peanut cv. Gajah when treated with either a complete (50 kg N, 75 kg K, 50 kg P and 3 foliar applications of a complete trace element mix) or complete-K fertilizer application. Absolute yields (kg/ha) are also shown for the complete fertilizer plots. Soil analytical data in Table 1 refer to R1 and R2 plots shown here.

		Yield of complete fertilizer (kg/ha)	Relative yields cf. control (%)	
			complete fertilizer	complete-K
Location 1	Rep 1	730	313	270
	Rep 2	470	167	79
	Rep 3	570	118	105
Location 2	Rep 1	270	143	105
	Rep 2	490	233	105
	Rep 3	560	125	76
Location 3	Rep 1	390	217	100
	Rep 2	370	137	111
	Rep 3	260	145	145
Location 4	Rep 1	500	139	119
	Rep 2	540	175	127
	Rep 3	740	625	100
Location 5	Rep 1	260	125	110
	Rep 2	270	270	149
	Rep 3	360	303	100

Table 4. Pod yields (kg/ha) of peanuts grown at three locations in the Jakenan district in 1990 season, with P and/or K fertilizer.

	No fertilizer	50 kg P/ha	75 kg K/ha	50 kg P/ha + 75 kg K/ha
L1	801 a	840 a	943 b	1257 c
L2	944 a	1161 b	1307 c	1504 d
L3	794 a	938 b	1053 c	1250 d

Data represent means of three cultivars (Gajah, local selection, and SHM1509) and three replicates. Different letters denote significant differences ($P < 0.05$) within each location.

discontinued due to the high incidence of peanut stripe virus in the area and the extreme variability encountered in crop growth. (The latter was due to variable shading from coconuts commonly planted around the small fields, and poor drainage encountered in lower-lying areas.)

Tuban province was chosen due to its high annual peanut production (approximately 25% of East Javan peanuts) and the frequent reports of 'yellow symptom' in peanuts and other crops, reportedly due to K deficiency. Experiment sites were located in regosol soils, with soil analysis data for each location (see Table 5). Only analytical data from the Jember laboratories are available for these studies, so the accuracy of values may be questionable (as indicated by the Jakenan analysis, Table 1). Data suggest a good range of soil test values for P and K, however.

Tissue samples were taken during early seed-fill, with analyses of nutrient concentrations in uppermost fully expanded leaves undertaken in Australia. Results are shown in Table 6 for selected treatments and nutrients, and suggest that at least in locations L1, L2 and L3 the K status of plants was below the reported critical concentration for optimal yields. Other nutrient levels appeared satisfactory, although P status of L3 was also marginal.

Visual observations of plants in the field during early seed-fill showed marked 'yellow symptom' development on all plants without foliar trace element applications. This consisted of interveinal chlorosis on older leaves, followed by bleaching and necrosis, leaf drop, etc. Severity of symptoms apparently increased and appeared higher up the plant during seed-fill, and were even apparent on plots with foliar trace element applications at maturity.

The existence of an apparently severe trace element deficiency suggested responses to P and K treatments were probably unlikely, and this turned out to be the case. Pod yields (Table 7) showed no significant responses to P and/or K, while the effects of foliar trace element application were significant (comparing treatments 2 with 3 and 6 with 7) at L1 and L4.

Research in 1990 and 1991 concentrated on attempting to identify the trace element deficiency, determine its extent and severity, and evaluate possible agronomic solutions. To this end, both soil and plant samples from fields with either healthy or deficient plants were collected for analysis in Australia. Results of plant analyses are shown in Table 8 (uppermost fully expanded leaves during early podding) and soil analyses in Table 9 (0–20 cm soil profile).

Once again, tissue analysis proved relatively uninformative in terms of diagnosing the unidentified nutrient deficiency. Deficient plants were characterised by concentrations of all elements higher than those of the healthy plants, probably due to a dilution effect in the healthy plants, which were producing more DM. The only difference worth nothing, however, was in Fe concentration, which was high in both 'healthy' and 'deficient' plants, with the latter exceptionally so. These high values were more likely due to surface contamination of leaf tissue than actual toxic tissue Fe accumulation, with the stunted, poorly developed canopies in the deficient areas more likely to be heavily surface-contaminated. All other elements tested within the range considered adequate for peanut, although Zn levels tended to be at the lower end of the normal range.

This lack of difference between 'healthy' and 'deficient' plants suggested that the plant part sampled may not have been appropriate. Mobilisation of reserves from other plant parts toward the growing point may have maintained tissue concentrations at adequate levels in this part of the canopy, resulting in the lack of a conclusive test.

Consideration of the full soil analyses from these areas was a little more informative (Table 9). The high pH, high proportion of total cations as Ca^{++} and the very low DTPA-Zn levels suggest that Zn deficiency is a likely candidate. Further studies are under way to seek confirmation of this tentative diagnosis in the field and in screenhouse studies in East Java.

Sites of soil sampling (Table 9) were different to those for the earlier tissue samples (Table 8) and suggest that K deficiency may well be a secondary consideration in areas such as the Tamsari locations. However, the primary limit to peanut production, and the cause of 'yellow symptoms' in Tuban and

Table 5. Soil chemical characteristics from regosol soils in Tuban Province, determined by Jember laboratories. Similar analytical procedures as in Table 1.

	Location 1		Location 2		Location 3		Location 4		Location 5		Location 6	
	0–10	10–20	0–10	10–20	0–10	10–20	0–10	10–20	0–10	10–20	0–10	10–20
pH (1:5, water)	7.3	7.9	—	—	—	8.5	7.3	7.2	7.7	7.9	8.1	8.2
Organic carbon (%)	0.83	0.59	—	—	—	0.70	0.93	0.79	0.83	0.63	1.13	0.98
Total N (%)	0.08	0.06	—	—	—	0.08	0.09	0.08	0.08	0.06	0.11	0.08
Exchangeable Ca (meq/100 g)	23.9	29.5	—	—	—	50.8	27.1	29.5	29.5	24.0	45.6	45.7
Exchangeable Na (meq/100 g)	0.10	0.13	—	—	—	0.02	0.07	0.10	0.10	0.13	0.02	0.02
Exchangeable K (meq/100 g)	0.46	0.44	—	—	—	0.18	0.78	1.27	0.16	0.07	0.23	0.18
Exchangeable Mg (meq/100 g)	3.0	3.1	—	—	—	0.8	2.8	2.8	3.3	2.6	1.8	1.4
Bicarbonate-P (ppm)	96	52	—	—	—	22	126	76	35	19	63	37
SO_4-S (ppm)	17	12	—	—	—	12	12	9	11	9	12	5

Table 6. Effect of fertilizer treatment on N, P, K and selected trace element concentrations of uppermost fully expanded leaves of Gajah peanuts during early seed-fill in 1989. Treatment numbers refer to those shown in Table 7; values are means (n = 3).

Treatment	L1	L2	L3	L4	L5	L6
N concn (% DW)						
1	3.1	3.8	3.4	3.9	3.3	3.8
3	3.5	3.8	3.7	4.2	3.6	3.9
6	3.6	3.8	3.7	4.2	3.7	3.9
7	—	—	3.8	4.2	—	3.9
P concn (% DW)						
1 (Control)	0.30	0.32	0.23	0.38	0.36	0.29
3	0.27	0.30	0.23	0.38	0.31	0.28
6	0.27	0.31	0.23	0.38	0.31	0.28
7	—	—	0.23	0.37	—	0.27
K concn (% DW)						
1	1.09	1.31	1.12	2.42	2.36	2.33
3	1.09	1.23	1.23	2.43	2.17	2.35
6	1.14	1.36	1.19	2.43	2.18	2.33
7	—	—	1.34	2.27	—	2.28
Zn concn (% DW)						
1	38.2	29.0	38.6	43.1	55.2	33.1
3	26.4	39.2	38.2	35.3	30.7	30.4
6	29.8	31.7	41.5	39.1	33.6	31.8
7	—	—	44.6	30.2	—	30.0
Fe concn (% DW)						
1	251.0	182.0	176.0	128.0	171.7	121.3
3	247.3	217.7	176.3	162.3	123.0	142.3
6	240.7	188.0	162.7	243.7	114.3	173.3
7	—	—	167.0	181.7	—	156.3

Table 7. Effects of fertilizer treatments on peanut (cv. Gajah) yield at a number of locations in Tuban, East Java in 1989.

Fertilizer treatment	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
1. Control (nil)	150b	1790a	340b	1750c	1460a	1590a
2. Ammonium sulphate (100 kg/ha)	120b	—	500b	2060bc	—	—
3. Ammonium sulphate + foliar trace elements*	460a	1450a	340b	2650a	1900a	1440ab
4. Ammonium sulphate + foliar trace elements + 50 kg P/ha	250b	1380a	540ab	2720a	1970a	1390ab
5. Ammonium sulphate + foliar trace elements + 75 kg K/ha	170b	1580a	460b	2770a	1960a	1470ab
6. Ammonium sulphate + foliar trace elements + 50 P + 75 K	390a	1620a	400b	2650a	1810a	1270b
7. Ammonium sulphate + 50 P + 75 K	230b	1350a	730a	2470ab	1860a	1230b

*Foliar trace elements were applied at a rate of 5 kg/ha in 200L water (Librel BMX® — a complete trace element mix) at 20, 35, 50 and 65 days after sowing. Different letters denote significant differences ($P < 0.05$) within each location.

Table 8. Leaf analysis data for peanut cv. Gajah grown in farmers' fields in Tuban province, 1990 dry season (sampling during early podding phase).

		Nutrient concentration												
		DW (%)								mg/kg				
		N	P	K	Ca	Mg	S	Na	Cl	Cu	Zn	Mn	Fe	B
Pangpongan	— healthy													
	1	4.8	0.41	2.3	2.0	0.55	0.39	B/L*	0.52	9.2	25.3	138	677	46
	2	4.0	0.35	1.9	1.8	0.56	0.36	B/L	0.68	9.5	28.6	145	612	39
	3	4.8	0.43	2.5	1.9	0.52	0.40	B/L	0.52	9.1	25.5	116	404	47
	— deficient													
	1	5.4	0.49	2.2	2.7	0.72	0.56	B/L	0.69	13.3	29.9	151	947	57
	2	5.1	0.50	2.7	3.0	0.80	0.51	B/L	0.80	12.1	28.9	144	882	59
	3	5.9	0.62	3.0	3.3	0.72	0.60	B/L	0.63	14.9	36.7	172	1243	68
	4	5.5	0.48	2.2	3.0	0.75	0.55	B/L	0.75	11.7	32.5	147	1174	67
Senori	— healthy													
	1	4.6	0.34	2.3	1.5	0.34	0.28	B/L	0.58	8.9	34.5	55	145	39
	2	4.7	0.33	2.7	1.5	0.35	0.30	B/L	0.42	9.2	28.0	55	287	39
	— deficient													
	1	6.0	0.46	2.6	2.4	0.55	0.50	B/L	0.48	16.7	37.6	148	1370	60
	2	5.8	0.39	2.4	2.2	0.51	0.47	B/L	0.41	14.7	35.5	147	1137	56
	3	3.7	0.25	2.3	1.5	0.28	0.25	B/L	0.50	9.0	26.0	56	747	42

*B/L = Below detectable limit.

Table 9. Soil analyses (0–20 cm) from farmers' fields in Tuban province supporting peanut crops exhibiting varying stages of nutrient stress during early podding stage.

Soil parameter	Location/status						
	Senori (healthy plants)	Senori (medium deficiency)	Senori (severe deficiency)	Temandang (healthy plants)	Temandang (deficient)	Tamsari (deficient)	Tamsari (deficient)
pH (1:5, water)	8.1	8.1	8.1	7.4	8.5	8.6	8.7
Electrical conductivity (ms/cm)	0.046	0.059	0.067	0.045	0.080	0.109	0.104
Cl (ppm)	3	31	14	6	8	35	16
Bicarb. P (ppm)	54	86	39	53	48	36	40
Organic C (%)	1.0	0.9	0.7	0.8	1.0	0.8	0.9
Total N (%)	0.10	0.08	0.06	0.07	0.09	0.08	0.09
Cat. exch. cap. (meq/100 g)	28	32	39	18	18	28	29
Exch. Ca (meq/100 g)	27.0	31.5	40.0	16.2	23.6	27.4	30.5
Exch. Mg (meq/100 g)	3.2	3.5	2.7	2.2	1.7	4.1	4.4
Exch. K (meq/100 g)	0.23	2.18	0.71	0.20	0.20	0.14	0.17
Exch. Na (meq/100 g)*	<0.01	0.01	<0.01	<0.01	<0.01	0.09	0.06
Aqu. NO_3^--N (ppm)	6	3	4	12	8	4	4
Total P (%)	0.132	0.130	0.074	0.140	0.162	0.099	0.135
Total K (%)	0.126	0.465	0.203	0.103	0.118	0.070	0.115
Total S (%)	0.022	0.018	0.015	0.018	0.024	0.016	0.022
DTPA Cu (ppm)	1.6	1.7	1.4	1.8	1.3	1.7	1.4
DTPA Zn (ppm)	0.3	0.2	0.7	0.6	0.4	<0.05	0.2
DTPA Mn (ppm)	7	7	4	18	6	3	3
DTPA Fe (ppm)	6	10	7	9	4	8	5

neighbouring provinces, seems not to be K, as reported in other studies. The agronomic solution to the problem may prove difficult, as micronutrient fertilizer (e.g. Zn) availability is low in Indonesia and appropriate application technology needs to be developed.

Kuningan–Majalengka (West Java)

Studies were conducted primarily in the Kuningan district of W. Java, although farmers' fields in the Majalengka region were also inspected for insect problems. The use of insecticides for control of insect pests during dry season peanut crops, in combination with various fertilizer input packages, was evaluated in 1989 and 1990. While the original study in project 8419 was undertaken at Kuningan in an area with a rice-palawija-palawija cropping system, studies during this project were largely confined to the vicinity of the nearby Cinagara region, which has a rice-rice-palawija system. This was due to the more regular cropping of dry season peanut in this area, in addition to an interest in possible N responses under that cropping system.

The 1989 study showed no benefits of insecticide application at 0, 7, 14 or 21-day intervals, with yields ranging 718–773 kg dry pods/ha. However, treatments were restricted to applications during the vegetative and early pegging stages only, and there were suggestions that later leaf miner infestations caused yield reductions.

Effects of various fertilizer packages (0, 25 or 50 kg/ha K; 0 or 30 kg/ha P; and 0 or 100 kg/ha N) were also examined in 1989. Effects of P or K fertilizer were non-significant, producing yields less than 10% greater than the unfertilised control. However, effects of N fertilizer were highly significant, with yield increases of 40–45% with N applications (955 kg/ha with 0 N, versus 1415 kg/ha with 100 N). This was the first occasion on which significant fertilizer N responses were recorded in either project 8419 or this project, so was of particular interest. This was also the first occasion on which we had grown peanut under lowland conditions after two consecutive rice crops, so the possibility of effects of the cropping system on the survival of the *Bradyrhizobium* sp. population was considered.

A follow-up study in Cinaraga district was undertaken in the 1990 dry season to investigate further the role of insects and N nutrition in peanut yield limitations. In order to gather more definitive data on the biological N_2-fixation occurring under this system, extensive collaboration with the ACIAR project of Dr Mark Peoples (measurement of N_2 fixation in legumes) was instigated. Part of a technical training visit by an Indonesian scientist (Ir. Suryantini) was spent at CSIRO in Canberra becoming familiar with the methods used in xylem sap analysis for assessing N_2-fixation in peanut. Samples of xylem sap were collected (along with DM estimates from destructive samples) on three occasions during the growing season in 1990, and returned to Australia for analysis.

Twenty treatments, consisting of a farmer's method and various NPK fertilizer and insecticide timing combinations, were tested in a randomised block design. Experimental error in this study was high, with coefficients of variation for pod and kernel yields in the range 25–31%. Nonetheless it was apparent that the farmer's technique (no fertilizer or insecticide application) was not substantially different from the other fertilizer or insecticide treatments (mean pod yield of about 1.0 t/ha). There was, however, a significant kernel yield response to the 'complete' treatment (all NPK + insecticide), relative to the farmer's method. The results from the study also indicated there was no pod yield benefit from applying N to peanut, and this supports other data from Indonesia which show little, if any, response to N fertilizer in peanut. Unfortunately, results of xylem sap analyses are not available at the time of compiling this report. Therefore the role of biological N_2-fixation in meeting crop N requirements cannot be assessed.

Implications for Production Research in Indonesia

We believe that agronomic studies undertaken in East, Central and West Java highlight serious deficiencies in the Indonesian peanut program. Attention to these deficiencies could result in improved national fertilizer recommendations across a wide range of soil types and cropping systems.

Research shows that, while fertilizer applications will certainly benefit peanut crops on the red-yellow podzolic soils of the Jakenan region, by far the highest priorities are K and, possibly, P applications. Even if responses to N fertilizer could be demonstrated under those conditions (and there is no evidence to support this in our studies) they are only likely to occur *after* the yield-limiting K and/or P deficiencies have been overcome. Farmers have limited cash reserves to purchase fertilizer for peanut crops, so it is important to maximise returns from limited inputs.

To this end it is essential that the development of yield to soil test relationships (for P and K in particular) continue on these (and other) soils for future peanut recommendations. We have begun the work in this project, but inadequate soil and plant diagnostic facilities in the area slow progress considerably. This problem must be corrected before more widespread activity can be undertaken.

The situation on the Regosol and Mediteran soils of E. Java is similar, although the apparent limiting nutrients are different. This project has successfully shown that the widespread 'yellow symptom' on crops in these areas (and probably in neighbouring soybean production areas like Bojonegoro and Ngawai) is not K deficiency, but more likely a pH-induced micronutrient deficiency, probably of Zn. Again, a widespread lack of appropriate analytical facilities for necessary diagnostic soil and plant analyses has hampered progress. However, considerable future work is required due to the large-scale palawija production in this region. The work should include conclusive identification of the deficiency (which is partially under way in the final stages of this project) and the evaluation of appropriate fertilizer application strategies for use by small farmers.

Research in West Java also provided little evidence to support high fertilizer inputs for peanut production, except for one study showing N responses. A more detailed analysis of the status of biological N_2-fixation as a means of supplying peanut N requirements, with the very short season cultivars used in Indonesia, is required. Of particular interest would be the comparison of proportions of total crop N fixed under upland versus lowland cropping systems, as well as the effects of crop rotations with those categories.

Once again, these results highlight the inefficiency of a uniform national fertilizer recommendation for peanut. This project demonstrates that a future priority for peanut research is a revision of this policy, with recommendations made on a regional basis and influenced by soil type and cropping system. In a review paper presented at the regional Asian Groundnut Scientists Meeting in Malang in November 1988, peanut was reported to be very unpredictable in its fertilizer response. This project has helped to show that this unpredictability can be eliminated (or at least reduced) by the appopriate use of diagnostic analyses, in combination with field fertilizer studies.

Due to the apparently limited occurrence of severe insect infestations (e.g. leaf miner) in the West Java production areas, future research on this aspect should be of low priority.

Lime Requirement for Peanut, and Screening of Peanut Germplasm for Tolerance to Acid Soils

A. Gani,* A. Tanjung* and M.J. Bell†

Introduction

LARGE areas of acid soils (largely oxisols and ultisols) occur throughout Indonesia, with the largest areas in Sumatra, Kalimantan, Sulawesi and Irian Jaya. As part of the extension of palawija production in areas outside Java, these soils have become significant as potential sites of major peanut production. As such, information must be gathered on the primary limits to peanut production on these soils and possible agronomic solutions to those limits, as well as investigating genotypic variation in response to components of soil acidity.

Research has been undertaken at the Sitiung substation of SARIF, utilising unlimed areas that have been homogenised for research purposes by the Tropsoils group based at SARIF. Typical soil chemical characteristics are shown in Table 1.

Work concentrates on two main activities:

- assessing the effects of various rates of dolomitic limestone on soil characteristics and peanut growth, both in terms of initial effects and also the residual value of the initial application (in interaction with organic matter management); and
- establishing a controlled acid soil screening nursery for peanut germplasm from the national program and from international agencies such as ICRISAT (this consists of areas maintained at predetermined levels of pH, Al-saturation and nutrient availability by the appropriate use of lime, fertilizers and so on).

Research Highlights

Agronomic studies

Original lime rate study

Eight rates of dolomitic limestone (0, 0.5, 1.0, 1.5, 2.0, 3.0, 4.0 and 5.0 t/ha) were applied in July 1988, prior to planting dry season peanuts. Rates were applied in 6 m wide strips of 60 m length, with each bulk lime rate split into 4 × 15 m replicates.

Within each replicate a range of peanut (33), mungbean (17), pigeonpea (27) and soybean (20) cultivars were grown to determine an appropriate range of lime rates (with associated soil properties) for future germplasm screening. Fertilizer applications of N, P and K were made to correct for the effects of known deficiencies (P and K) or effects on *Bradyrhizobium* sp. function, as determined in Tropsoils and SARIF studies. As future activity concentrates on peanuts, data from peanuts only will be presented in this report.

Table 1. Typical soil chemical analyses of unlimed red-yellow podzolic soil found on the Sitiung substation of SARIF.

Parameter	Depth (cm)	
	0–20	20–40
pH (1:5, water)	4.2	4.0
Organic C (%)	1.5	1.6
Total N (%)	0.15	0.11
Effective CEC (meq/100 g)	5.62	6.04
Exch. Ca (meq/100 g)	0.18	0.75
Exch. Mg (meq/100 g)	0.12	0.20
Exch. Na (meq/100 g)	0.44	0.40
Exch. K (meq/100 g)	0.20	0.16
Exch. H (meq/100 g)	0.38	0.32
Exch. Al (meq/100 g)	4.30	4.20
Al saturation (%)	76.5	69.7
DTPA Cu (ppm)	3.4	4.0
DTPA Zn (ppm)	5.0	6.0
DTPA Fe (ppm)	52.8	38.1
DTPA Mn (ppm)	108.6	704.8
Texture		
Sand (%)	39	28
Silt (%)	24	17
Clay (%)	37	55

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Effects of lime rate on selected soil properties (0–20 cm) determined at flowering stage (approximately one month after planting) are shown in Table 2. Major effects of applying dolomitic limestone were (i) raising pH from 4.4 (0 lime) to 5.7 (5 t/ha); (ii) reducing exchangeable Al and Al-saturation from 2.98 meq/100 g, 45% saturation (0 lime) to 0.42 meq/100 g, 6% saturation (5 t/ha); reducing DTPA-extractable Mn and Zn by 35–40%; and raising exchangeable Ca and Mg levels 4–5-fold, from 0.95 and 0.29 meq/100 g to 4.27 and 1.57 meq/100 g respectively.

Response to lime by peanuts grown in this experiment varied with cultivar and with growth parameter (i.e. top dry weight versus kernel dry weight). Significant variation in cultivar response to lime was recorded for most growth parameters, so pattern analysis procedures were used to group cultivars for each yield parameter. Selected data for pod and kernel DM are shown in Figure 1, with data shown only for lime rates up to 3 t/ha due to an invasion by wild pigs at harvest.

Top DM (data not shown) was generally maximised at 0.5–1.0 t/ha, with subsequent values relatively unaffected by increasing lime. However, a subset of cultivars showed a low level of top DM production at intermediate lime rates (1–2 t/ha) for an as yet undetermined reason. (This phenomenon (i.e. a stimulation of top DM at low lime rates, little or no effect at intermediate lime rates and then stimulation at high lime rates) was repeated to some extent in the following season.) Top DM at 0 lime ranged 50–70% of maximum top DM yields for most cultivars.

In contrast to top DM, yields of pods and kernels showed much stronger lime responses in most cultivars. Pod yields at 0 lime ranged from 15–30% of yields at 3 t lime/ha (with some cultivars showing almost linear increases in pod yield with increasing lime), while kernel yields responded even more strongly. Only a small subset of cultivars showed evidence of a plateau in lime response in terms of kernel yield (up to 3 t/ha) but unfortunately these lines produced very low kernel yields at the lowest lime rates.

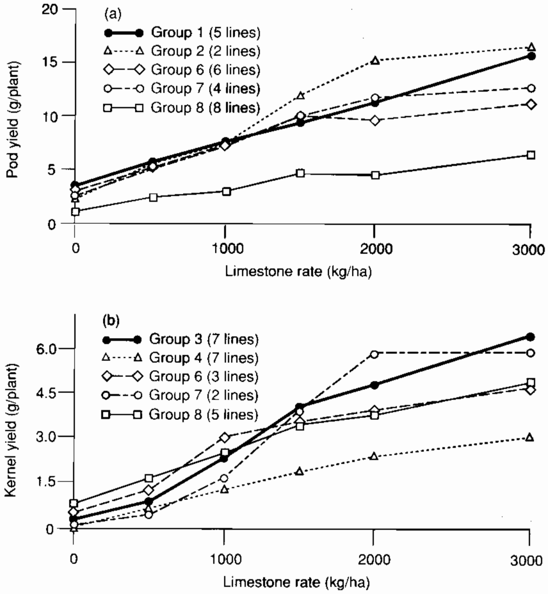

Figure 1. Effects of rate of dolomite on pod and kernel yields of peanut groups in 1988 in Sitiung, dry season.

Table 2. Effects of lime rate on selected soil chemical properties (0–20 cm) at Sitiung 40 days after lime incorporation.

Parameter	Lime rate (t/ha)							
	0	0.5	1.0	1.5	2.0	3.0	4.0	5.0
pH (1:5, water)	4.40	4.55	4.60	4.75	4.90	4.95	5.30	5.65
Exch. Ca (meq/100 g)	0.95	1.13	1.24	1.51	2.07	2.35	2.74	4.27
Exch. Mg (meq/100 g)	0.29	0.34	0.44	0.71	0.87	1.00	1.38	1.57
Exch. K (meq/100 g)	0.48	0.44	0.42	0.41	0.39	0.37	0.36	0.36
Exch. Na (meq/100 g)	0.90	0.88	0.82	0.81	0.80	0.78	0.77	0.73
Exch. H (meq/100 g)	0.98	0.94	0.76	0.62	0.57	0.42	0.32	0.27
Exch. Al (meq/100 g)	2.98	2.76	2.62	1.99	1.60	1.45	0.89	0.42
Al saturation (%)	45.00	43.00	42.00	33.00	25.00	23.00	14.00	6.00
Effective CEC (meq/100 g)	6.58	6.49	6.30	6.05	6.30	6.37	6.46	7.62
DTPA Zn (ppm)	5.75	4.85	4.44	4.33	4.30	4.28	4.11	3.60
DTPA Mn (ppm)	85.5	81.0	72.5	72.5	70.0	67.6	64.0	55.5
DTPA Cu (ppm)	6.4	7.2	7.6	7.8	8.4	8.4	8.7	10.9
DTPA Fe (ppm)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Residual value of applied limestone

The residual value of dolomitic limestone applied in 1988 was assessed in terms of soil chemical properties and growth of peanut crops in 1989, 1990 and 1991. The initial study looked at residual effects on growth of three peanut cultivars under conditions of removal of all organic residues, while subsequent studies examined the interactions between organic residue management (tops removed or returned to plots) and residual lime effects.

The change in selected soil chemical parameters over time is shown in Figures 2a, b, c, d and e. Prior to the 1990 season, soil pH and exchangeable Ca and Mg in unlimed or low lime rate plots had fallen below levels in the original unlimed condition, while exchangeable Al, Al-saturation and DTPA-Mn had increased. Although soil pH in all plots was either lower than or not significantly different to that of the original unlimed soil, other soil characteristics were still significantly improved after two years in the high lime plots.

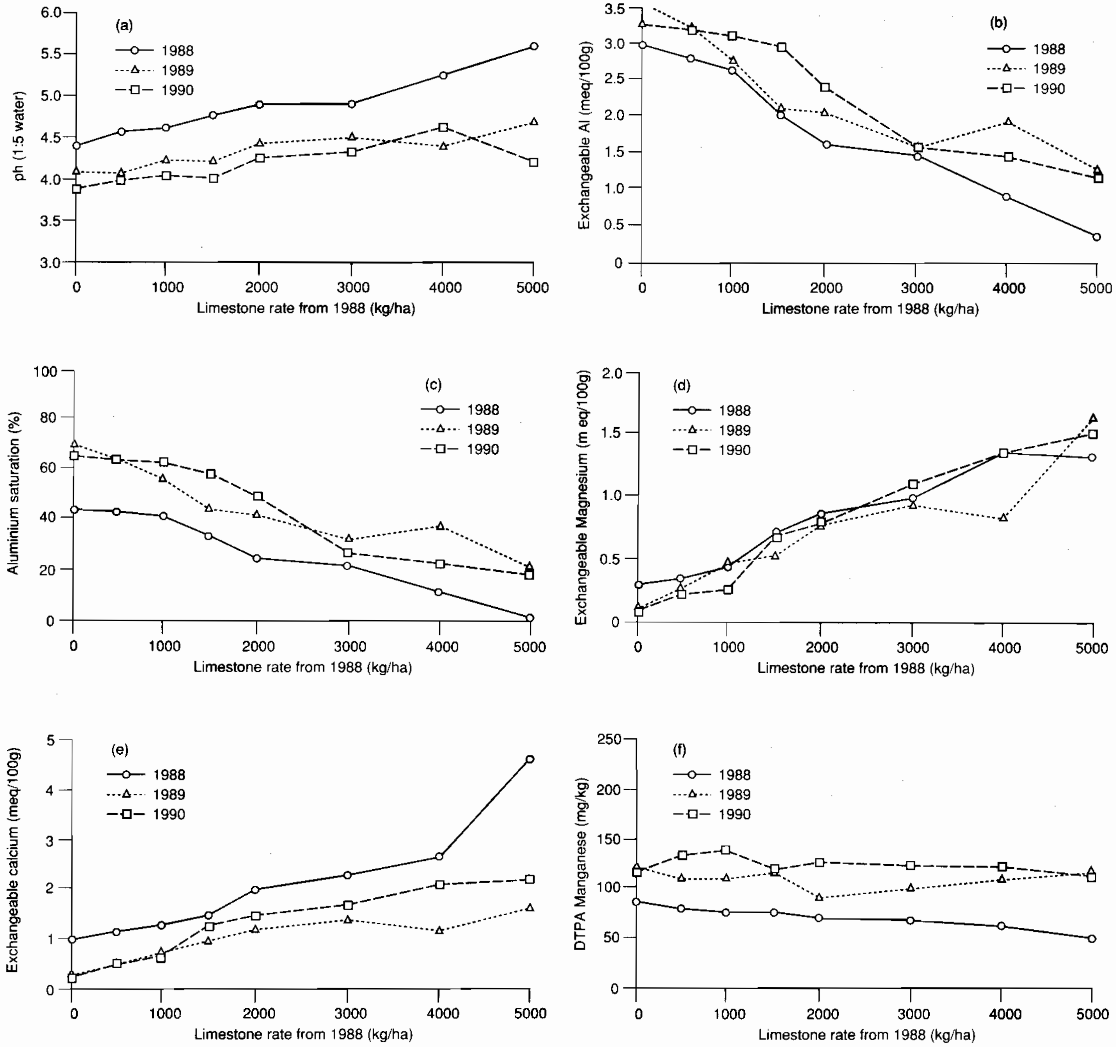

Figure 2. Effects of dolomite applied prior to 1988 on soil chemical properties in 1988, 1989, and 1990 growing seasons. Data are shown for (a) pH, (b) exchangeable Al, (c) Al saturation, (d) exchangeable Mg, (e) exchangeable Ca, (f) DTPA Mn.

Soil analyses at flowering in 1990 showed that returning residues from the preceding crops had little effect on soil chemical properties (data not shown). However, as the amounts returned were relatively low in the most severely acidic plots (i.e. 3-4 t/ha from the 1989 crop, versus 6-8 t/ha for the high lime plots), and this was the first year of the organic residue management, this was not surprising. Effects are expected to become more evident with time.

Despite the generally rapid (declining) changes in chemical fertility status over time, peanut yields were quite respectable in the high lime plots, and strong residual lime effects were evident (Fig. 3). Relative yields of top DM, pods and kernels in the 5 t/ha plots were approximately 400%, 550% and 2000% respectively of those in the unlimed plots. In addition, there was an interaction between cultivar and residual lime rate, with Gajah higher-yielding at lower residual lime rates for all yield parameters. This result was entirely consistent with results of the earlier initial cultivar screening (Fig. 1), and highlights the potential advantages of selection for performance on acid soils.

As noted earlier, by the 1990 season soil pH values had fallen to those of the original unlimed soil (or below) in all lime rates. Soil analyses showed a number of other chemical differences which may have been contributing to the residual effects measured in growth parameters shown in Figure 3. To provide some indications of the relative importance of these various lime-induced differences in soil chemistry, plant tissue samples (uppermost fully expanded leaf blades) were taken at flowering in 1990. Key results are shown graphically in Figure 4, and illustrate a number of effects, from residual lime rates and from organic residue management. Data suggest the most likely reasons for improved growth with liming (in addition to the alleviation of Al-toxicity effects on root growth and function) are:

- a reduction in the level of Mn toxicity with increased lime — although tissue concentrations are still very high at 5 t/ha (critical values reported for Mn toxicity in peanut in the literature are 600-800 ppm for the same plant part);
- possibly improved Ca and Mg status, especially at low lime rates. Some doubt exists as to the critical tissue concentrations for both elements in the literature, but Ca concentrations less than 1.25% are considered low, as are Mg concentrations less than 0.3%. The level of exchangeable Ca in the soil is likely to be more important than tissue Ca, however, to ensure good kernel development. Critical values are approximately 2.0 meq/100 g, so low soil Ca is likely to be a serious limit to seed yield. Selection for seed yield alone may be (indirectly) selecting more for efficiency of Ca uptake by pods than for tolerance to Al and Mn; and
- possibly the alleviation of toxic levels of Fe, especially in the plots without organic residues. Again, some doubt exists as to the critical levels of tissue Fe for toxicity to occur, but the normal range is 50-250 ppm, with values of more than 300 ppm considered high. There is, however, a possibility of surface contamination of leaf samples with Fe, so this result is not clear.

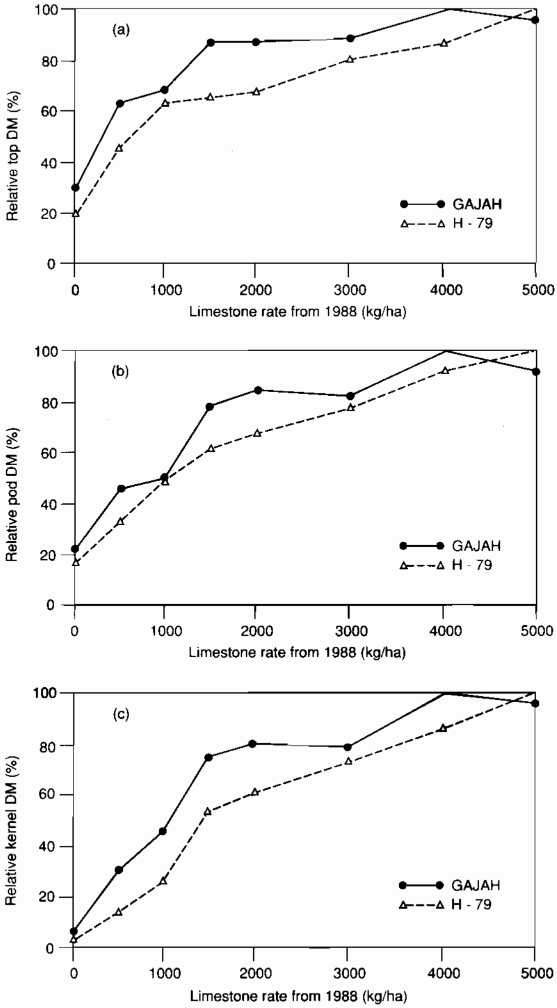

Figure 3. Relative yields (1990 dry season, Sitiung) of tops dry matter, pods and kernels for two peanut cultivars (Gajah and H-79-IIID-ST-3-2) grown on residual limestone treatments applied in 1988. (Values for each cultivar are means of two organic matter treatments, n = 8.)

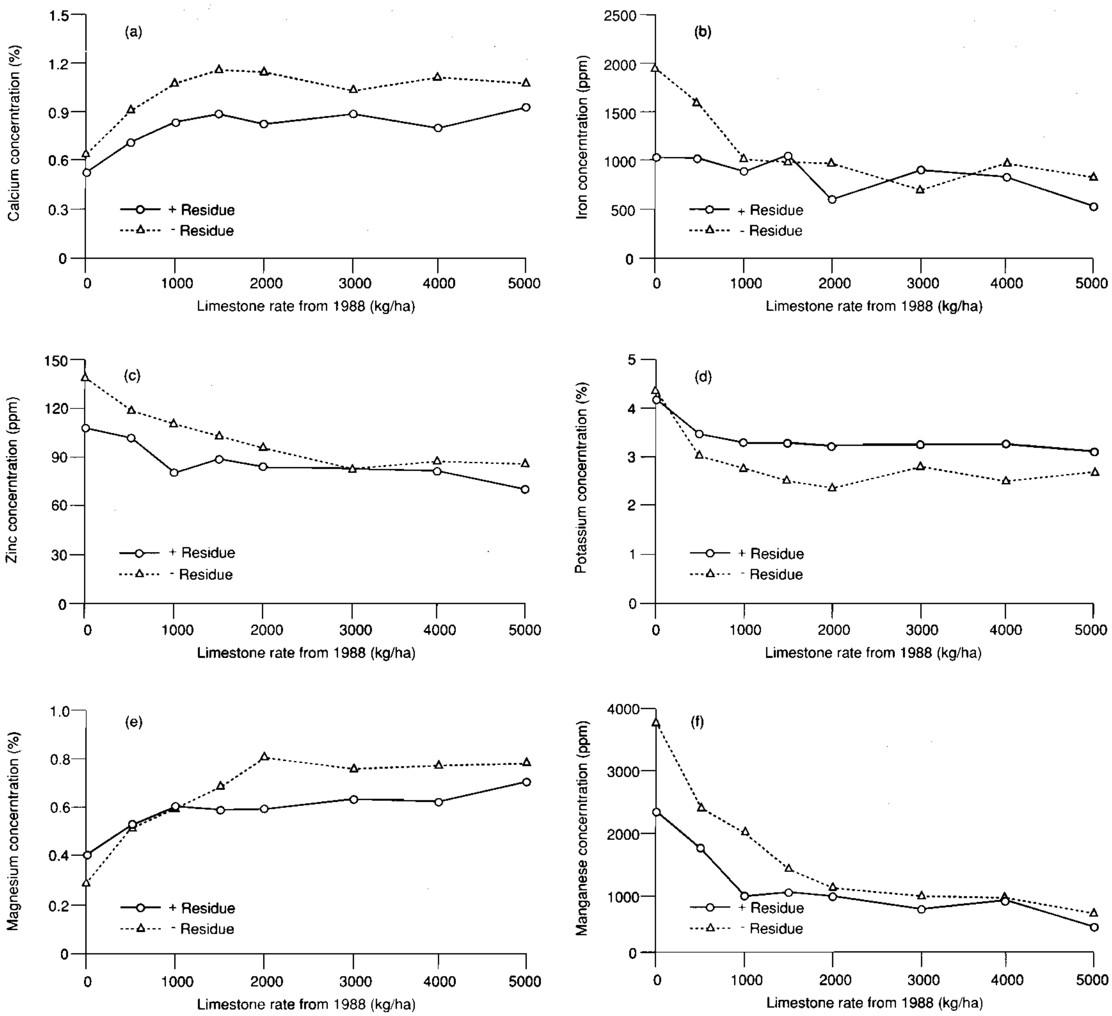

Figure 4. Tissue concentrations (uppermost fully expanded leaves) at flowering of (a) Ca, (b) Fe, (c) Zn, (d) K, (e) Mg, and (f) Mn from peanuts grown in residual dolomite study. There were no significant differences with O.M. treatments or cultivar so means are from n = 8 values.

Differences due to organic matter management, although not always significant at this early stage (i.e. first year of treatment imposition) were consistent. Tissue concentrations of all elements tended to be lower with organic matter retained, especially at low lime rates. This reflected the slight but not significant growth promotion with organic matter at 0 t/ha shown in top DM at maturity (Fig. 5a). (Although similar consistent advantages of organic matter retention were observed in pod and kernel yields in 0 lime lots, yields of both treatments were very low.) An apparent exception to this trend is tissue K concentration, which remained greater with organic matter retained for all lime rates. Further evidence of the effects of residue management is expected with increased study.

It is expected that this study will continue to provide useful information for peanut production on the very acidic soils at Sitiung, especially with respect to the residual effect of dolomitic limestone on soil chemical characteristics. The value of tissue analysis in determining the significant components of soil acidity for peanut production has been demonstrated, and highlights the deficiencies of some soil test results (e.g. DTPA-extractable Mn) for predicting nutritional problems.

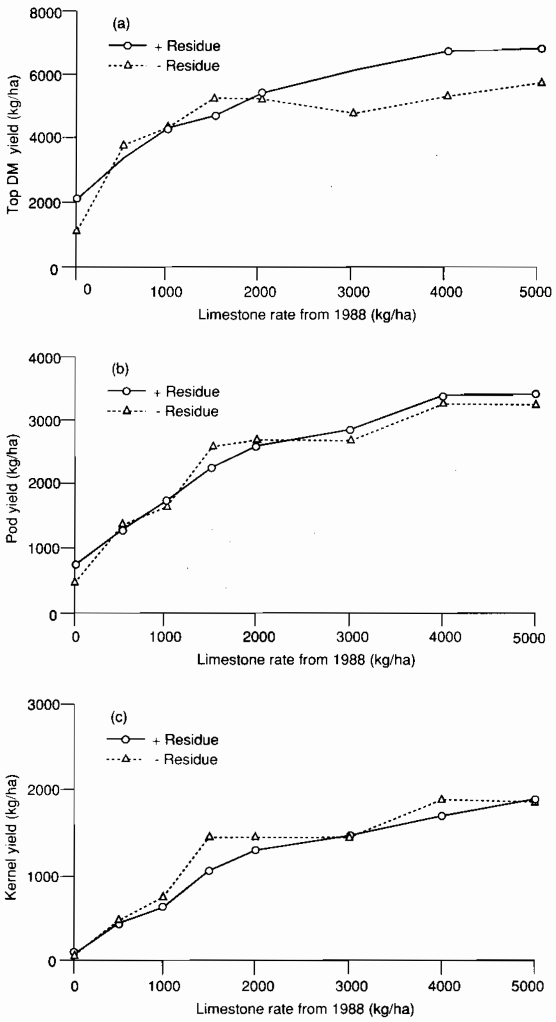

Figure 5. Yields of top DM, pod DM and kernel DM for peanuts in the residual dolomite study in 1990 (year 3) for each of two O.M. residue treatments. Values are means of two cultivars (n = 8).

Cultivar screening for acid soil tolerance

The nursery for screening germplasm for acid soil tolerance was established in 1989, following an analysis of the results of the effects of rates of dolomitic limestone on growth of the 33 peanut cultivars in 1988. A 1.2 ha block of homogenised soil with no history of liming was established at Sitiung in 1989, with the area split into five blocks. Differing lime rates (0, 500, 1000, 2000 and 3000 kg/ha of dolomitic limestone) were used to establish various levels of exchangeable acidity, available cations and micronutrients on each block. Soil analyses for each treatment prior to sowing in 1989 and 1990 are shown in Table 3.

Single-row plots of 68 local and introduced peanut cultivars were grown in 1989 and 230 cultivars in 1990. Cultivar performance was evaluated in terms of production of above-ground DM and pod and kernel yield, all assessed at maturity. Some problems were encountered in lime application and incorporation and plant establishment in the high lime plots (2 t and 3 t/ha) in 1989, so those data are somewhat incomplete.

As noted earlier, any variation in performance at different acidity levels is likely to be due to responses to levels of Al and Mn (total DM) in addition to levels of soil Ca (for kernel yields). This report concentrates primarily on kernel yield responses.

In both 1989 and 1990, yields were compared to the mean yield of the one or two check cultivars (Gajah and Kelinci) at each lime rate/level of soil acidity. There was very large variation in cultivar performance at the various levels of soil acidity each year, with material both markedly worse and considerably better than the mean check yield, both in terms of top growth (data not shown) and kernel yield (Table 4). Data are shown for the best performing cultivars, especially in the unlimed or low-lime plots, in each year. Unfortunately the full response for cultivars screened in 1989 could not be determined, for reasons described earlier. In addition, increased soil acidity in the unlimed plots (reflected in increased exchangeable Al and Al-saturation figures in Table 3) in 1990 meant that none of the 230 lines established satisfactorily and/or were able to produce DM. Future screening seasons need to ameliorate those 'unlimed' plots to somewhere near the original 60–65% Al-saturation to make them useful for varietal evaluation.

As in the residual limestone study, and indeed in the original screening experiment, top growth was generally less responsive to reduced soil acidity than pod and kernel yield. In fact, top DM was often maximised at 0 lime (1989) or 0.5 t/ha lime (1990), probably due to the fact that almost all DM was present as tops, with reproductive growth very limited in those treatments. Kernel DM generally responded much more strongly to reduced acidity, although considerable variation was evident. Typical kernel yield responses to levels of acidity are shown in Figure 6 (illustrating the various response types, relative to Gajah and/or Kelinci), while a more complete table showing relative performance at each lime rate of a number of promising cultivars is shown in Table 4. Data illustrate there is considerable potential for selecting germplasm with improved ability to yield under very acid conditions, both in terms of top DM and, more importantly, seed yield.

Table 3. Soil chemical characteristics induced by the limestone treatments in (a) 1989 and (b) 1990 (soil samples taken 40 days after sowing).

	Lime rate				
	0	0.5	1.0	2.0	3.0
(a) 1989					
0–20 cm					
pH	4.08	4.33	4.37	4.29	4.35
Exch. H^+ (meq/100 g)	0.0	0.14	0.0	0.96	0.96
Exch. Ca (meq/100 g)	1.25	1.45	2.55	1.75	1.40
Exch. Mg (meq/100 g)	0.11	0.22	0.16	0.15	0.10
Exch. Na (meq/100 g)	0.32	0.27	0.36	0.25	1.27
Exch. K (meq/100 g)	0.26	0.22	0.19	0.22	0.16
Exch. Al (meq/100 g)	3.27	2.87	2.14	2.75	2.72
Effective CEC	5.21	5.17	5.39	6.07	5.60
Al saturation (%)	62.9	56.6	41.2	45.2	48.7
DTPA Cu (mg/kg)	3.75	3.85	5.55	3.20	3.15
DTPA Zn (mg/kg)	4.60	6.50	6.60	6.65	6.50
DTPA Mn (mg/kg)	113	138	142	128	123
DTPA Fe (mg/kg)	n.d.	n.d.	n.d.	n.d.	n.d.
CEC (meq/100 g)	n.d.	n.d.	n.d.	n.d.	n.d.
20–40 cm					
pH	3.84	4.25	4.40	4.17	4.27
Exch. H^+ (meq/100 g)	0.89	0.21	0.85	0.64	0.68
Exch. Ca (meq/100 g)	0.55	0.95	2.25	1.45	3.05
Exch. Mg (meq/100 g)	0.12	0.16	0.19	0.13	0.12
Exch. Na (meq/100 g)	0.27	0.29	0.28	0.29	0.30
Exch. K (meq/100 g)	0.12	0.17	0.12	0.14	0.14
Exch. Al (meq/100 g)	3.34	3.17	2.38	2.54	1.61
Effective CEC	5.29	4.93	6.05	5.18	6.03
Al saturation (%)	63.1	64.2	39.3	49.1	26.8
DTPA Cu (mg/kg)	3.65	4.00	6.20	3.70	3.40
DTPA Zn (mg/kg)	4.70	7.30	7.60	8.25	6.90
DTPA Mn (mg/kg)	117	127	144	109	110
DTPA Fe (mg/kg)	n.d.	n.d.	n.d.	n.d.	n.d.
CEC (meq/100 g)	n.d.	n.d.	n.d.	n.d.	n.d.
(b) 1990					
0–20 cm					
pH (1:5, water)	3.96	3.94	4.01	4.42	4.34
Exch. H^+ (meq/100 g)	0.38	0.31	0.28	0.17	0.15
Exch. Ca (meq/100 g)	0.18	1.40	2.60	4.45	4.40
Exch. Mg (meq/100 g)	0.12	0.31	0.78	1.36	1.21
Exch. Na (meq/100 g)	0.44	0.52	0.44	0.44	0.44
Exch. K (meq/100 g)	0.20	0.26	0.42	0.28	0.29
Exch. Al (meq/100 g)	4.30	3.45	3.00	0.8	0.55
Effective CEC	5.62	6.25	7.52	7.50	7.04
Al saturation (%)	76.5	55.2	39.9	10.7	7.8
DTPA Cu (mg/kg)	3.40	3.30	3.80	4.30	4.50
DTPA Zn (mg/kg)	5.0	4.3	4.4	4.7	4.5
DTPA Mn (mg/kg)	108.6	146.2	164.0	129.0	120.9
DTPA Fe (mg/kg)	52.8	43.6	40.4	30.3	29.4
CEC (meq/100 g)	27.0	26.1	26.9	22.7	26.1
20–40 cm					
pH	3.94	3.98	4.03	4.15	4.22
Exch. H^+ (meq/100 g)	0.32	0.39	0.40	0.25	0.27
Exch. Ca (meq/100 g)	0.75	0.95	1.65	1.75	3.20
Exch. Mg (meq/100 g)	0.20	0.16	0.25	0.26	0.41
Exch. Na (meq/100 g)	0.40	0.38	0.39	0.42	0.44

Table 3. Soil chemical characteristics induced by the limestone treatments in (a) 1989 and (b) 1990 (soil samples taken 40 days after sowing). — *continued*

	Lime rate				
	0	0.5	1.0	2.0	3.0
(b) 1990 — *continued*					
Exch. K (meq/100 g)	0.16	0.12	0.16	0.14	0.17
Exch. Al (meq/100 g)	4.20	3.70	3.20	2.60	2.10
Effective CEC	6.03	5.70	6.05	5.42	6.59
Al saturation (%)	96.7	64.9	52.9	48.0	31.9
DTPA Cu (mg/kg)	4.00	3.90	3.90	3.80	7.30
DTPA Zn (mg/kg)	6.0	5.5	6.1	6.1	7.3
DTPA Mn (mg/kg)	104.8	107.4	146.7	155.5	122.2
DTPA Fe (mg/kg)	38.1	38.5	38.8	34.7	36.5
CEC (meq/100 g)	23.6	28.8	21.1	22.7	19.4

However, the rapid decline in soil chemical characteristics with continued cropping (see soil analyses, Table 3 and Figure 2) shows that continued inputs of some kind (lime, or perhaps organic matter) are required with even the most acid-tolerant lines for yield to be maintained. Failure to do so will result in complete crop failure, as shown in the unlimed acid screen areas in 1990. There seems to be for peanut growth a definite limit which lies somewhere between the unlimed soil conditions of 1989 and 1990. This limit is probably associated with toxic levels of Al (Al-saturation ranged from 63% to 77%), although results from the tissue analyses suggest Mn toxicity is also likely to be important.

It is interesting to note that cultivars selected in the PCAARD/PCRSP program at Los Baños generally have not yielded well under Sitiung acid soil conditions, although top growth at low lime was quite respectable in 1989 (data not shown). This highlights the need for detailed site characterisations if germplasm produced from such screening efforts are to be distributed for use in other regions.

Implications for Peanut Production and Future Research in Indonesia

This research highlights a number of significant factors for both acid soil management and peanut germplasm selection. These include the following points.

- Manganese toxicity and Ca-deficiency, in addition to Al-toxicity, are important yield-limiting factors in peanut production on the red-yellow podzolic soils of Sitiung.

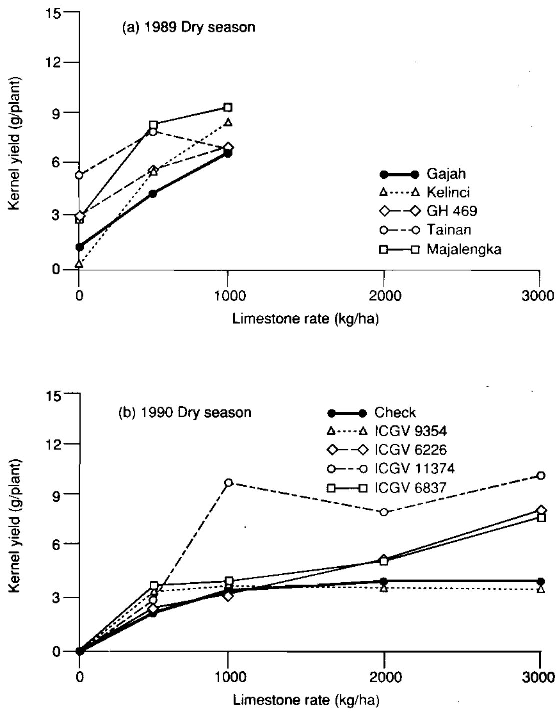

Figure 6. Kernel yields of selected peanut cultivars from (a) 1989 and (b) 1990 germplasm screening studies. Lime rates produced soil chemical characteristics as shown in Table 3 for each season. The 1990 'check' is the mean of Gajah and Kelinci.

Table 4. Relative kernel yields of selected peanut cultivars grown at a range of lime-altered soil acidities in (a) 1989 and (b) 1990 growing seasons at Sitiung. Yields are expressed in relation to mean yields of the local check cultivar (Gajah) at each lime rate, derived from single row 'hill' plots. Yields were calculated as g/plant.

	Lime rate				
Cultivar	0	0.5	1.0	2.0	3.0
(a) 1989					
Check (Gajah)	100	100	100	n.d.	n.d.
ICGV 3704	369	151	49	n.d.	n.d.
ICGV 86644	345	96	M*	n.d.	n.d.
ICGV 86708	55	160	131	n.d.	n.d.
H 726/875-B-2-2	218	133	82	n.d.	n.d.
H 80-121c-St-4-1	99	189	96	n.d.	n.d.
GH 469	263	130	105	n.d.	n.d.
IPB Pn-48-90	100	178	124	n.d.	n.d.
Lokal Majalengka-1	256	193	139	n.d.	n.d.
Tainan	488	182	102	n.d.	n.d.
SHM-1509-Si	196	108	102	n.d.	n.d.
Lokal Natal Common	280	100	M*	n.d.	n.d.
Kelinci	19	131	126	n.d.	n.d.
TMV2	139	191	143	n.d.	n.d.
(b) 1990					
Check (Gajah + Kelinci)	0*	100	100	100	100
ICGV 6165	0	110	144	173	134
ICGV 6837	0	161	121	129	185
ICGV 4999	0	132	147	191	102
ICGV 9354	0	147	113	91	88
ICGV 6226	0	106	92	133	196
ICGV 7271	0	135	177	128	171
ICGV 5103	0	108	192	116	116
ICGV 11390	0	131	152	93	96
ICGV 11374	0	121	290	197	244
ICGV 7361	0	115	125	74	184
ICGV 6832	0	119	223	153	84
ICGV 3293	0	115	285	164	105
ICGV 86021	0	189	195	103	222
ICGV 10443	0	150	277	66	83
ICGV 9805	0	155	290	121	148
ICGV 11290	0	128	233	121	76
SHM-1509-Si	0	162	120	87	102
472/920-26-1	0	104	152	132	178
L. Holan St. Ramon	0	106	270	257	187
L. Genteng	0	136	284	111	71
L. Check-1	0	191	194	143	108
NC AC 2190/NCAC	0	157	228	232	105
17090-4-36-4	0	162	114	133	95
IPB Pn-2-25	0	97	79	69	116

M* Denotes missing data due to insufficient plant establishent. *All cultivars did not produce kernels in the unlimed plots.

- Applications of dolomitic limestone are successful in overcoming soil acidity problems, and allow quite high yields to be achieved. However, some effects are relatively short-lived (e.g. pH of 5 t/ha limestone plots had fallen to near-original levels in two years), and unless combined with other management practices (e.g. organic matter inputs), regular lime applications are needed. The latter represents an unacceptable cost burden to poorer farmers, so the results of organic matter management treatments such as those continuing in the residual dolomite study are of considerable importance. This work should be continued and expanded.
- Reliance on soil tests to provide evidence of certain nutrient imbalances (e.g. Mn toxicity) seems inappropriate. Development of an expanded tissue-testing service may prove beneficial in diagnosing specific yield limitations.
- Considerable scope appears for selecting peanut germplasm with improved tolerance to Sitiung acid soil conditions. The value of such data selection will be improved considerably if future work accurately diagnoses specific limits to productivity — both in terms of DM production as such, and specifically for the production of kernel yield. This will allow the potential use of such selections in other situations (e.g. other areas of Indonesia or in the Philippines) to be assessed, and will make a significant contribution to the world peanut database.
- For future germplasm screening to be effective, attention must be paid to quality of seed of cultivars being screened. Information on relative performances of lines is often confounded with germination problems (particularly of seeds from local programs in Indonesia, and those flowing from the PStV screening activities). This is a factor that must be addressed if germplasm screening is to continue.
- Finally, both the residual dolomite and acid-screening studies show that, while peanuts may be relatively tolerant of soil acidity, that tolerance is not unlimited. Tolerant cultivars are capable of producing good yields only when soil is maintained above a certain critical level of acidity. Factors important in determining this critical soil condition (e.g. Al, Mn) and ways of maintaining it should be future research priorities. Future peanut production in such areas requires a carefully integrated package of agronomic and genotypic inputs to be successful.

Drought Tolerance Traits Conferring Adaptation to Drought Stress in Peanut

G.C. Wright*, T. Adisarwanto,† A. Rahmianna† and D. Syarifuddin‡

PEANUTS are grown under a variety of cropping systems throughout Indonesia and Australia where both protracted and/or intermittent drought stress limit growth and pod yield. The detrimental effects of drought can be modified to some extent through such management options as supplementary irrigation, manipulations in either maturity type or planting date, and intercropping differing maturity cultivars. Increases in pod yield under water-limited conditions are possible also through the identification and selection of cultivars better able to resist and/or adapt to such drought effects. Unfortunately, selection for drought resistance/tolerance has proved difficult in breeding programs because of the need to test large numbers of genotypes in multiple seasons and locations. Large costs in space, time and resources mean that selection for characters other than pod yield at maturity is not feasible. More detailed understanding of the developmental and physiological adaptations enabling superior performance of genotypes under drought stress is therefore needed to identify reliable indices of drought resistance/tolerance. Selection for these traits should complement conventional breeding programs and lead to more efficient use of time and resources.

In this project, pod yield performance was analysed in terms of a simple framework, where pod yield in water-limited environments is considered as the product of three components: the amount of water transpired (T), the efficiency of the use of transpired water in the production of biomass (TE), and harvest index (HI), the proportion of total biomass harvested as pods. Considerable cultivar variation for each of these attributes has been shown, including the following points.

- Significant variation in ability to extract soil water from deep in the profile, indicating that cultivar differences in root activity and extent exist.
- Cultivar differences in TE exist in peanuts grown as spaced plants under glasshouse conditions (variations from 1.3 to 2.0 g/kg were shown). This finding dispels current beliefs that intraspecies variation in TE does not exist and is therefore not worthy of selection in breeding programs.
- TE was shown to be negatively correlated with the ratio of 13C/12C (Δ) in the glasshouse studies, in accordance with the theory proposed by Professor Farquhar, Australian National University (ANU), Canberra. This finding suggests Δ can provide an extremely efficient selection procedure for TE. Since Δ may be measured on an individual leaf basis, every plant in a breeding nursery potentially can be screened non-destructively for high TE.
- Large differences in HI were demonstrated, with a range of 0.3–0.55 occurring in response to differing drought regimes applied in glasshouse and field studies.
- TE and HI were shown to be negatively associated, cultivars with high TE having poor partitioning characteristics, and vice versa.

The broad aims of the drought physiology component of the project were therefore to:

(i) further identify peanut genotype variation for ability to adapt to water deficits, through studies of T, TE and HI;
(ii) begin to utilise such variation by developing suitable traits for selection of cultivars with improved adaptative and yield performances;
(iii) further collaborate with Professor Farquhar at ANU to assess the applicability of the Δ technique for selection of TE in peanuts; and
(iv) further investigate the negative correlation between the potentially useful TE and HI traits. The hypothesis that this correlation was due to either a genetic linkage phenomenon or a direct physiological effect needs to be addressed.

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This paper reports a number of studies conducted in both Australia and Indonesia to address these objectives.

Research Highlights

Amount of water transpired (T)

Cultivar variation

Under water-limited conditions, plants are forced to rely on soil water reserves to meet evaporative demand. In terminal drought situations, such as occur when peanut is grown after rice during the dry season, the ability of a cultivar to access and exploit soil water reserves deep in the soil profile can increase T and potentially improve pod yield. Significant variation in ability to extract deeply held soil water was demonstrated in phase I, with the cultivar VB extracting about 40 mm more soil water than three other cultivars during a terminal drought (Wright et al. 1991).

Another experiment during 1989 further investigated genetic variation in ability to extract deeply held soil water. A more diverse range of cultivars (VB, Q18803, RMP-91, Rangkasbitung, EC-271, Q22289) was used, including two lines from Indonesia (Rangkasbitung and Q22289) which were found previously to differ in their yield response to drought stress. Rainout shelters were used to exclude rainfall, with increasing water deficits being experienced from the beginning of pod fill (72 days after planting (DAP)) until maturity during a terminal drought stress. Soil water measurements to a depth of 1.8 m were taken throughout the drying cycle. There were considerable genetic differences in water extraction measured between 72 and 120 DAP. Figure 1 shows the cultivar extremes. VB extracted more soil water than Rangkasbitung at most depths throughout the profile, with the accumulated difference being about 30 mm of soil water.

Soil water profiles for the other four cultivars were intermediate between VB and Rangkasbitung (data not shown). The total amount of soil water extracted during the drying cycle was 82, 70, 69, 52, 75 and 60 mm for VB, Q18803, RMP-91, Rangkasbitung, Q22289 and EC-271, respectively. Interestingly, VB was also the deepest-extracting cultivar identified in studies in phase I.

Selection criteria

To screen large numbers of lines for depth and extent of water extraction in the field is extremely difficult and expensive. Ideally a simple, inexpensive technique to assess root water uptake capacity in the laboratory or glasshouse, and which correlates well with field performance, is desirable. Unfortunately, little research has been conducted in this area in peanut or any other species. Indeed, the demonstration that differences exist among peanut in the ability to extract deeply held soil water is a new and significant finding.

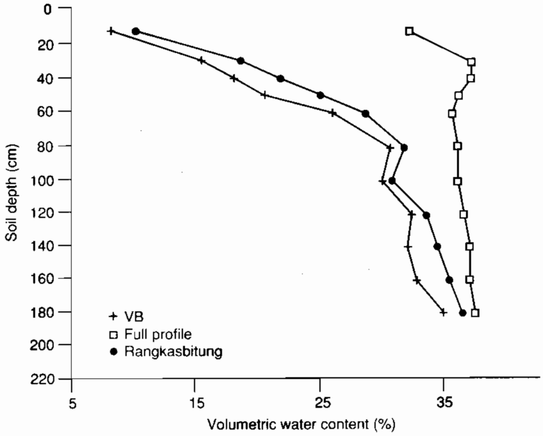

Figure 1. The change in volumetric water content with depth at maturity for cultivars Virginia Bunch and Rangkasbitung in response to an end-of-season drought regime.

A preliminary attempt was made to identify a simple water-extraction capacity technique by measuring a number of rooting traits among a subset of contrasting cultivars in small pots in the glasshouse. The approach adopted was to determine whether any root characteristic measured in 6″ pots correlated with water-extraction capacity observed in the field. Thus the six cultivars studied in the field experiment were assessed by droughting plants until death occurred. Root parameters such as root mass, root length, root to shoot ratio and specific root length (cm/g DM) were then measured after 50 DAP. Table 1 shows how the root parameters varied among cultivars.

Table 1. Root parameters measured in 6" pots for six cultivars, after plants had extracted all available water and were permanently wilted (50 days after planting).

	Root mass (g)	Root length (cm)	Root to shoot ratio	Specific root length (metres/g)
VB	0.62	2213	0.50	4.95
Q18803	0.67	2065	0.65	4.27
RMP-91	0.42	2179	0.55	6.52
Rangkasbitung	0.49	2673	0.69	7.93
Q22289	0.48	3079	0.81	8.62
EC-271	0.49	2254	0.73	6.87
l.s.d. (P = 0.05)	0.13	585	0.18	2.11

There was significant variation among cultivars in each of the root parameters. There was a suggestion that VB generally had more root mass, lower root to shoot ratios and lower specific root length (or 'thicker' roots), compared to the other cultivars tested. The data presented are preliminary, and further discussion about possible mechanisms and correlations with field performance would be speculative. The important point, however, is that significant cultivar variation in a number of root parameters has been shown. More intensive research is required to determine if a root trait measurable in pots is correlated with field water-extraction capability.

Transpiration Efficiency (TE)

Cultivar variation

Significant variation in TE among peanut cultivars has been demonstrated in spaced plants in the glasshouse (Hubick et al. 1986), which suggests this trait could be selected for to improve dry matter production per unit of water transpired.

Further experimentation was conducted in this project to determine whether cultivar differences in TE observed in the glasshouse were, in fact, occurring in plants grown in canopies in the field, under both well-watered and water-limited conditions. The hypothesis that cultivar differences in TE under glasshouse conditions were an artefact of 'controlled' conditions needed to be disproved before this trait could be proposed as a selection criterion in breeding programs.

Two large field experiments using minilysimeters were conducted to determine whether cultivar differences in TE were occurring in small canopies. One experiment was conducted under full irrigation, while the other imposed two levels of soil water deficits, both during a 50-day treatment period following flowering. The minilysimeter facility, in combination with portable rainout shelters (developed during phase I) enabled accurate measurements of water use and total (including root) biomass, which are essential in TE determinations under field conditions. Table 2 shows results from these experiments, which clearly indicate that significant differences in TE exist among peanut cultivars in the field, under both water non-limiting and limiting conditions.

In general, variation in TE among peanut cultivars occurred due to differences in biomass rather than to differences in water use. The result indicates that photosynthetic capacity, rather than leaf/canopy stomatal conductance, is dominating the TE response. Evidence for this hypothesis is provided by the highly significant positive correlation between TE and radiation use efficiency (RUE, the efficiency of conversion of solar radiation into dry matter) shown in Figure 2. These data clearly demonstrate

Table 2. Biomass (including roots), water use, TE and specific leaf area in peanut cultivars under well-watered conditions (1988 study) and two levels of water-limited conditions (1991 study). The treatment period was from about 40 to 90 days after planting.

Study	Cultivar	Biomass (g)	Water use (kg)	TE (g/kg)	SLA (cm^2/g)
Well-watered	Tifton-8	63.1	17.0	3.71	167
	VB-81	46.9	16.2	2.90	175
	Robut 33-1	55.3	19.0	2.91	213
	Shulamit	51.6	16.8	3.07	182
	McCubbin	48.6	16.9	2.88	211
	Cianjur	43.4	16.3	2.66	185
	Rangkasbitung	41.6	16.9	2.46	182
	Pidie	47.3	16.6	2.85	189
l.s.d. (P = 0.05)		7.0	1.5	0.3	12.9
Water-limited (intermittent stress)	Tifton-8	37.5	12.2	3.07	145
	Shulamit	35.7	12.8	2.79	136
	McCubbin	36.3	13.4	2.71	181
	Chico	20.5	11.4	1.80	192
(terminal stress)	Tifton-8	31.3	10.0	3.13	111
	Shulamit	29.0	9.9	2.93	123
	McCubbin	26.8	10.0	2.68	142
	Chico	17.8	8.8	2.02	160
l.s.d. (P = 0.05)		5.61	1.90	0.38	12.8

that differences in photosynthetic capacity were dominating TE response among cultivars. This finding also suggests that selection for high TE (via Δ, discussed earlier) would also lead to peanut cultivars possessing high RUE, which is an important trait for high biomass production under water non-limiting conditions. Even more evidence for this hypothesis comes from specific leaf area (SLA, or leaf thickness) data (Table 2), which indicates high TE cultivars have lower SLA (or 'thicker leaves'). Thicker leaves suggest the plant has more photosynthetic machinery per unit leaf area, and hence higher capacity. Interestingly, the ranking of TE appears to be maintained across the water stress environments, indicating that there is little genotype × environment interaction for this trait.

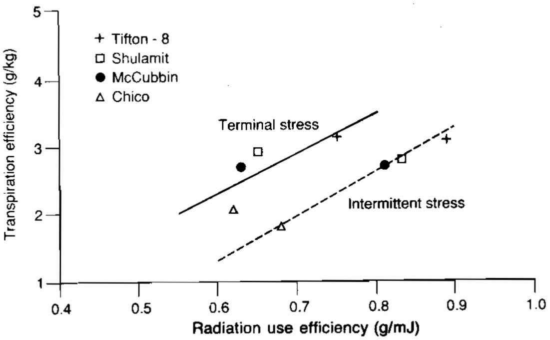

Figure 2. Relationship between radiation-use efficiency and transpiration efficiency for four cultivars, under terminal and intermittent drought regimes.

Selection criteria

To screen large numbers of lines for TE is extremely difficult, if not impossible, because of the need to measure accurately both transpiration (i.e. accounting for soil evaporation) and total biomass (including roots). Indeed, the difficulty in measuring accurately T and biomass under field conditions is the major reason why cultivar variation in TE in a range of species has not been demonstrated or perused as a selection trait in breeding programs.

Current research in this project clearly demonstrates that considerable variation in TE exists in peanut, a factor which must have enormous potential for improving growth and yield per unit of water used.

Fortunately, earlier work in the project, in collaboration with the ANU/ACIAR Water Use Efficiency project, showed that the ratio of 13C/12C (Δ) was very well correlated with TE in peanut cultivars grown in the glasshouse, in accordance with the theory of Professor Farquhar. This technique, being non-destructive and easily measured, offers considerable promise as a selection criterion to screen for high TE.

The important questions to be answered before breeders can safely use this technique as a screen for TE are therefore:

i) does Δ correlate with TE for peanut cultivars grown in canopies in the field (as opposed to the glasshouse) under both well-watered and water-limited conditions? and

ii) how early in a plant's life cycle can Δ be selected for, and still represent its TE characteristics?

(i) Δ analyses were performed on leaves from the two field experiments described above, and the relationships between Δ and TE are shown in Figures 3a,b. Under both watering regimes, highly significant correlations were observed between Δ and TE (r^2 = 0.68 and 0.93 for well-watered and water-stressed, respectively). These data provide unequivocal evidence for the existence of an association between TE and Δ for field-grown peanuts, and for the suitability of this technique as a selection criterior for the screening of high TE.

(ii) An experiment investigating how Δ changed with crop ontogeny was performed by growing three cultivars contrasting in TE and Δ characteristics in small pots in the glasshouse. Harvests were made every three to four days until day 54 (and also at maturity), and Δ on leaf material measured. Figure 4 shows the temporal change in Δ, and clearly indicates that after about 15 DAE, Δ remains constant until maturity.

A similar procedure was carried out in a field experiment at Kingaroy, where leaves were sampled for Δ in four cultivars at two-weekly intervals from 89 to 131 DAE. It was shown there was no significant interaction between irrigation treatment and time of sampling for the four cultivars (Wright et al. 1991). A number of other data sets collected in the field also indicated a similar response.

The stability of Δ throughout crop ontogeny clearly indicates that selection could take place very early during crop development. The ability to screen early in the life cycle of the plant should facilitate rapid generation time and maximise the potential for genetic gain.

During the numerous experiments conducted on TE and Δ under both glasshouse and field conditions during the project, it was observed that specific leaf area (SLA, or leaf thickness) was extremely well correlated with both TE and Δ. As discussed earlier, this response is believed to be a function of leaf photosynthetic capacity. Figure 5 shows examples of the strong relationship observed between Δ and SLA under glasshouse (Fig. 5a) and field conditions from studies at Kingaroy and Bundaberg (Fig. 5b). A significant relationship between Δ and SLA was also

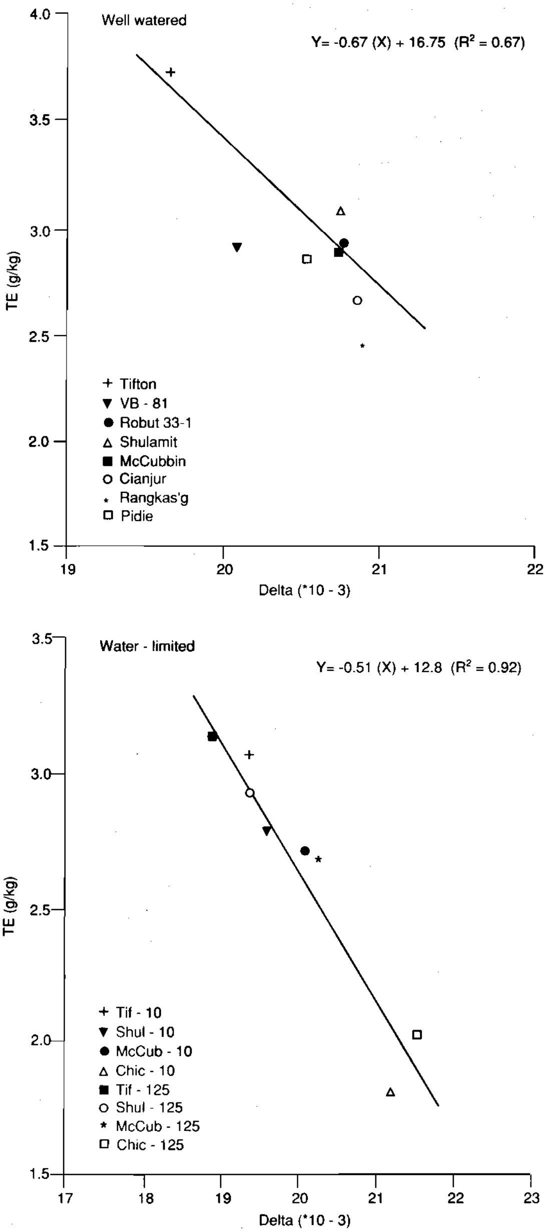

Figure 3. Relationship between transpiration efficiency and delta for a range of cultivars grown in the field under well-watered and water-limited conditions.

observed for some 300 F_3 plants derived from a single cross of a high and low Δ Indonesian cultivar grown in the field (Fig. 5c, details, see later). Clearly there is overwhelming evidence to support the hypothesis that a very strong association exists between Δ and SLA. The significant implication is that breeders could use the inexpensively measured SLA, rather than the more expensive Δ ($30 per sample), to screen for high TE. Our research in fact has shown that Δ and SLA are strongly correlated to form a universal relationship over a range of environments (temperature, humidity, and water stress) (Fig. 5b). The exact physiological mechanism involved here is unknown, but is currently under investigation by ANU researchers. More research is required further to understand this relationship and to derive suitable sampling procedures. SLA is easily measured by planimeter or image analysis, and should be suitable for large-scale screening, particularly in the Indonesian breeding program.

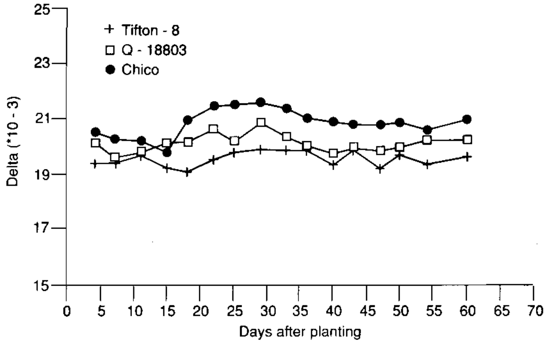

Figure 4. Changes in leaf delta with time for cultivars Tifton-8, Q18803 and Chico for plants grown in the glasshouse.

Harvest Index (HI)

Cultivar variation

Significant variation in HI among peanut cultivars was demonstrated in phase I. Further experimentation was conducted in this project to determine the extent of variation among diverse peanut cultivars, particularly under severe water-limited conditions. In addition, research into possible mechanisms involved in causing HI differences was conducted.

Table 3 shows biomass, pod yield and harvest index at maturity measured for six contrasting cultivars (from a field experiment described earlier) where increasing water deficits were imposed from early pod set to maturity. Pod yields ranged from 750 to 1820 kg/ha, with these differences associated with significant variation in harvest index (e.g. 12.9 cf. 40.5). Interestingly, HI in the Indonesian cultivars Rangkasbitung and Q22289 differed significantly, indicating the potential importance of this trait in influencing pod yield performance under water-limited conditions in Indonesia.

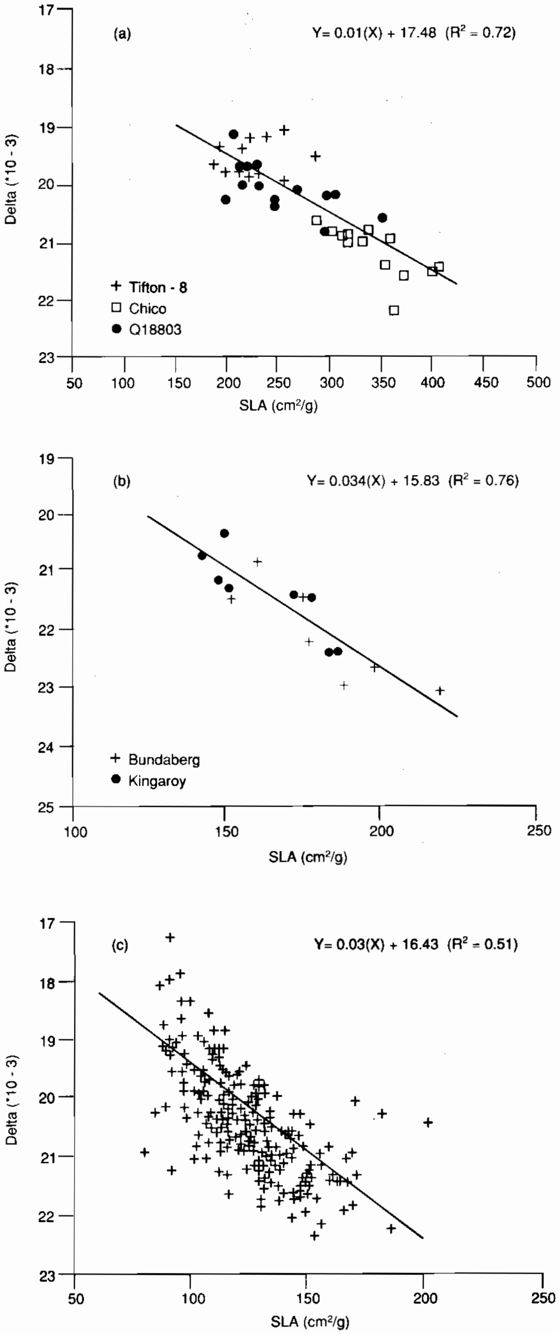

Figure 5. Relationship between delta and specific leaf area for (a) glasshouse plants for cultivars Tifton-8, Q18803 and Chico, (b) cultivars Chico, McCubbin, Tifton-8 and Shulamit grown in the field at Kingaroy and Bundaberg, and (c) field-grown F_3 plants derived from a cross between Tapir and Rangkasbitung.

A glasshouse experiment in large pots investigated cultivar variation in HI, and how HI response differed under well-watered compared to droughted (intermittent) conditions. Table 4 shows significant variation in HI among a subset of cultivars, ranging 26-52% under well-watered, and 39-60% under droughted conditions. Interestingly, water deficit generally improved HI; however, the ranking of cultivars appeared to be maintained, indicating genotype × environment interaction for this trait may be small.

The partitioning ratio (PR), defined as the proportion of post-flowering (early pod set) biomass partitioned into pods, allows a simple analysis of the degree of remobilised assimilate to be made. The PR was calculated for both experiments reported here (Tables 3 and 4) and indicates that under water-limited conditions, some cultivars with high HI have PRs in excess of 100%. This result suggests that assimilate from storage elsewhere in the plant prior to pod filling may have been translocated, and thereby improved HI and pod yield. It appears cultivar variation in this response is significant, and further research into its role in improving HI and pod yield under drought conditions seems warranted.

An experiment was also conducted at Muneng in East Java to determine the physiological factors responsible for peanut cultivar pod yield variation. In a collaborative experiment between the ACIAR peanut project and ICRISAT peanut drought physiology program, some 20 cultivars (including 15 lines from ICRISAT which have been identified as drought-tolerant) were grown during the dry season and exposed to a severe end-of-season drought pattern typical of post-rice peanut production throughout Indonesia. Table 5 presents total biomass, pod yield and harvest index data for these cultivars.

Results from this study indicate:

- there were significant differences among cultivars in total biomass production (3.1–4.9 t/ha) indicating that either deep water-extraction capacity and/or transpiration efficiency differences exist among cultivars in response to this severe drought regime;
- there were significant differences in pod yield arising from differing partitioning characteristics (or HI) among cultivars (6.2 cf. 17.8%); and
- harvest indices, in general, were extremely low, suggesting some factor is limiting partitioning of dry matter in this environment or stress regime. For instance, if HI could be improved to around 40%, pod yields of up to 2 t/ha are achievable under this drought pattern.

Poor partitioning in peanut in response to severe drought can occur due to low pod numbers and hence sink limitation. Observations of peanut crops

Table 3. Total biomass, pod yield, harvest index and partitioning ratio for six cultivars grown under terminal drought stress in the field at Kingaroy, Queensland during 1987–88.

Cultivar	Total biomass (kg/ha)	Pod yield (kg/ha)	Harvest index (%)	Partitioning ratio (%)
VB	6220	1110	17.9	29.2
Q18803	6445	1780	27.6	67.3
RMP-91	5850	750	12.9	31.1
Rangkasbitung	4500	1820	40.5	124.6
EC-271	4440	1720	38.8	141.2
Q22289	4520	1260	27.9	62.0

Table 4. Harvest index and partitioning ratios for six cultivars grown in 1-metre pots under well-watered and water-stressed (intermittent drought) conditions in the glasshouse during 1987–88.

	Harvest index (%)		Partitioning ratio (%)	
	Wet	Dry	Wet	Dry
McCubbin	45.3	47.7	65.0	100.1
Gajah	34.2	45.5	36.1	79.2
Tapir	25.8	39.1	28.4	64.3
Rangkasbitung	46.9	56.6	55.2	110.1
Q18803	47.1	44.3	84.1	143.2
Robut 33-1	51.7	59.7	64.5	116.2

Table 5. Total biomass, pod yield and harvest index for 20 cultivars at Muneng, East Java during 1990 dry season.

Lines/cultivars	Total biomass (kg/ha)	Pod yield (kg/ha)	Harvest index (%)
ICG 1697	4360	580	13.3
ICG 2738	3510	590	16.8
ICG 3400	3980	480	12.1
ICG 3704	3830	360	9.4
ICG 4790	3690	230	6.2
ICG 5305	3460	560	16.2
ICG 7331	4470	340	7.6
ICG 8084	3670	460	12.5
ICGV 86635	4750	540	11.4
ICGV 86644	4880	500	10.2
ICGV 86707	3830	270	7.0
ICGV 86742	4650	380	8.2
ICGV 86754	3480	620	17.8
ICGV 87354	3710	540	14.6
ICGV 87358	4020	560	13.9
Tapir	3350	400	11.9
Kelinci	3150	350	11.1
Gajah	3950	360	9.1
Macan	3888	410	10.5
Pelanduk	3810	510	13.4
l.s.d. (P = 0.05)	1170	140	3.6

in Indonesia, particularly in post-rice dry season production systems, indicated that dry and hard surface soil was limiting peg entrance and subsequent development into fertile pods. There is very little information in the literature on effects of pod zone environment on reproductive development in peanut. Some experiments were therefore conducted to investigate its importance in influencing partitioning of dry matter and hence pod yield, and to determine whether cultivar variation existed.

Two experiments were conducted in pots where the root zone and podding zone were separated, and soil water status or soil strength in the podding zone independently varied. In the first experiment, three cultivars were grown in pots where the root zone was well watered, and the podding zone was kept either 'wet' or 'air dry'. This experimental system typified the post-rice production system where the soil profile is fully charged; however, lack of rainfall results in a very dry surface podding zone. Table 6 shows the effect of this system on yield and components. Results from the study indicate that in two cultivars (McCubbin and Gajah) seed yield was significantly reduced in 'dry' compared to 'wet' podding zone, while yield in Robut 33-1 was unaffected. Dry surface soil reduced mainly pod numbers in McCubbin, while seeds per pod were reduced in Gajah. The demonstration that cultivar variation in reproductive development exists under these conditions suggests that selection for cultivars adapted to dry pod zones may be possible. Further details of this experiment are reported by Wright (1989).

The second experiment studied the influence of soil strength in the podding zone on reproductive development in two cultivars (McCubbin and Robut 33-1). Figure 6 illustrates the sensitivity of depth of peg entrance to soil strength. Pegs cease to penetrate soil at greater than about 2.0 MPa resistance. Interestingly peanut roots cease to elongate at about 5.0 MPa. There was no evidence of cultivar differences in peg response to soil strength, however, further experiments assessing cultivar variation in the 0–2.0 MPa region need to be performed with greater precision. The experiment has, however, demonstrated that peg entrance (and hence pod development) is extremely sensitive to soil hardness, which commonly increases with declining surface soil water content. Based on the findings of these two experiments, it can be hypothesised that the low pod yields and harvest indices observed under Indonesian conditions (e.g. Table 5) may be associated with poor peg and pod development in dry and hard soils. The ability of some cultivars to produce higher pod yields via improvement in HI may therefore be associated with superior pegging/podding characteristics under dry and hard surface soil conditions. Clearly, further research in this area is warranted.

Selection criteria

Harvest index is measured easily at or near maturity, provided adequate disease control measures are taken to prevent leaf disease and associated early senescence. In an experiment investigating the genetics of the negative association between TE and HI (see next section), a cross between two Indonesian cultivars contrasting in HI was made. The parents (Tapir, low HI, and Rankasbitung, high HI), F_1 and F_2 progeny were grown under well-watered conditions in the glasshouse and HI (and other measurements) were made at maturity. It was shown that the broad-sense heritability for HI was quite high (0.64). In subsequent field experiments, where a subset of the F_2 families was investigated, there were highly significant differences in HI among families. Unfortunately, HI of families from the F_3 and F_4 were not consistently correlated with HI measured in the F_2, indicating that selection for this trait may be more difficult than originally thought. The experiment conducted here should be treated as a preliminary attempt to study the genetics of HI. The small number of F_3 and F_4 families studied (28 and 8, respectively) means that firm conclusions concerning the selection potential for HI are difficult to make. In addition, the early generation material that was used was still segregating, such that, while significant differences in HI existed among families, the within-family variation was still quite high (evidenced by segregation for branching pattern, and leaf colour). The study has confirmed, however, that variation for HI is large in peanut, and that more detailed studies concerning its selection potential need to be conducted before it can be recommended for use in large-scale breeding programs.

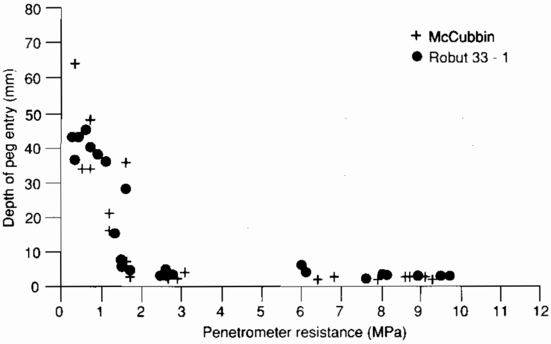

Figure 6. The relationship between depth of peg entry and penetrometer resistance for cultivars McCubbin and Robut.

Table 6. Total biomass, seed yield and components of three cultivars in response to 'wet' and 'dry' pod zone moisture regimes.

Cultivar	Treatment	Total biomass (g/plant)	Seed yield (g/plant)	Seeds/plant	Harvest index (%)
McCubbin	Wet	103.8	38.6	66.3	37.2
	Dry	91.7	22.2	39.0	24.2
Gajah	Wet	76.4	23.4	42.0	30.6
	Dry	92.3	15.2	28.0	16.5
Robut 33-1	Wet	54.4	20.7	38.7	38.1
	Dry	57.3	21.5	38.0	37.5
l.s.d. (P = 0.05)		13.2	7.7	0.36	5.3

Negative association between TE and HI

Pot studies in earlier glasshouse experiments showed that a significant negative correlation between TE (and Δ) and HI (and partitioning ratio) existed among six contrasting peanut cultivars. Thus the cultivars with high TE (and low Δ) tended to have low partitioning characteristics, and vice versa. A similar glasshouse experiment in large pots, using a more diverse range of cultivars (McCubbin, Gajah, Tapir, Rangkasbitung, VB, Q18803 and Robut), again showed that a highly significant negative correlation between TE and partitioning ratio existed (Fig. 7a). The relationship still exists when dry matter is converted to glucose equivalent (to account for the higher energy costs of synthesising oil in kernels), indicating that the relationship is not an artefact of dry-matter energy costs.

In the 1988 field experiment studying TE variation, it was observed that total biomass production at maturity for eight cultivars was negatively correlated with TE (and Δ), while pod yield was not, again providing field evidence of the negative association (see Figure 6 in Wright et al. 1988). The data in this experiment suggested that selection for low Δ (high TE) would substantially increase total biomass while having minimal influence only on pod yield improvement.

Studies in this project were therefore initiated further to understand, and, hopefully, determine, whether this association is a physiological response or due to a genetic linkage.

Genetic linkage

A preliminary genetic study, in which a cross between a low-TE, high-HI line (Rangkasbitung) and a high-TE, low-HI line (Tapir) was made, investigated whether the association between TE and HI could be broken by breeding. The parents, F_1 and F_2 progeny were grown under well-watered conditions in the glasshouse, and TE (via Δ measurements) and HI measured at maturity. Figure 7b shows that HI and Δ were negatively correlated, although considerable scatter in the relationship suggests crossing may have disturbed the association.

About 28 F_3 families derived from individual F_2 plants were selected on the basis of low Δ, high HI, or the best of both traits, and grown as spaced plants in the field under well-watered conditions. Figure 7c

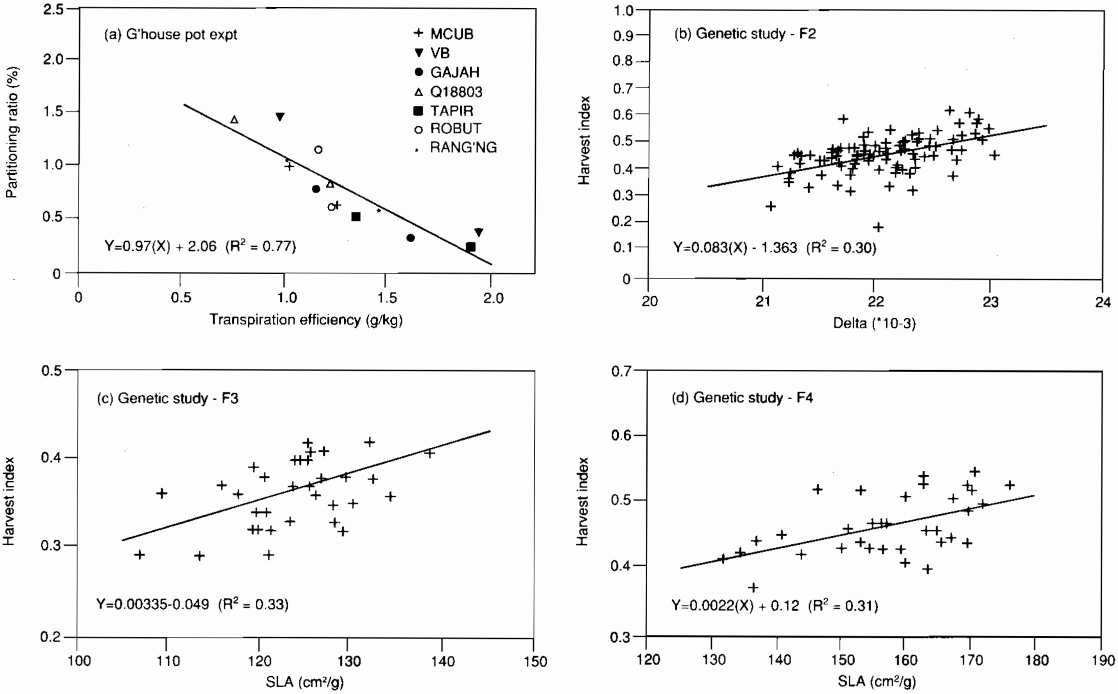

Figure 7. Relationship between (a) partitioning ratio and transpiration efficiency for cultivars grown in large pots in the glasshouse, (b) harvest index and delta for F_2 progeny, and harvest index and specific leaf area for F_3 (c) and F_4 (d) progeny, derived from a cross between Tapir and Rangkasbitung.

shows that TE (via SLA measurements) and HI were negatively associated for F_3 plants, with no obvious outliers possessing both high TE and high HI. During the next season eight F_3 families were again selected based on high HI, low Δ (via SLA) or the best of both traits. The F_4 families were grown as replicated yield plots, under well-watered or rainfed conditions in the field. Figure 7d shows that the negative association between HI and TE (via SLA) still appears to exist, although considerable scatter in the data is evident.

In summary, on the basis of the data presented here, it is evident that plants in the F_2, F_3 and F_4 generations (derived from the cross between Tapir and Rangkasbitung) show a negative correlation between TE and HI, which suggests that the possibility of breaking the linkage through breeding or selection may be small. This statement should be qualified, however, in light of some of the limitations of our experiment. Firstly, as selection for high HI and low Δ was practised in the F_2 generation, it could be argued that our F_3 sample was not random and could have biased the negative association. Secondly, our original F_2 population was very small (63 plants) and may not have been large enough to allow the expression of plants possessing both high HI and TE (i.e. gene frequency for this occurrence may be very low). Nonetheless, the moderate strength of the negative correlation between W and HI in this study (ca. $r = -0.55$) suggests that concurrent improvement in these traits may be difficult, but should be possible. Indeed, the association should be able to be broken, since cultivars such as Q18803 and VB-81 have moderately large TE and HI.

Physiological association

A preliminary experiment which altered the partitioning characteristics of two cultivars (VB and Q18803) by depodding or defoliating 50% of pods or leaves was set up in pots in the glasshouse. The aim of the experiment was to determine whether the change in partitioning was associated with changes in TE, in order to provide evidence for a physiological linkage. Figure 8 shows that the changes in partitioning induced by depodding or defoliating were associated with changes in TE, such that a negative association between TE and HI was observed. Interestingly, the changes in partitioning were also associated with changes in Δ, such that defoliating in, for example, VB, caused higher partitioning, lower TE and higher Δ (Δ data not shown). One hypothesis to explain this response is that high-partitioning lines (or lines that are forced to become high-partitioning) may remobilise vital nutrients (e.g. nitrogen) involved in the photosynthetic process and hence reduce photosynthetic capacity per unit of water transpired (or lower TE). Leaf nitrogen content measured on defoliated and depodded plants, however, did not change significantly in this study.

The data suggest that TE changed in response to changes in partitioning patterns within the *same* cultivar (probably through altered photosynthetic capacity), and indicate that the association between TE and HI may well be physiological in nature.

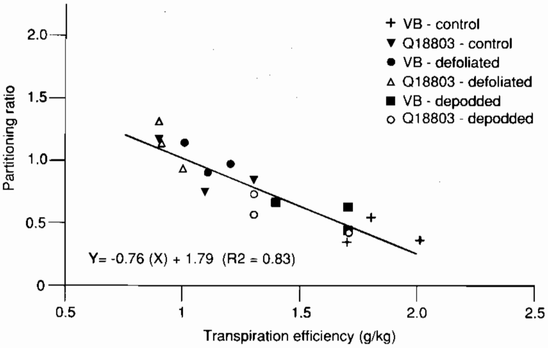

Figure 8. Relationship between partitioning ratio and transpiration efficiency for two cultivars (VB and Q18803) which had been either defoliated, depodded or untreated at the beginning of pod fill. Plants were grown in large pots in the glasshouse.

Implications for Peanut Production for Future Research in Indonesia

Research conducted in the drought physiology section of this project has greatly improved our understanding of the effects of water deficit on peanut cultivar yield performance, and identified potential traits for selection of better-adapted cultivars in breeding programs in Indonesia and Australia. The implications of this research for peanut production and future research in Indonesia are noted below.

- Demonstration of significant cultivar variation in ability to extract soil water from deep in the profile during severe end of season droughts. The capacity of cultivars to exploit deeply-held soil water reserves is of particular importance in post-rice production of peanut in Indonesia where crops begin with a ‘full’ profile and subsequently depend on soil water reserves to meet their water requirements. In upland production systems, where intermittent stress is common, deeper rooting/extracting cultivars should be able to avoid crop water deficits for longer during drying cycles, and avoid stress at critical development stages (e.g. pegging and pod set). The ability of some cultivars to extract more soil water results in greater transpiration and hence higher biomass production. Provided the extra dry matter is partitioned into pods, higher pod yields will result.

The difficulty of accurately and routinely measuring root growth and water extraction means identification of suitable selection traits is virtually impossible in the field. Preliminary attempts to correlate root parameters measured in small pots with observed field extraction performance were made in this project. The results indicate significant variation in many root characters, which may correlate with field performance. Further research in this area also has implications for the identification and selection of root systems capable of penetrating hard and compact soil layers, which can severely limit peanut production following rice culture.

- Demonstration of highly significant cultivar variation in transpiration efficiency (production of biomass per unit of water transpired) in field-grown peanuts under well-watered and water-limited conditions. Inclusion of high levels of this trait in peanut cultivars will improve biomass production per unit of water transpired, and, provided the extra biomass can be partitioned to pod growth, improved pod yields under water-limited conditions will result. There is considerable scope for improvement in TE in Indonesia, as currently grown cultivars have significantly lower TE levels than other higher-TE cultivars tested during this project.
- Identification of the carbon isotope discrimination technique (Δ) as a suitable selection trait for TE. Glasshouse and field testing show Δ is highly correlated with TE in peanut under a range of drought and other environmental conditions. Associated studies (Hubick et al. 1986, 1988) also show the trait is highly heritable, and genotype × environment interaction is low.
- Identification of a strong correlation between Δ and specific leaf area (SLA). The ease of measurement of SLA compared to Δ has significant implications for breeding programs in which screening for TE is desired. In particular, access to mass spectrometry in Indonesia is limited and expensive, hence the national program must rely on SLA as a screen for TE.
- Demonstration of significant cultivar variation in harvest index (HI), which has been shown to be a very important trait in determining pod yield variation in peanuts in Indonesia. Cultivar variation in the ability of pegs to penetrate into (and pods to develop in) dry soil has been demonstrated, and is associated with large differences in HI among cultivars. HI is easily measured provided adequate leaf disease control is practised. Heritability of HI is shown to be relatively high, although more definitive genetic studies are needed to verify this hypothesis.
- A worrying negative association between TE and HI among peanut cultivars has been demonstrated. An attempt to determine whether the association could be broken via breeding was made; however, a consistent negative association existed in F_1, F_2, F_3 and F_4 generations. There were limitations to the design and conduct of this study. Further research is warranted to determine whether existing peanut germplasm containing high TE and high HI is available, or whether the linkage may be broken by breeding. Limited evidence was presented to suggest that the association may be physiological.

Based on observations to date, it seems that selection for high TE (or low Δ and SLA) may be appropriate immediately in cropping systems where both pod yield for human consumption and vegetative yield for animal fodder need to be maximised. Where pod yield is the primary concern, breeders need to be aware of the potential negative association between HI and TE in any breeding program incorporating Δ or SLA as a selection trait.

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Effects of Photoperiod, Temperature and Irradiance on Peanut Growth and Development

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EFFECTS of environmental components such as photoperiod, temperature and irradiance on peanut growth and development are not well understood. However, these effects are of considerable importance in understanding cultivar adaptation responses. The need for this understanding is increasingly important with the widespread international germplasm exchange currently undertaken via collaborative projects such as this one, as well as via agencies such as ICRISAT and the peanut CRSP network.

Examples of the poorly understood effects of environmental parameters on peanut growth and development include the following points.

- Reports of photoperiod insensitivity in terms of time to flower, but quite strong photoperiod responses (typically short day, SD, responses) during subsequent reproductive development. The latter take the form of reduced numbers of reproductive structures (flowers, pegs and pods) and lower harvest indices (HI) in long photoperiods (LD) (e.g. 14–16 h) compared to SD (12 h). Such results prompt concern in many breeding circles, as most of the commonly used foliage disease-resistant parents show very strong photoperiod responses. As such, the progeny of crosses with these parents may have low yield potential in the subtropics. However, most subtropical environments are characterised by good reproductive development and high HI. Studies in the previous phase of this project also showed negligible effects of photoperiod in daylength extension studies in the field.
- The often-quoted occurrence of 'rank growth' in peanuts grown in tropical environments. Basically this constitutes relatively poor reproductive growth and development (compared to vegetative growth), resulting in low HI crops. Pod numbers per unit area and HI are approximately 50% of those recorded for the same cultivar in the subtropics, while plant populations necessary for optimum pod yields are twice as high. Typically, yields of 2–2.5 tons dry pods/ha are reported at populations of 200 000–250 000 plants/ha in the wet tropics and 4–5 tons dry pods/ha at 100 000 plants/ha in the subtropics.
- The extremely quick maturity of peanuts grown in the wet tropics (e.g. 85–95 days from sowing to harvest), versus that for similar cultivars grown in the hotter semi-arid tropics (105–115 days) or the cooler subtropics (120–130 days).
- The relatively low rates of dry matter accumulation per unit radiation intercepted in cooler environments, which result in similar yields and amounts of dry matter accumulated despite crop durations 15–25% longer.

Studies in this project were designed to (i) investigate the importance of photoperiod sensitivity in peanut cultivar adaptation; (ii) investigate the causes of low HI/high optimum plant populations under Indonesian field conditions; and (iii) gain an understanding of interactions among environmental components like photoperiod, temperature and irradiance of significance for predicting crop performance in the field across a range of production environments.

Research Highlights

Photoperiod studies

The effects of photoperiod on reproductive development and yield of two Virginia, one Spanish and one Valencia peanut cultivars were investigated in the field at Kingaroy, Queensland. The objective was to assess the importance of photoperiod as a limitation to post-flowering reproductive development in a cool subtropical environment. A total of five experimental sowings was made during the 1986–87 to 1988–89 growing seasons. Treatments consisted of either

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natural (ranging from 11 to 14 hours, depending on sowing date and growth stage) or long (16 hour) photoperiods during a range of phenological stages, both pre- and post-flowering. Long photoperiods were achieved by using low-intensity light from incandescent bulbs with equal extension periods both morning and evening. Different sowing dates and seasons were used to produce a range of natural photoperiods, radiation and temperature regimes, while shadecloth was used to alter incident irradiance during the 1988–89 experiments.

Photoperiod responses were significant in only one experiment (S2, 1986–87), and were due to effects of treatment during the immediate post-flowering period. Numbers of flowers, pegs and pods were reduced under long photoperiods in cv. Robut 33-1 and, to a lesser extent, in cv. White Spanish. The Virginia cv. Uf 78114-5 was unaffected (Fig. 1). The effects of long photoperiods during this 30-day post-flowering treatment were not expressed until after the treatment period. Effects were relatively small and reproductive (pod) yields at maturity were not significantly reduced (Table 1).

The lack of strong photoperiod responses in cv. Uf 78114-5 (and also in the reportedly sensitive Valencia cv. NC 17090, data not shown) and the occurrence of the strongest response in the relatively insensitive cv. Robut 33-1 were unexpected. Analysis of climatic data from these experiments and others reported in the literature suggested interactions between photoperiod and temperature, with photoperiod effects being significant only at higher temperatures, i.e. in these studies, when mean daily temperature during the treatment period was 26 °C.

The effects of temperature on the response to photoperiod by peanut cultivars were subsequently examined under glasshouse and phytotron conditions at two locations (Kingaroy and Canberra). Two Virginia (Early Bunch and Robut 33-1), two Spanish (White Spanish and TMV-2) and a single Valencia (NC 17090) cultivars were grown in the experiments. White Spanish was common to both studies.

Strong photoperiod × temperature interactions were shown for all cultivars in both experiments, with the sensitivity of pod number to photoperiod increasing at higher temperatures (Table 2). Photoperiod responses were all indicative of SD response types, and were always expressed in post-flowering reproductive development. No effects of photoperiod on time to first flower were evident, but numbers of pegs (data not shown) and pods and total pod weight per plant were reduced in long (16 or 17 hours) photoperiods.

Data from field experiments at Kingaroy were pooled with those from the glasshouse and controlled environment studies to estimate the critical temperatures above which photoperiod sensitivity became significant. Hourly temperature readings were used to calculate a daily heat sum (°C h) above a base temperature of 10 °C for each experiment.

Table 1. Effects of photoperiod and cultivar on (a) pod yield and (b) harvest index (HI) of three peanut cultivars in 1986–87. Yields are means of two sowing dates, while photoperiod treatments consist of natural (N) and long (16-hour, L) photoperiods during the emergence to flowering and/or flowering to flowering + 30 days periods.

	Photoperiod				
	N,N	L,N	N,L	L,L	Cultivar mean
(a) Pod yield					
Robut 33-1	6133	6331	5921	5978	6091
Uf 78114-5	5263	5472	5267	5431	5358
White Spanish	4679	4544	4464	4275	4491
Photoperiod mean	5358	5449	5217	5228	
l.s.d. ($P<0.05$) (a) Cultivar = 266 (b) Photoperiod = 484					
(b) HI					
Robut 33-1	0.47	0.45	0.44	0.43	0.45
Uf 78114-5	0.54	0.50	0.51	0.48	0.51
White Spanish	0.43	0.36	0.39	0.38	0.39
Photoperiod mean	0.48	0.44	0.45	0.43	
l.s.d. ($P<0.05$) (a) Cultivar = 0.03 (b) Photoperiod = 0.06					

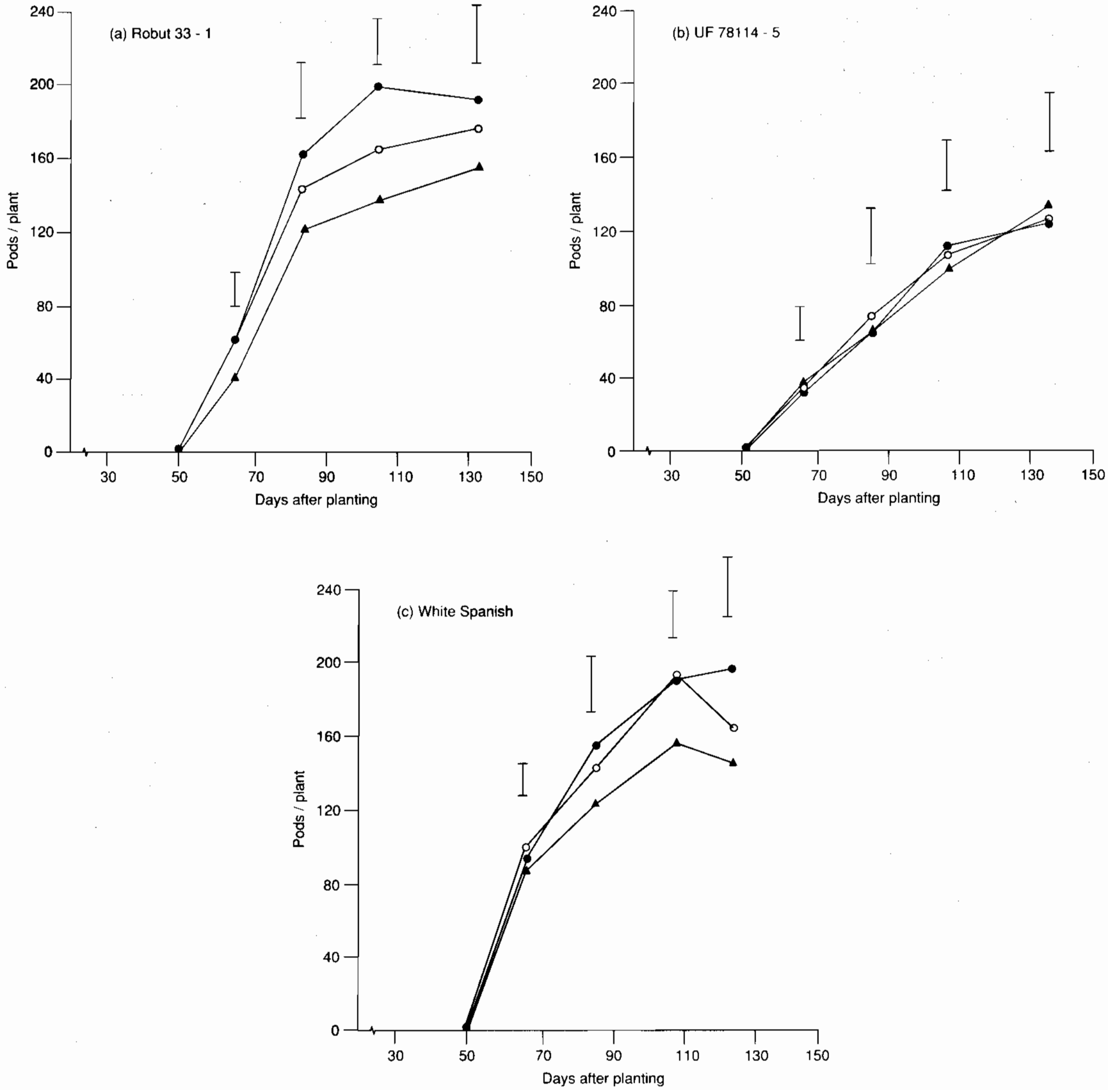

Figure 1. Total pod numbers per plant for cultivars (a) Robut 33-1, (b) UF 78114-5, (c) White Spanish from sowing in 1986-87. Treatments are natural photoperiods from emergence to 30 days post-flowering (●); 16 hour photoperiods from emergence to flowering (o); or 16 hour photoperiods from flowering to 30 days post-flowering (▲).

This index of the temperature condition proved satisfactory as a possible discriminatory method to describe environments based on likely photoperiod response. Environments where daily heat unit accumulations greater than 340-350 °C h were recorded during the treatment period showed significant photoperiod responses (Table 3).

The possibility of minimum temperature being the predominant component of the temperature × photoperiod interaction proved less effective in discriminating between environments for photoperiod response, but data were insufficient to discount this possibility, and further studies are needed. The finding is of considerable significance in assessing the importance of photoperiod sensitivity for cultivar adaptation to long day or subtropical environments. Results question the relevance of photoperiod as a factor limiting reproductive development of peanuts, particularly in cooler subtropical environments.

Table 2. Effects of temperature and photoperiod on (a) pod number per plant, (b) pod weight per plant and (c) harvest index (HI) for the peanut cultivars White Spanish and NC 17090 at Kingaroy. L.s.d. values ($P<0.05$) are indicated for each parameter. Photoperiods are either natural (11.9–13.5 h, ND) or long (17 h, LD). Data were analysed using total above-ground dry matter (DM) as a covariate.

	33/17 °C		33/23 °C	
	ND	LD	ND	LD
(a) pod number				
White Spanish	39.87	28.80	39.26	18.18
NC 17090	18.49	11.25	13.69	5.91
l.s.d. ($P<0.05$) = 4.17				
(b) pod weight (g)				
White Spanish	6.58	4.89	8.50	1.20
NC 17090	3.63	2.81	4.00	0.68
l.s.d. ($P<0.05$) = 0.98				
(c) HI				
White Spanish	0.204	0.154	0.244	0.059
NC 17090	0.108	0.069	0.123	0.033
l.s.d. ($P<0.5$) = 0.032				

Night temperature effects on phenology and dry matter accumulation

Temperature effects

Three peanut cultivars were grown under optimal field conditions in two environments in subtropical Australia contrasting primarily in night temperature. Mean minimum temperatures were 16.7 °C (Kingaroy, cool) and 20.1 °C (Bundaberg, warm). Dry matter (DM) production was similar in both environments for each cultivar, but pod yields were slightly higher with warm nights ($P<0.05$). This occurred despite large differences in rates of development between environments. Crops grown in the warm night environment were 4–5 days earlier to first flower (R1), 16 days earlier to the beginning of seed fill (R5) and 23–24 days earlier to maturity.

Crop growth rates were 30% higher with warm nights, while rates of pod yield accumulation were 25–50% higher with warm nights. Accumulation of energy-corrected DM was highly correlated with cumulative intercepted short-wave solar radiation (S) for all cultivars. There were no significant differences in the rate of accumulation of energy-corrected DM per unit S intercepted (radiation use efficiency; RUE, g/MJ among cultivars in either environment. Data were pooled for each environment, with RUE in the

Table 3. Mean daily and minimum temperatures, daily heat unit accumulation above a base temperature of 10 °C, photoperiod response in field (Bell and Harch 1991), and controlled environment studies.

Location photoperiod	Temperature (°C)		Daily heat units accumulated	Response
	Daily mean	Mean min. (°C h)		
Kingaroy, field S2, 1986–87 sowing to flowering	24.2	16.9	300–310	No
Kingaroy, field S2, 1986–87 first 30 days after flower appearance	26.0	19.9	350–360	Yes
Kingaroy, field S3, 1987–88 sowing to flowering	24.6	18.0	310–320	No
Kingaroy, field S3, 1987–88 flowering to mid-podfill	23.3	17.0	300–310	No
Kingaroy, glasshouse 33/23 °C	26.7	23.0	410–420	Yes
Kingaroy, glasshouse 33/17 °C	24.3	17.0	340–350	Yes
Canberra phytotron 30/25 °C	26.7	25.0	400	Yes
Canberra phytotron 24/19 °C	20.7	19.0	156	No

warm night environment 39% higher than in cool nights (Fig. 2). This low RUE in the cool night environment occurred despite better radiation distribution within the canopy (i.e. lower canopy extinction coefficient; K) and higher specific leaf nitrogen (SLN; g N/m^2).

A subsequent glasshouse study with cv. Early Bunch compared growth and RUE at temperature regimes of 33/23 °C and 33/17 °C, and confirmed the role of night temperature in determining rates of DM accumulation via effects on RUE. Cool night effects were associated with increased specific leaf area and lower stomatal conductances, with both effects evident seven days after treatment imposition. Analysis of published RUE data for cv. Early Bunch from a range of environments, along with that from these field studies, showed a highly significant ($P<0.01$) negative linear relationship between RUE and night temperature (Fig. 3). Results suggest significant environmental limitations to peanut production in subtropical regions previously considered to have near-optimal conditions for peanut growth.

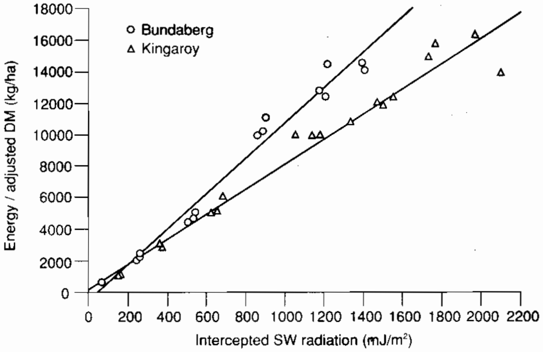

Figure 2. Energy-adjusted DM as a function of total intercepted SW radiation for peanuts grown at Kingaroy and Bundaberg. Slopes represent canopy RUE, with values of 1.19 (±0.04; n=17) for Bundaberg, and 0.81 (±0.03; n=20) g/MJ for Kingaroy.

Interactions between temperature and leaf nitrogen

A non-nodulating (non-nod) cultivar of peanut was grown at two subtropical Australian locations contrasting primarily in night temperature. Crops were grown in field plots at nitrogen (N) rates ranging from 0 kg N/ha (with 10 t/ha finely chopped cereal straw) to 260 kg/ha, with N applied at planting (50 kg/ha) and in a series of 30 kg/ha side-dressings during crop growth. Dry matter and N accumulation were monitored in two sowing dates in the cooler environment (Kingaroy) and at a single sowing in the warm environment (Bundaberg). These were compared with similar data collected for three nodulating lines grown at the same location.

The early sowing in the cool environment (S1) accumulated similar levels of DM at high N (260 kg/ha) to the comparable treatment in the warm environment (S2, 260 kg/ha), despite a crop duration (emergence to maturity) 31 days longer. Dry matter accumulation and crop development were restricted in the second sowing in the cool environment (S3) due to frost occurrence which prevented the crop reaching maturity. Slower DM accumulation in S1 was related to reduced interception of incident radiation due to slow leaf area development, as well as a 20% lower RUE. The lower RUE in S1 and S3 could be related to effects of low minimum temperature (tmin).

Relationships between the total amount of N per unit leaf area (specific leaf nitrogen, SLN; g/m^2) and RUE were established. These relationships were strongly dependent on tmin during the assessment period, with the RUE responsiveness to SLN increasing with increasing tmin (Fig. 4). Data could be adequately described using a family of curves for differing tmin conditions.

Results suggest that under conditions of tmin limitation, both nod and non-nod lines accumulate leaf N in excess of that required for maximum RUE. Only under optimal temperature conditions do SLN values in nodulating lines fall (during seed-fill) close to values which may limit subsequent rates of DM accumulation (Fig. 5). Factors affecting rates of N-uptake during seed-fill in warm environments (e.g. water stress and assimilate shortages due to high partitioning to pods) may result in some source limitation due to falling SLN.

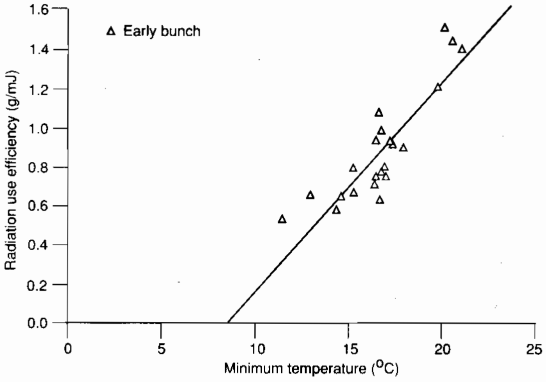

Figure 3. Pooled data for RUE as a function of minimum temperature for peanut cultivar Early Bunch from a range of published experiments. The regression was highly significant, with a slope of 0.104 (±0.012; n=24).

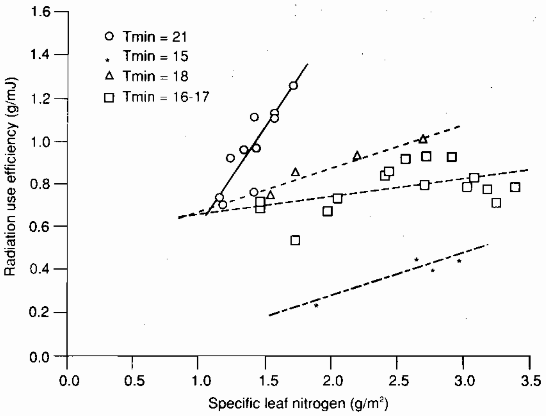

Figure 4. Relationship between SLN, (g/m²) and canopy RUE (g/MJ) at a range of minimum temperatures for a non-pod peanut cultivar. All data sets were limited in that the full RUE–SLN relationship could not be determined.

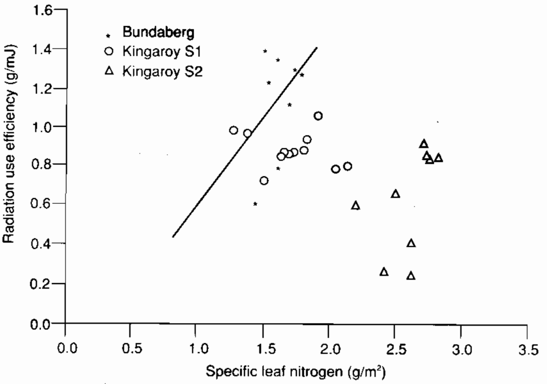

Figure 5. RUE of canopies in nodulating peanut cultivars at Bundaberg and Kingaroy in relation to the critical values determined for a non-nod line in the absence of temperature limitations. Values of SLN and RUE were determined at various stages of growth.

Effects of partitioning characteristics on N_2-fixation during seed-fill

The contribution of symbiotic N_2-fixation to the nitrogen economy of nodulating peanut lines with differing partitioning characteristics was evaluated using the relative abundance of ^{15}N and the difference methods in 1989–90. This work was undertaken to test the hypothesis that high partitioning lines (which often remobilise stored assimilates to fill pods) may suffer N limitations and resultant low rates of DM accumulation due to reduced rates of N_2 fixation during pod fill. Two Virginia cultivars (Early Bunch and Virginia Bunch) and two (Bundaberg) or one (Kingaroy) Spanish cultivars (TMV2 and Tapir) were grown in single sowing dates at each location. Dry matter accumulation and crop development were restricted in the Kingaroy sowing due to the occurrence of frosts, which prevented the crop reaching maturity.

The relative abundance of ^{15}N and the difference method provided similar estimates of N_2-fixation at both locations (Fig. 6). Accumulation of both total and fixed N could be related directly to accumulation of energy-corrected DM (Figs 7, 8), with no significant differences in rates of accumulation of N among cultivars at each location. Accumulation of N occurred as a constant proportion of energy-corrected DM at each location. There were no significant differences between locations, so all data were pooled and the following relationship was obtained:

$$y = 0.021x + 0.88; R^2 = 0.99$$

(i.e. N was accumulated as a constant 2.1% of total DM throughout the season).

Similarly, N accumulation from fixation occurred as a constant proportion of total DM at each location, with no significant differences among cultivars. A comparison of pooled data for each location showed N_2 fixation occurring at twice the rate in Bundaberg, compared to Kingaroy, viz:

Bundaberg	$y = 0.015x - 0.72; R^2 = 0.98$
Kingaroy	$y = 0.008x - 0.12; R^2 = 0.71$

Fixation of atmospheric N_2 provided 55–65% of total crop N at Bundaberg (with the Spanish cultivars fixing the lesser proportions of total N), and 38–49% of total crop N at Kingaroy (no consistent botanical differences). Net crop N budgets (N fixed − N removed in pods) were always negative for the Spanish cultivars (−10 kg/ha at Kingaroy and −30 kg/ha at Bundaberg), but were positive for Virginia cultivars at Kingaroy (+10 to +30 kg/ha) and

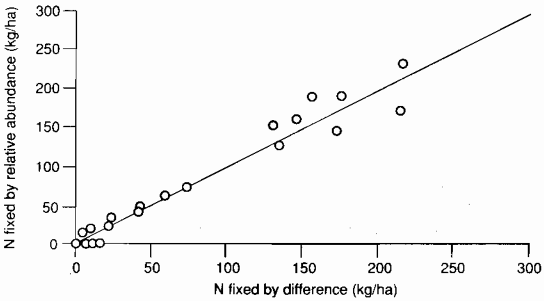

Figure 6. Comparison of relative abundance ^{15}N and difference methods for estimating N_2-fixation in 1989–90 season at Bundaberg and Kingaroy.

neutral (Virginia Bunch) or negative (−35 kg/ha, Early Bunch) at Bundaberg. The premature harvest caused by frost incidence at Kingaroy is probably the main reason for a positive N input in the Virginia cultivars, where pod yields were very low.

Data provided no evidence to support the hypothesis that declining rates of N_2 fixation occurred during pod-fill, even in high partitioning cultivars. Further work is required to quantify effects of stress (e.g. cool temperatures, water deficit) on crop N_2-fixation, particularly once a full pod load has been established.

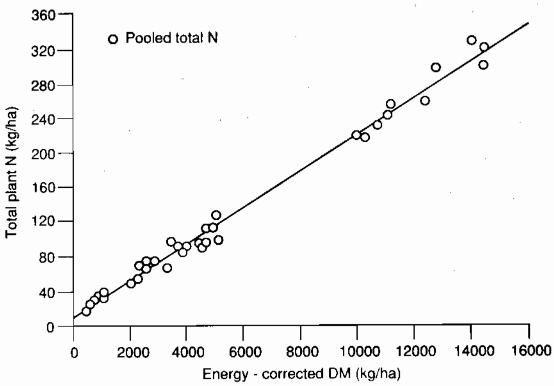

Figure 7. Accumulation of total crop N by nodulating peanuts at Bundaberg and Kingaroy in relation to accumulation of energy-corrected DM. Data were pooled for four cultivars grown at Bundaberg and three at Kingaroy.

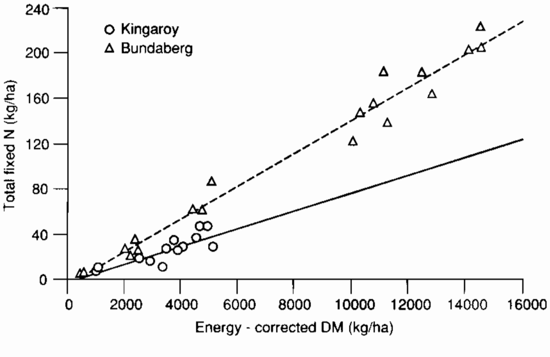

Figure 8. Crop N derived from N_2-fixation as a function of energy-corrected DM for peanuts grown at Bundaberg and Kingaroy in 1989–90. Data for each location represented pooled data from four (Bundaberg) and three (Kingaroy) cultivars.

Factors contributing to low HI in the wet tropics

Preliminary studies in the previous project suggested that low levels of incident irradiance in wet tropical environments may be a factor contributing to low HI and the 'rank growth' phenomenon. Shading studies at Kingaroy had shown that peanuts grown under continuous shade (producing daily irradiance levels similar to those in wet or dry season tropical environments in Indonesia) produced proportionally less reproductive DM (i.e. lower HI) as the daily irradiance level was reduced (Fig. 9). There was a suggestion also of cultivar variation in sensitivity to shade shown in that early study.

Research has examined variation in sensitivity to low irradiance (a) among cultivars of differing botanical type and varying partitioning characteristics; and (b) among Spanish cultivars originally selected for performance under a range of irradiance levels. The emphasis in all studies has been both to quantify the effects of shade or low irradiance and to attempt to understand the basic physiology of the responses.

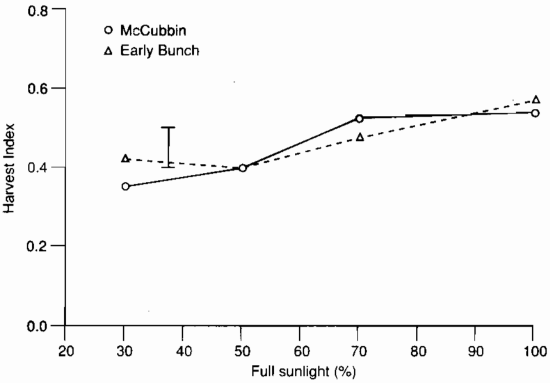

Figure 9. Effects of shade on harvest index at maturity for a Virginia (cv. Early Bunch) and a Spanish (cv. McCubbin) peanut cultivar grown at Kingaroy in 1987–88. Crop duration was delayed with increasing shade, with individual plots harvested when mature.

Effects of shade on cultivars of differing botanical type and partitioning characteristics

Effects of shading on growth and accumulation of DM and HI for two Virginia cultivars (the low partitioning Virginia Bunch and the high partitioning Early Bunch) and one Spanish cultivar (TMV2) were examined at Kingaroy and Bundaberg in 1989–90. The objective was to test the hypothesis that higher partitioning or more physiologically determinate cultivars would be less shade-sensitive than low partitioning or indeterminate cultivars. The inclusion of the Bundaberg environment allowed testing in a temperature environment close to that found in Indonesian production areas.

Dry matter production was less affected by shading than cumulative intercepted radiation, due to changes in canopy structure (higher canopy extinction coefficients with shading), and also to possible effects on the relative proportions of incident S which were either direct-beam or diffuse (Table 4). Radiation use efficiency was 20–30% higher with the shade treatments at Bundaberg (25% shade) and 20–25% higher with shade at Kingaroy (either 50% or 70% shade).

Shade effects on HI were consistent with the original hypothesis in that the less determinate, low partitioning Virginia Bunch was consistently more shade-sensitive than either Early Bunch or TMV2 (Table 4). However, there appear to have been some interactions with environment (probably temperature effects) in terms of shade effects. Unlike previous results with McCubbin (Fig. 9), TMV2 showed no HI response to shade at Kingaroy, although effects at Bundaberg were significant. Conversely, Early Bunch responded as expected at Kingaroy, but showed no response at Bundaberg. As the Bundaberg and Kingaroy environments differ primarily in night temperature, our results suggest some as-yet unidentified interactions with temperature which are not inconsistent with our findings for photoperiod sensitivity.

Further studies in this area are warranted. However, the fact that low irradiance or shade can significantly lower HI has been established, as has the fact that sensitivity varies with cultivar. Recent discussions with scientists from the peanut CRSP project in the Philippines, screening peanut germplasm for shade tolerance (to use as a crop underneath coconut plantations), reveal similar effects of shade on HI in tropical environments. Whether the ability to yield well under shade (the selection criterion in the Philippines studies) is due to the ability to maintain HI has yet to be determined.

Shade sensitivity of diverse Spanish germplasm

Shade sensitivity, assessed in terms of both pod yield and HI, of a range of Spanish cultivars from sources characterised by either high (USA, Australia) or relatively low (Indonesia, Philippines) irradiance environments, were assessed in field studies in 1988–89 and 1989-90 at Kingaroy. Shade treatments (100, 70, 50 and 30% full sunlight) were chosen to cover the range of daily irradiance environments experienced by peanuts (e.g. 27–30 MJ/m^2/day, down to 9–10 MJ/m^2/day).

Significant differences ($P<0.05$) in cultivar sensitivity to shade were found, both in terms of pod yield and also in terms of HI (Fig. 10). However, these differences were not necessarily linked to the radiation levels of the cultivar origins. For example, the high-irradiance (Australia) cultivar McCubbin showed significantly lower HI and pod yield with 70% full sunlight, while others did not decline significantly until 50% full sunlight (e.g. Gajah). Some cultivars seemed especially tolerant of shading,

Table 4. Effects of shading (% full sunlight) at two locations on interception of incident radiation (S, MJ/m^2), dry matter accumulation (DM, kg/ha), radiation use efficiency (RUE, g/MJ) and harvest index (HI) of three peanut cultivars in 1989–90.

Location	Cultivar	Shade (% full sun)	Dry matter kg/ha	Inter. radn MJ/m^2	RUE (g/MJ)	HI
Kingaroy	Virginia bunch	100	13967	2095	0.67	0.44
		50	10245	1211	0.85	0.30
		30	5744	688	0.83	0.25
	Early bunch	100	16373	1959	0.84	0.53
		50	9908	1014	0.98	0.41
		30	5881	605	0.97	0.40
	TMV2	100	12431	1544	0.81	0.44
		50	7631	853	0.89	0.46
		30	5339	536	1.00	0.45
Bundaberg	Virginia bunch	100	14539	1388	1.05	0.47
		75	11312	1068	1.06	0.41
	Early bunch	100	14093	1400	1.01	0.57
		75	13215	1124	1.18	0.56
	TMV2	100	12815	1173	1.09	0.44
		75	10027	937	1.07	0.36

the best examples being the local selection from Rangkasbitung region (Indonesia — both pod yield and HI) and the USA cultivars Pronto and Spanco (HI).

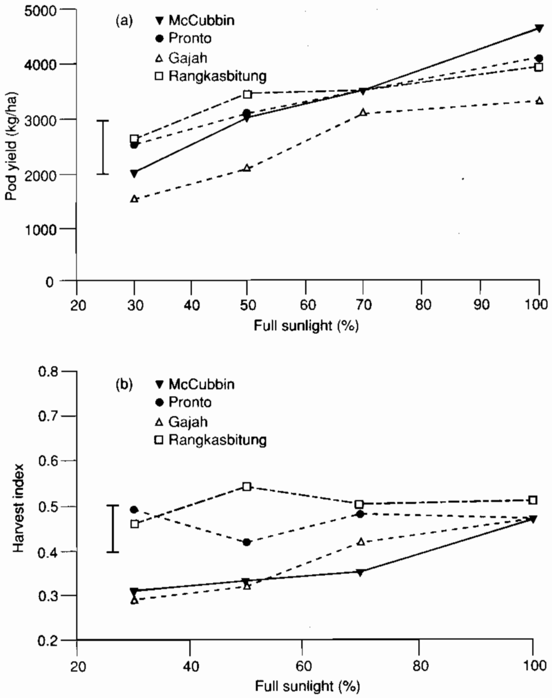

Figure 10. Effects of shade on (a) pod yield and (b) harvest index of selected Spanish cultivars from high irradiance (Australian, McCubbin; USA, Pronto) and low irradiance (Indonesia, Gajah and Rangkasbitung) environments in 1989-90.

This existence of significant cultivar variation in the ability to maintain yields at low incident irradiances is of considerable significance for yields in wet tropical environments. However results from this study suggest that high-yielding cultivars from such environments (e.g. Gajah) need not necessarily have greater tolerance to low light conditions.

Implications for Peanut Production and Future Research in Indonesia

This research has made a number of significant contributions to our understanding of the effects of environmental factors (especially photoperiod, temperature and irradiance) on peanut growth and development.

- Demonstration of significant photoperiod to temperature interactions. These provide an explanation for the better-than-expected performance of photoperiod-sensitive (SD) cultivars in long photoperiod, subtropical production environments. Further work is required to quantify fully these interactions (e.g., is the important temperature component a heat sum, or a night or minimum temperature effect), with the final outcome of considerable significance for international and national germplasm exchange. Of special significance is the implication for breeding for foliar disease resistance, as most resistant sources show strong photoperiod sensitivity in ICRISAT studies. Our result suggests this material can be successfully utilised in the cooler subtropics.
- Elucidation of another important role of temperature, this time in terms of the effects of minimum temperature on rates of DM accumulation. This is thought to operate via effects on assimilate transport with subsequent feedback inhibition of photosynthesis, and is the basis of continuing research in field and controlled environments at the University of Guelph. The ability to identify appropriate sources of tolerance to cool nights (which, from preliminary evidence, appears to exist) within currently available germplasm, and to utilise this material in local breeding programs, has the potential to raise yields by 20–25% in cooler, subtropical environments.
- The interactions between specific leaf nitrogen and minimum temperature in determining radiation use efficiency, and hence rates of DM accumulation, have been demonstrated using a non-nodulating line. The data suggest that SLN is unlikely to limit canopy photosynthetic capacity under well-watered conditions, with the possible exception of high partitioning cultivars in warm night environments.

Rates of N_2-fixation were shown to vary with environment, but to be reasonably constant across cultivars within environments. Varying levels of DM partitioning to pods during the pod-fill period did not affect the fixation process, with the amount of fixed-N a constant proportion of crop DM until maturity. Despite large amounts of fixed-N (i.e. 200+ kg/ha) high-yielding crops generally were net N exporters, although below-ground N (roots and nodules) was not estimated in these studies.

Future work on the effects of stress (e.g. water stress, unfavourable temperatures) on the N-nutrition of the peanut crop needs to be undertaken, especially with stresses during pod-fill. Similarly, further work on the N-nutrition of peanuts in various Indonesian cropping systems needs to be undertaken. Findings in this project suggest that, as in these Australia studies, fixation and soil N reserves appear to supply adequate N for crop requirements. This needs to be confirmed, with the role of N_2-fixation in the total N budget elucidated, perhaps by xylem sap analysis. Such findings may enable modifications to be made to the Indonesian national fertilizer recommendation of 50 kg N/ha for peanuts.

- Strong evidence of the role of low incident irradiance in the phenomenon of 'rank growth' in peanuts grown in wet tropical regions like Indonesia has been gathered in this project. Appropriate shading treatments have produced low HI crops with similar total biomass to Indonesian sowings (Table 5).

Cultivar variation in sensitivity to low irradiance has been demonstrated, and is already being utilised (indirectly) in selection for yield under shade in the Philippines. However, there are suggestions of interactions between temperature and irradiance in determining both phenology and HI, and these need to be examined further (e.g. concepts of photothermal quotients). It is a strong belief of project scientists that these interactions hold the key to the high plant density requirements under Indonesian conditions, as well as the low HI phenomenon. Progress in this area is of considerable importance for raising yield potentials under Indonesian conditions.

Table 5. Site variation in crop dry matter production (DM, kg/ha), harvest index (HI) for five peanut cultivars grown under Indonesian and Australian (Kingaroy and Bundaberg) conditions with or without shading.

Location	Shade treatment		Tapir	Tupai	Kidang	McCubbin	Early Bunch
Indonesia	Full sun	DM	6870	7240	7135	6750	6520
		HI	0.34	0.33	0.35	0.29	0.35
Australia							
Kingaroy	Full sun	DM	8250	8650	8570	10170	11500
		HI	0.43	0.48	0.45	0.54	0.57
	0.5 sun	DM				9077	7934
		HI				0.33	0.41
Bundaberg	Full sun	DM	8865				11054
		HI					0.54
	0.75 sun	DM					9866
		HI					0.56

Development of a Peanut Growth Model to Assist in Integrating Knowledge from Management and Adaptation Studies

G.L. Hammer,* Irmansyah,† H. Meinke,* G.C. Wright‡ and M.J. Bell‡

A major objective of the peanut improvement project was to explore environmental constraints limiting the productivity of peanuts in Australia and Indonesia. A number of crop physiological studies were undertaken to examine the effects of a range of environmental factors. In order to identify major limitations in relevant environments it was necessary to integrate the findings of the crop physiological research. This was approached by developing and applying a peanut growth model.

A number of crop modelling approaches, covering a broad range in level of detail, can be considered. For peanut, two existing models, differing greatly in level of detail, provided a useful starting point for this work. The first, PNUTGRO, simulates a peanut crop at a level of complexity that attempts to account for plant physiological processes in some detail. Its strength is in its ability to focus plant physiological research to advance understanding of processes and their interactions. Its weakness is that it is a cumbersome predictive tool, demanding of detailed coefficient specification, and ultimately relying on a key empirical factor to calibrate yield predictions. The second, Sinclair's soybean model, employs a simple, yet still mechanistic, framework to simulate the main phenomena occurring at crop level. It uses few, easily interpretable coefficients. The weakness of this approach is that it has not been applied to peanut.

To isolate the ecophysiological limitations to peanut production, the Sinclair framework has clear advantages in that main phenomena are isolated and simply modelled. This enables us to identify major limitations readily. Detailed understanding could be pursued with further physiological research as required. This 'top-down' approach (Shorter et al. 1991) demonstrates this capability in similar studies aimed at integrating physiology, modelling and crop improvement in other species.

Our objectives in this part of the project were thus:

(i) to integrate the crop physiological research undertaken by developing a simple phenomenological model for peanut based on the Sinclair soybean model, and

(ii) to use the model to identify and quantify the major environmental constraints limiting peanut productivity in Australia and Indonesia.

Research Highlights

Model development

The framework and logic employed in the peanut model (Q-NUT) are presented in Figure 1. The form of the model is derived directly from Sinclair's soybean model (Sinclair 1986). Pod yield is predicted as the product of harvest index and total biomass. Total biomass is predicted by accumulating daily growth, which is calculated from the product of radiation intercepted by the canopy and the efficiency of conversion of that radiation to biomass. Light interception depends on crop leaf area and radiation use efficiency (RUE), which is influenced by environmental factors (water, temperature and nitrogen). Crop leaf area is incremented daily depending on growth in the number of nodes on the main stem, which depends on temperature. Branching pattern affects the relationship between main stem node number and plant leaf area. Soil water limitation restricts leaf area growth so a daily soil water budget is maintained. Harvest index (HI) is predicted

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by determining the timing of the start of the increase in HI, and the daily rate and duration of the increase. HI increases linearly with time once it has started to increase, allowing prediction of pod yield as it increases during pod filling. HI cannot increase above a specified maximum. HI increase is halted if the crop fully depletes the soil water.

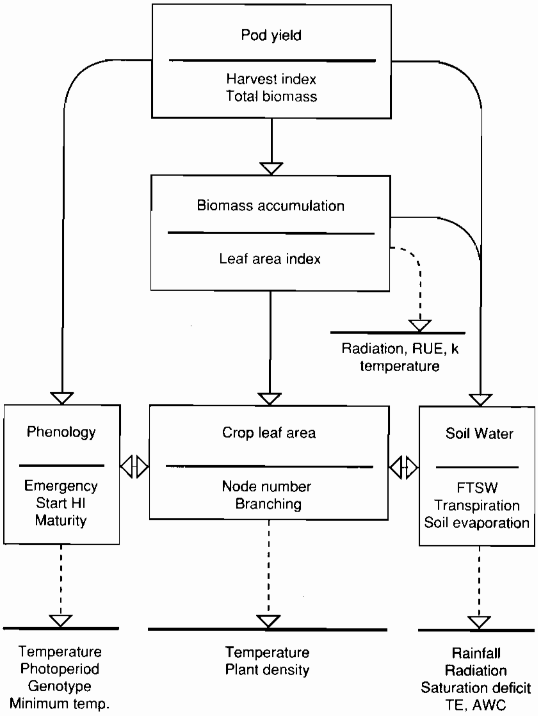

Figure 1. Overview of framework and top-down logic used in the peanut model Q-NUT.

During 1989 a prototype of the peanut model was developed. Simultaneously, collation of data from field experiments conducted as a part of this project and others commenced to enable derivation of functions for the model and model testing. Dr Tom Sinclair was invited to participate in the development of Q-NUT and visited Australia in September-October 1989. Initial simulations with the prototype highlighted the point that further research efforts on the effects of low temperature and leaf nitrogen on radiation use efficiency were required before a satisfactory model could be developed. This led to the design of subsequent experimentation. Other issues associated with developing the prototype required further analysis of available data. This was undertaken during 1990 and an operational version of the model was developed when Dr Hammer worked with Dr Sinclair in Florida (October–December 1990).

Initial work on model development concentrated on cultivar 'Early Bunch' under irrigated conditions as data sets were available for this genotype for a very broad range of environments in Australia, Indonesia, and USA. Linear regressions were fitted to data on HI for each experiment and fitted well (e.g. Fig. 2), although there was a tendency for HI to plateau in some experiments. Maximum HI was 0.55. The regressions were used to define the timing of onset of HI increase and the rate of increase. An iterative optimisation procedure (Hammer et al. 1989) was used to derive the best basis to calculate thermal time for predicting time to onset of HI increase. A base temperature of 9 °C and optimum of 29 °C (Fig. 3) gave best fit. This was consistent with other studies for peanut. It is likely that development rate declines at temperatures above the optimum, but with this data set we were unable to discern such a response. Using this method to calculate thermal time we found that 837 °C d were required for 'Early Bunch' to progress from sowing to the start of HI increase. Figure 4 shows the adequacy of this approach.

The rate or slope of HI increase was affected by temperature (Fig. 5). There was a rapid decline in HI slope at very high temperatures. These data were all from experiments in north-western Australia. Whether this effect is caused by a direct effect of temperature on seed growth requires experimental testing. Our analysis indicated that other genotypes (e.g. Florunner) did not show this decline. Further elucidation of these findings would be useful for such

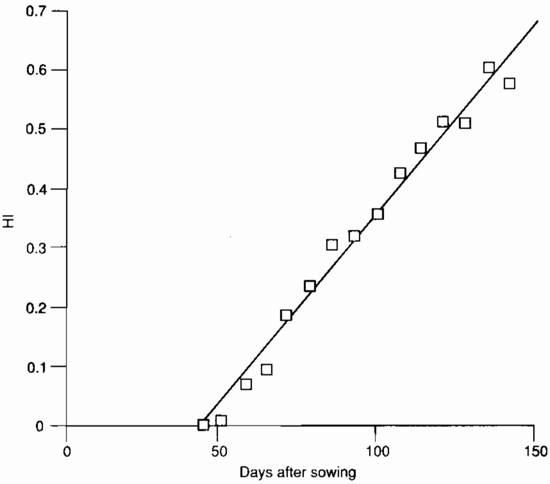

Figure 2. Harvest index (HI) against days after sowing for peanut cultivar 'Early Bunch' grown under irrigated conditions at Gainesville, Florida.

high temperature environments. However, such temperatures are rarely experienced in the main peanut-growing regions in Australia and Indonesia.

Thermal time from onset of HI increase to maturity was calculated using the same basis as for sowing to onset of HI increase (Fig. 3). Maturity was taken to be time of the last biomass harvest in each data set. There was substantial variability in the thermal time requirement but three distinct geographical groups occurred (Table 1). The longer maturation period in north-west Australia was likely related to our inability to model retardation of development at very high temperatures. However, the finding of more rapid maturation for the Indonesian experiments (both at Jambegede) could not be immediately explained.

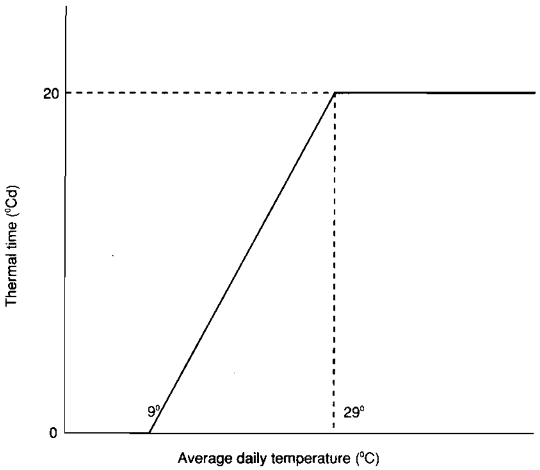

Figure 3. Basis of thermal-time calculation for peanut.

Biomass accumulation depends on radiation use efficiency (RUE). The experiments conducted at Kingaroy and Bundaberg in 1990 with a non-nodulating cultivar showed that RUE responds to both low minimum temperature and leaf nitrogen (Fig. 6). Other data indicate that nodulating cultivars are not limited by nitrogen, although this has not been resolved categorically. Hence at this stage we do not model the N response but set RUE to 1.0 g/MJ and modify this when the minimum temperature drops below 17 °C, using a factor that decreases from one to zero as minimum temperature falls from 17 to 9 °C. This effect has greatest impact at Kingaroy. Genetic variation in tolerance to low minimum temperature may thus be advantageous in this region.

Biomass accumulation also depends on the amount of radiation intercepted, which is determined by leaf area index (LAI). We used data on peanut branching patterns and on the response of node and branch appearance to temperature to derive a simple algorithm to predict leaf area production. At this stage, environmentally-induced changes in branching pattern and the effects of plant density have not been incorporated. The functions were derived from data collected in crops growing at densities of 8–12 plants/m^2. Our data indicated that, on average, effective leaf area production ceased at 1000 °C d after sowing.

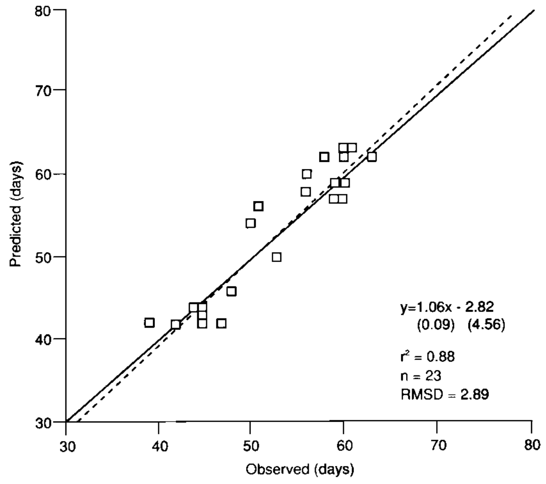

Figure 4. Predicted against observed number of days to onset of HI increase for peanut cultivar 'Early Bunch'. Numbers in brackets beneath regression coefficients are their standard errors.

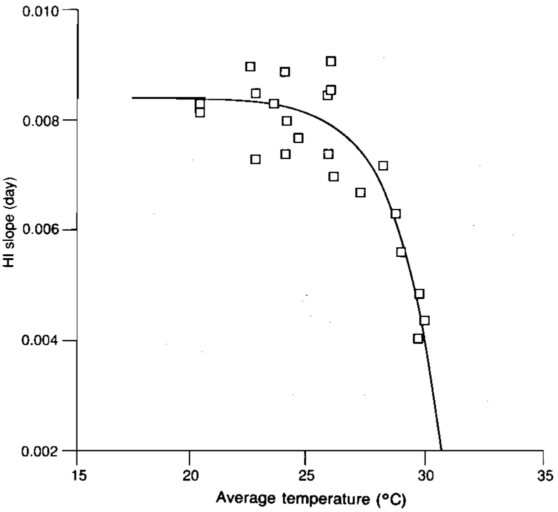

Figure 5. Slope of harvest index (HI) increase against average temperature from sowing to onset of HI increase for peanut cultivar Early Bunch.

Table 1. Number of observations and average thermal time from onset of harvest index increase to maturity for three geographical groups for peanut cultivar Early Bunch.

Group	No.	Thermal time (°C d)
North-west Australia	6	1587
East Australia and Florida	9	1094
Indonesia	2	782

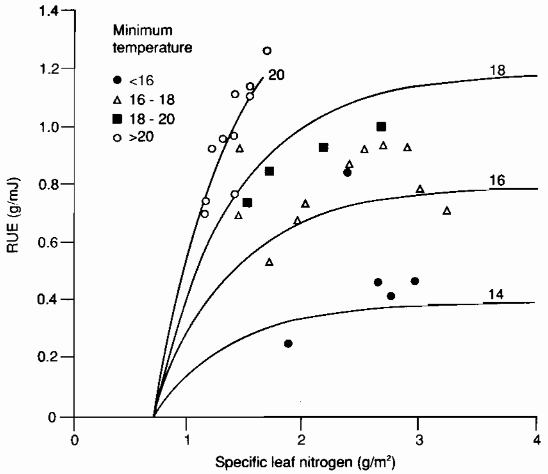

Figure 6. Radiation use efficiency (RUE) against specific leaf nitrogen and minimum temperature for a non-nodulating peanut cultivar.

The comparison of simulated and observed pod yields for the data sets on Early Bunch showed good fit except for the two Indonesian experiments (Fig. 7). Yield was substantially overpredicted for those two experiments. This was related to overprediction of HI. In the experiments, HI ceased to increase once it reached about 0.3, whereas in all other data sets HI continued to increase towards the maximum HI (i.e. 0.55) throughout the maturation period. There was no immediate explanation for this finding.

During 1991 water stress effects on leaf area development and RUE were incorporated and the model tested on independent data from experiments conducted at a range of locations in northern Australia. The functions simulating water stress effects were taken directly from the Sinclair soybean model. The pot experiment required to derive these functions for peanut is underway at Kingaroy. The model performed well on the independent data (Fig. 8) but hopefully will improve with further effort on modelling the water balance and stress effects.

Coefficients for other genotypes were determined from the available data. For cultivar Tapir there were five experimental data sets (four in Indonesia, one in Australia). The average HI slope was 0.0085/d, which was similar to that for Early Bunch. The average thermal time to onset of HI increase was 677 °C d and average thermal time to end of leaf growth was 900 °C d, which were both lower than for Early Bunch (837 and 1000 °C d, respectively). For the sites in Indonesia, average thermal time from onset of HI increase to maturity was 919 °C d, which was greater than for Early Bunch (782 °C d), but significantly less than the thermal time required at the single Australian experiment (1423 °C d).

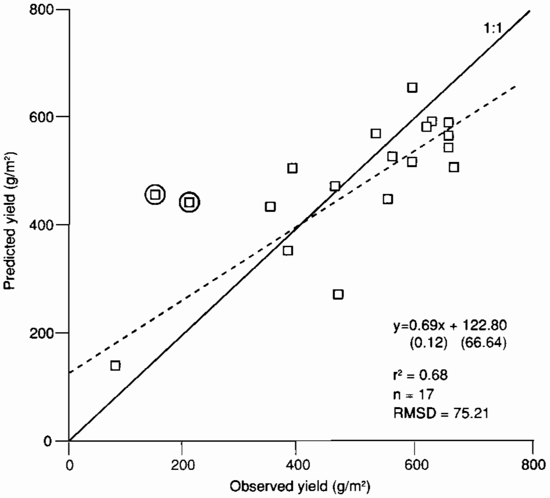

Figure 7. Predicted against observed pod yields for cultivar Early Bunch. The two circled points are for the two experiments in Indonesia excluded from the regression.

These coefficients were used to simulate the experiment conducted with Tapir at Muneng in 1990. The experiment was grown at a density of 25 plants/m^2, so no attempt was made to simulate LAI as density effects were not incorporated in the model. We did not simulate the dryland treatment as data on available soil moisture at planting to potential rooting depth in the soil profile were not available. Biomass and yield of the irrigated treatment were simulated well until the final stages of the crop were reached (Fig. 9). HI ceased to increase at about 0.25. This was similar to the finding with cultivar Early Bunch for experiments at Jambegede. These genotypes have the capacity to achieve higher levels of HI, but are not expressing this capacity in Indonesia.

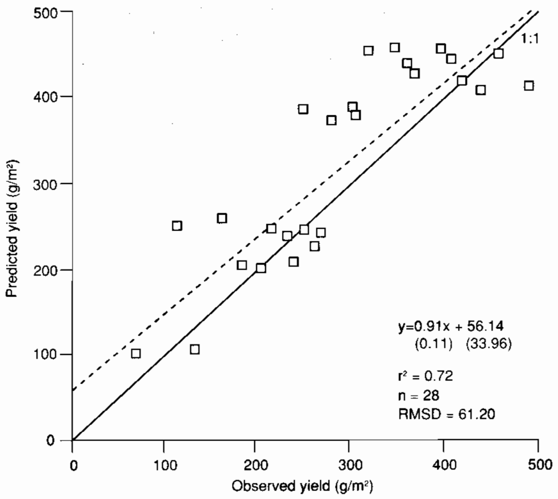

Figure 8. Comparison of observed and predicted pod yields for peanut grown at a range of locations in northern Australia (P. Poulton, pers. comm.).

Quantifying environmental constraints

We have conducted a number of simulation studies using the model to quantify environmental constraints and examine the impact of targeted genetic modification.

The value of low temperature tolerance for RUE at Kingaroy was examined by simulating a hypothetical tolerant cultivar and comparing it with the standard (Early Bunch). In the standard cultivar RUE declines linearly from 1.0 to 0.0 g/MJ as minimum temperature declines from 17 to 9 °C. Low temperature tolerance was simulated by lowering the temperature threshholds by 2 °C. For a standard planting date at Kingaroy, the simulation showed that this degree of tolerance could increase biomass production and pod yield for an irrigated crop by about 10% (Fig. 10).

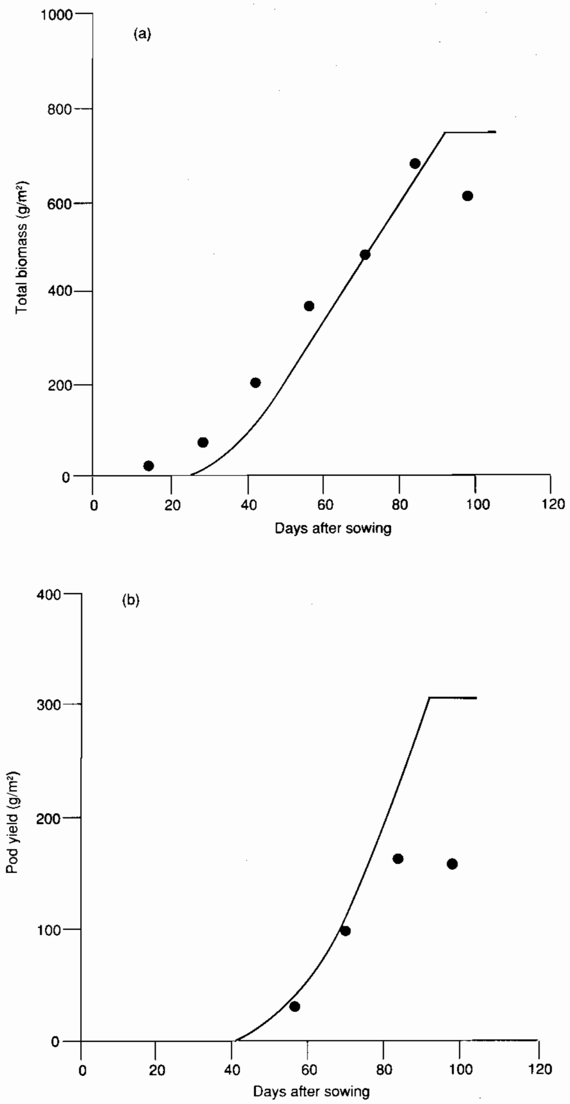

Figure 9. Observed (points) and simulated (lines) (a) total biomass and (b) pod yield against days after sowing for the irrigated treatment of the Meneng experiment.

Under dryland conditions at Kingaroy, it is possible that cultivars maturing earlier than those currently used may be better suited to the environment because water limitation is a key feature in peanut production at this location. We simulated pod yields for a cultivar of standard maturity (Virginia Bunch) and a hypothetical early-maturing type, which we assumed required 20% less thermal time than the standard for the period from sowing to maturity. Yields were simulated for each of the 85 years of rainfall record, assuming the crops were planted each year on 15 November into a fully wet soil holding 180 mm of available water in the potential rooting zone (i.e. to a depth of 200 cm). The sequences of simulated yields were used to calculate the probability of exceeding any given yield level (Fig. 11). A yield of 150 g/m^2 was exceeded in 85% of years with the early-maturing type, compared with only 45% of years for the standard. That is, there was less risk of obtaining very low yields with the early-maturing type. However, the standard type had the capacity to achieve yields of 350 g/m^2 or more in about 20% of years, whereas the early type had a yield potential of only 235 g/m^2. Hence the comparative performance of early and standard types

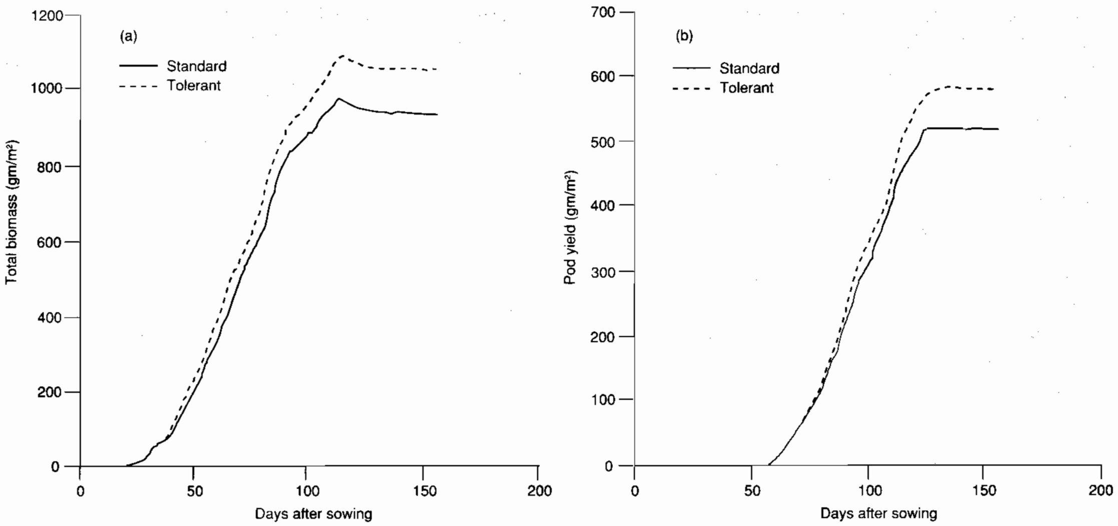

Figure 10. Simulated (a) total biomass and (b) pod yield against days after sowing for standard and hypothetical low temperature tolerant cultivars under irrigated conditions at Kingaroy.

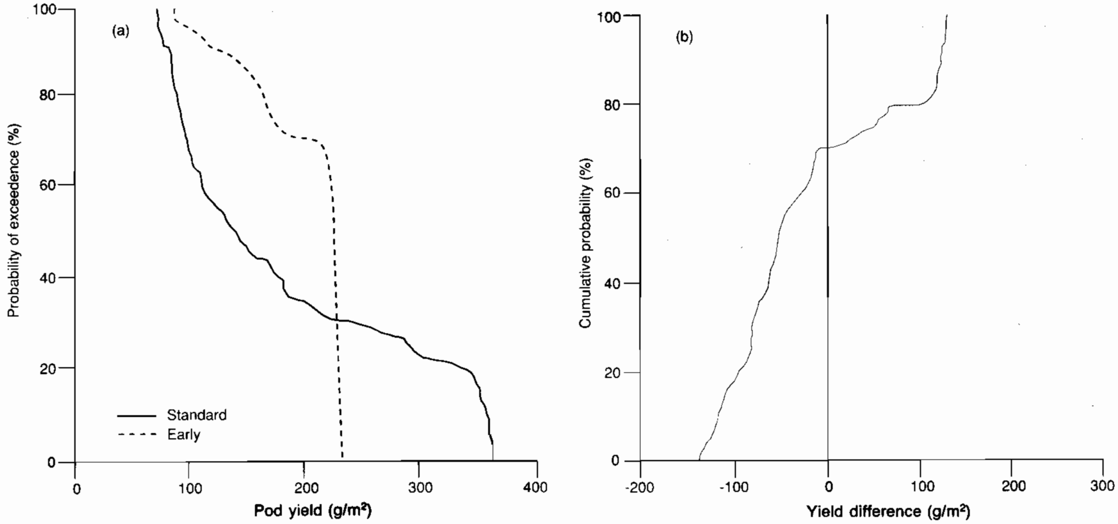

Figure 11. Comparison of simulated pod yields for standard and hypothetical early maturing cultivars at Kingaroy (a) probability of exceedence against pod yield, and (b) cumulative probability against yield difference between types (standard and early).

depends on the type of season. As the early type outyielded the standard in 70% of years (Fig. 11) it seems generally better suited to this environment, but this must be weighed against the potentially higher yields that would be foregone in the other 30% of years if only the early-maturing type was planted.

In Indonesia, we simulated the impact of ability to express high HI for cultivar Tapir. To simulate the standard situation for this cultivar in Indonesia we set maximum HI to 0.3 and thermal time from onset of HI increase to maturity to 919 °C d. For the hypothetical 'High HI' cultivar we set maximum HI to 0.55 and thermal time from onset of HI increase to maturity to 1200 °C d, which was based on the 40% extra time measured for duration of this phase at sites where HI potential was expressed (Table 1). In high HI situations, we observed very low radiation use efficiency (RUE) late in the season, presumably associated with nitrogen depletion of leaves. This was simulated by setting RUE to zero once HI had reached 0.45. In the low HI situation in Indonesia, the RUE cutoff was applied once HI reached its maximum value of 0.3. The comparative performance of the standard and 'high HI' types for an example simulation is shown in Figure 12. There are large increases in total biomass and pod yield associated with the ability to express high harvest index.

Using the coefficients for the standard and hypothetical 'high HI' types, we simulated impact of ability to express high HI for a range of planting times in the post-rice dry season crop (March to June) and the wet season crop (November to December) for a single year at Jambegede. We were restricted to a single year at a single site because daily weather records for longer periods at other locations were largely missing or inaccurate, especially for radiation. Crops of cultivar Tapir were simulated for planting dates on the 15th of each of March, April, May, June, November, and December. It was assumed that the soil profile was fully wet at planting and held 210 mm of available water to the potential rooting depth (200 cm). Crops were simulated for fully irrigated and dryland conditions.

For the standard cultivar, pod yields under irrigated conditions varied little among planting dates and were always near 150 g/m^2 (Fig. 13). Under dryland conditions, yield was reduced for sowing in May and June. This reflects the increasing impact of water limitation with plantings later in the dry season. The timing of this decline will depend on rainfall distribution at a location.

Under irrigated conditions, pod yields were increased two- to three-fold when the HI limitation was released (Fig. 13). Yields increased slightly with later sowing in the dry season, reflecting the more favourable radiation and temperature environment later in the season and the ability of this type to capture the potential under irrigation. Yields were lower for wet season crops. Under dryland conditions, yields for the dry season crops were lower, especially for sowings in April, May and June. The high HI type still clearly outyielded the standard for a March sowing and for the wet season sowings. This indicates that lack of water limited the expression of the additional potential only in the sowings later in the dry season.

Implications for Peanut Production and Future Research in Indonesia

Although the peanut model requires further work on a number of aspects not yet dealt with adequately (e.g. water relations, plant density, nitrogen), we consider that we have satisfied the objectives of this part

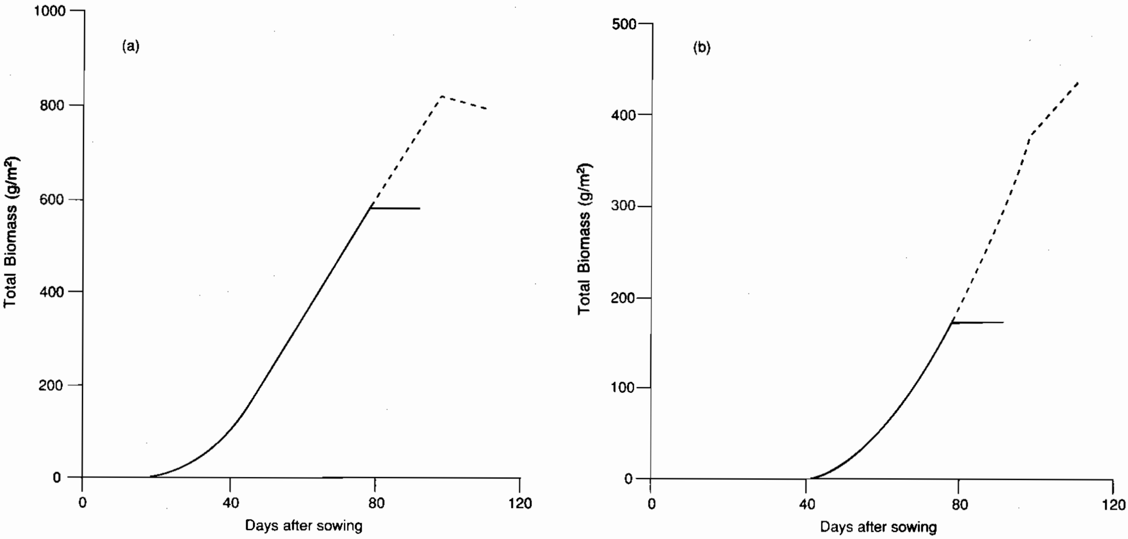

Figure 12. Simulated (a) total biomass and (b) pod yield for standard (solid line) and hypothetical 'high harvest index' (broken line) cultivars for an irrigated crop planted in June at Muneng.

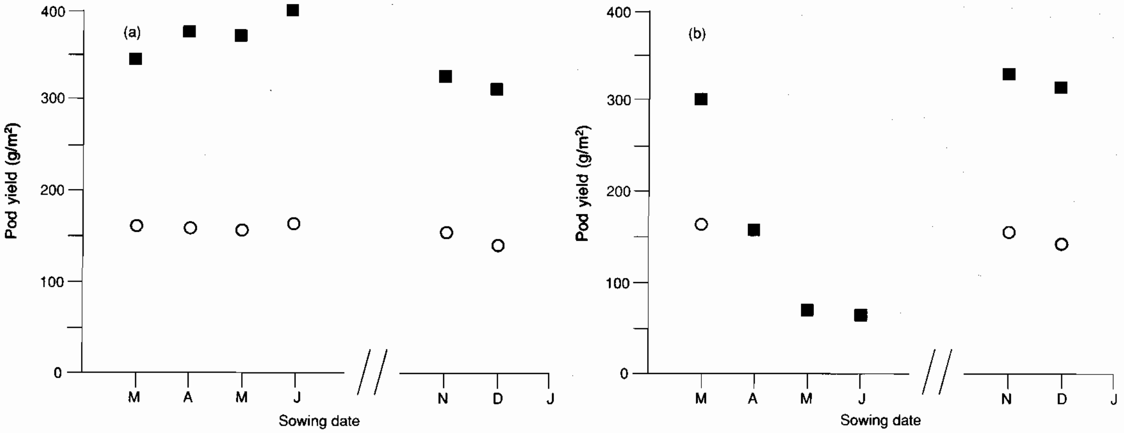

Figure 13. Simulated pod yields for standard (○) and hypothetical (■) 'high harvest index' cultivars for a range of sowing dates for (a) irrigated and (b) dryland crops at Jambegede.

of the project to the extent possible now. A number of implications for Indonesia and Australia can be drawn from the work to date.

In Australia, our analyses imply that minimum temperature limitations on RUE restrict potential yield. At Kingaroy, an increase in tolerance of 2 °C was associated with 10% increase in potential yield. The sensitivity of the yield increase to degree of tolerance to minimum temperature, and whether this trait retains its value under dryland conditions, could be the subject of more detailed simulation analyses to assess more thoroughly the value of such a trait. Such analyses would provide a sound basis for determining the utility of effort in targeting selection and breeding on such a trait.

Our analyses in Australia also suggest that using earlier-maturing cultivars at Kingaroy lowers the risk of obtaining low yields. However, it also reduces the yield potential in favourable seasons, so the strategy to adopt would depend on a manager's attitude to risk. Planting a mix of maturity types on the available cropping area could be considered to buffer the positive and negative consequences associated with each type. There is some potential to explore a flexible strategy based on varying the area planted to different maturity types depending on seasonal climate forecasts derived from the state of the El Niño Southern Oscillation (ENSO) phenomenon, as summer rainfall in north-eastern Australia is related to ENSO. Further analyses of this nature would determine the potential for improvements in practice based on these concepts.

In Indonesia, our lack of good quality climate data hindered the simulation analyses. It is imperative for interpretative studies that such data is collected and quality control installed. Without this, much of the effort put into field experimentation is wasted. Nonetheless, the simulation studies clearly demonstrate the huge productivity losses associated with the inability of peanut to express its HI potential in this environment. It remains, though, to determine the causes for the low HI and what, if anything, can be done about it.

A plausible hypothesis for the cause of low HI in Indonesia is that the balance between growth and development causes a reduced pod load. In Indonesia, the ratio of radiation to temperature is lower than at other locations. Radiation levels and hence daily crop growth rates are low, and temperature is high and near the optimum for rate of development. Hence fewer pods are set as there is less assimilate available per unit of development. Each potential pod site requires a minimal amount of assimilate to initiate but there is insufficient available to satisfy the demand associated with the temperature-driven rate of development of pod sites. Hence many pod sites are not initiated before the crop progresses beyond the pod initiation phase. This hypothesis is consistent with observations in shading experiments, as some genotypes reduce pod load under shaded treatments. It is also consistent with the observation that rate of HI increase is not affected in Indonesia, but the increase terminates prematurely (e.g. Fig. 9).

It is also plausible that the number of potential pod sites is reduced in Indonesia. Branching is likely to be reduced as insufficient surplus assimilate is available to initiate branch axes because of the imbalance between radiation and temperature. This causes plants to be smaller and, hence, reduces the number of potential pod sites. Observations on density responses in Indonesia are consistent with this concept. However, the reduction in branching is not fully compensated for by increased density. The shorter duration of the pod maturation period in

Indonesia (Table 1) may be caused by this lack of pod sites.

It is possible that cultivars capable of expressing the HI potential of peanut in Indonesia could be selected. Some cultivars were less sensitive to reduced radiation than others in the shading experiments. Also, if our hypothesis on the physiological basis for low HI in Indonesia is valid, then slowing the development rate better to match the growth rate is a plausible means of intervention. Further research is required to test the hypothesis, but it is also appropriate to screen genotypes for HI in Indonesia, because the potential for improvement is huge.

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