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Food Legume Improvement for Asian Farming Systems

Proceedings of an international workshop held in Khon Kaen, Thailand, 1–5 September 1986

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Contents

Foreword

LEGUME crops play a particularly important role in Asia, both in the nutrition of humans and animals and as a component of farming systems of the region. Despite this, the production of food legumes in many Asian countries is stable or declining, unlike the situation with many cereal crops. The reasons for this failure of food legume production to expand in response to apparent demand are complex and poorly understood.

The accomplishment of increased food legume production is of vital importance to most countries in the Asian region. Therefore the theme of the Workshop held at Khon Kaen was an analysis of the limitations to productivity and adaptation of food legumes in the farming systems of Asia. The intention was to avoid being crop-specific, country-specific or discipline-specific, and to take an integrated view of the factors limiting food legume production in Asian farming systems.

The Workshop was sponsored by the Australian Centre for International Agricultural Research (ACIAR), the Thai Department of Agriculture and Khon Kaen University, and was organised by a committee with representation from Thailand, Indonesia, Philippines and Australia as well as ICRISAT, AVRDC, IRRI, NifTAL and FAO. Over 300 scientists from 18 countries and nine international agencies attended.

The Workshop program comprised 16 invited papers and 148 short communications, forming an important compendium of the major limitations to production, improvement and use of the legume crops in Asia. The Workshop culminated in a series of recommendations which will provide a useful guide to the identification and resolution of these limitations, both by research and through policy change, at the international, national and local levels.

ACIAR would like to thank the members of the Organising Committee for their efforts in the organisation and conduct of the Workshop. Thanks are also due to Mrs Janet Lawrence and Mr Brian Lee of ACIAR for editorial direction and preparation of the proceedings. Many others who contributed to the success of the Workshop are acknowledged separately.

J.R. McWilliam
Director,
ACIAR

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The Workshop — an Overview

D.E. Byth, E.S. Wallis and I.M. Wood

Scientific workshops, to be effective, involve detailed planning and management by the organisers and active participation by the delegates. They are expensive activities, in terms of the time of those involved, their transport and accommodation, and the costs of publication. Consequently clear objectives need to be enunciated and pursued at such workshops in order to gain appropriate benefit from the investment.

This Workshop was structured around the premise that a major change in approach is necessary if the potential of the food legumes in Asian farming systems is to be realised. The Organising Committee proposed for consideration at the Workshop a philosophy of crop improvement based on an integrated multidisciplinary approach to the identification and resolution of primary limits to productivity and adaptation.

This chapter is designed to review the Workshop, to assess the degree of acceptance of this philosophy of crop improvement, and to summarise the views of delegates regarding the limits to production of food legumes in Asian farming systems. Research and extension needs and strategies required for their resolution are also considered.

Genesis and Nature of the Workshop

Food legumes are an important component of the farming systems of Asia, both ecologically and in terms of human and animal nutrition. At least 18 species are considered important at various locations throughout the region, and they differ markedly in their agronomic traits, cultural needs, uses and roles in the farming systems. As a result, the food legume crops present special difficulties in the planning and organisation of structured improvement programs.

Furthermore, the food legumes currently are considered secondary to the cereal crops. They are perceived to be lower yielding, less responsive to inputs, more variable in production from season to season, and to involve a higher risk of crop failure than the cereals. Partially as a result of these perceptions, the cereals generally are grown as main crops under the most favourable conditions and management, while the food legumes tend to be relegated to more marginal soils and production environments, generally with limited management and no inputs of fertiliser, irrigation and crop protection. It is hardly surprising, then, that despite the relatively high yield potential known to exist for some food legumes, average on-farm yields are low and there are numerous limitations to the attainment of improved productivity.

This Workshop was conceived as a forum to discuss these problems. The basic objective was to provide guidelines for development of a research methodology through which increased production of the food legumes in Asia could be achieved.

The Organising Committee, which convened for the first time in Khon Kaen in early 1985, included representatives of national research institutions from four countries in the region (Australia, Indonesia, Philippines and Thailand) and from six international agencies (ACIAR, AVRDC, FAO, ICRISAT, IRRI and NifTAL). All the organisations represented shared a common interest in food legumes in the region.

The Committee deliberately avoided a narrow species-specific, discipline-specific or country-specific format. It adopted an integrated approach, centred on crop improvement, through which the primary limits to production, productivity and adaptation of food legumes in Asian farming systems would be identified and characterised. A series of recommendations to guide future activity and research into resolution of those limits was planned as the logical outcome of the Workshop.

A format was developed to address this basic theme in a number of ways: first, invited papers were commissioned to review the role of the crop legumes in Asian farming systems and the major limits to their production, improvement and use; secondly, contributed papers were requested to address the major limits and aspects of food legumes in particular production systems; thirdly, a poster session was scheduled to encompass the 'Research, Training and Publication' activities of various institutions in the region; fourthly, a field tour of the region around Khon Kaen was designed to enable observation of some regional limitations to crop legume improvement and inspection of aspects of research aimed at their resolution; and fifthly, the Workshop culminated in concurrent forum sessions at which major issues and potential resolutions were discussed. Finally, these proceedings were to be published as a record of the Workshop with the intention that they would provide a useful contribution to knowledge of the food legumes and an authoritative guide on the future needs for research, development and extension.

The Organising Committee was eager to encourage active participation and contribution by all delegates, and to centre this on overall crop improvement. The Forum sessions were designed to generate interactive contribution on the importance, impact and resolution of various limits within each of a comprehensive set of subject areas: social/economic/political/extension; markets/quality/utilisation; climate and soil; biotic; crop improvement; new crops; information base; research planning.

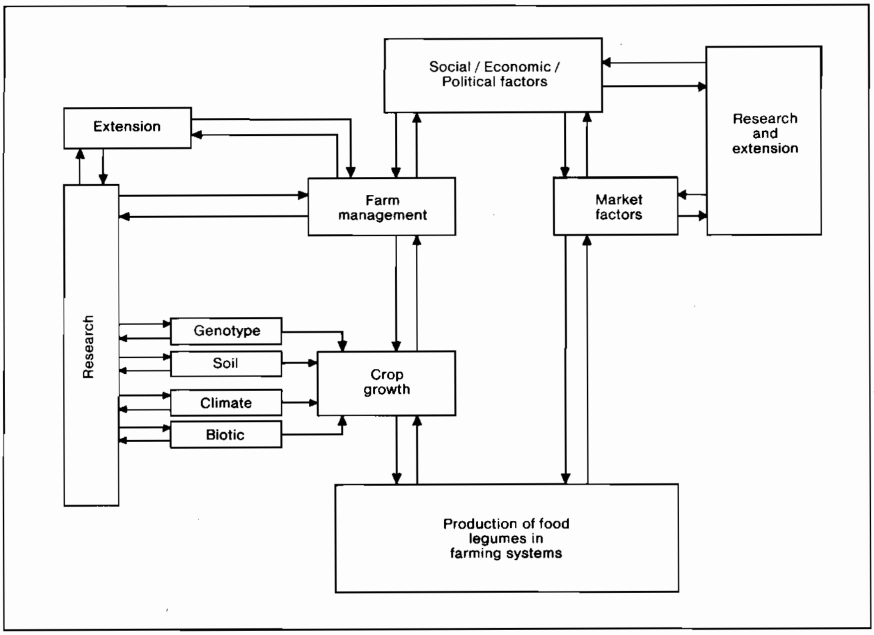

Fig. 1. Major factors and interactions in the production systems for crops.

There was active discussion in the forum sessions of crop improvement in the context of these factors and their interactions (Fig. 1). Aspects of these discussions are reported in later sections.

Despite the full and exhausting program, there was active participation by delegates of all disciplinary backgrounds. The integrative theme of crop improvement did enable a multidisciplinary approach by delegates, although a more narrow disciplinary focus occasionally was necessary.

Crop Improvement — a Viable Focus?

The Organising Committee adopted 'crop improvement' as the central theme or focus for the Workshop because it epitomises the objectives of all discipline-based research programs which seek to improve the productivity of particular crops in farming systems, and therefore unifies the various disciplines.

The concept of an integrated multidisciplinary crop improvement program is essentially an application of systems analysis. This has been applied widely in industry and commerce but, to date, has rarely been used in agricultural research. This concept of crop improvement explicitly includes the interaction of social, political, economic, physical and biological factors that limit production. The limits that exist may vary in relative importance in different crops and farming systems, and the research strategy adopted needs to take this into account.

This does not necessarily infer establishment of a 'crash program' concentrated narrowly and in a consequentive manner on individual limitations in order of priority. Rather, the research strategy should focus on resolution of the primary limit(s). Research into other, less fundamental problems may be included in the strategy but should be predicated on the absence (through appropriate resolution) of the primary limit(s).

Thus this approach is designed to focus on the potential productivity of a crop in a particular farming system. Limitations to achieving this potential can then be addressed in a systematic framework. The adoption of a philosophical approach to research centred on crop improvement should ensure that real needs are addressed, and that the potential dangers of a narrowly-based disciplinary approach are avoided while exploiting its strengths and contributions as appropriate. This concept of plant improvement inevitably leads to consideration of the farming system as a whole and we contend that all research should be conducted in the context of the farming system of interest. However a distinction is drawn between 'farming systems research' and integrated research which addresses the needs of the crop within the numerous and complex farming systems used by farmers. The latter has particular relevance to the highly diverse usages of food legumes in farming systems throughout Asia.

There was considerable discussion of this approach at the Workshop. While there was essentially universal agreement that increased use of multidisciplinary teams of scientists would contribute to the resolution of the limitations to production of food legumes, particular difficulties were seen in the implementation and management of such an approach. Aspects of this are discussed in later sections.

Food Legumes — 'Slow Runners' Forever?

The past twenty years have seen a dramatic increase in cereal production in Asia. Self-sufficiency is becoming accepted as the long-term norm in several countries of the region (e.g. India, Indonesia and Thailand). In marked contrast, the production of crop legumes has been stagnant or declining, and in general they continue to justify the title of 'slow runners' conferred on them by Borlaug in 1973.

This Workshop has contributed in a number of ways towards changing this situation. The matters on which there was consensus among delegates, together with those on which there were differences of opinion, are discussed in the following sections.

Irrigated vs Dryland Farming Systems

Two plenary forum sessions were planned to address separately the needs of food legumes within irrigated and dryland (rainfed) farming systems which was originally perceived as a logical and distinct dichotomy. Subsequently, this division was seen to be somewhat artificial, in that a continuum of agricultural systems ranging between these extremes exists in practice. Furthermore, with very few specific exceptions, there were no clear differences in the research strategy appropriate to these situations. Consequently, while two Forum sessions were conducted because of the large number of participants, both addressed the general topic of limitations to production, improvement and use of food legumes in Asian farming systems.

Production vs Productivity

Clear distinctions were drawn between the concepts of production and productivity of crops produced in a district, country or region.

Production is the total amount of crop produced, and this is influenced by many factors in addition to the physical and biological factors prevailing in a particular system. Government policy, socioeconomic factors in the society, and supply and demand all interact to determine the level of production of a commodity in a particular area.

By contrast, productivity is the production per unit area of land. While the objective of each farmer regarding productivity is influenced by socioeconomic and policy factors, physical and biological factors are the fundamental determinants of the productivity within particular farming systems. An overriding factor in the productivity of a food legume crop is the extent of the adaptation of that crop to that particular location and system.

Production may be increased by either expansion of culture of that crop into new areas or new applications, or by improvement in productivity, or both. In most areas of Asia there are only limited prospects for expansion of arable farming, so that in general increased production of food legumes must arise either from intensification of production or substitution for other crops. Such changes will be predicated largely on relative income from, and perception of risk associated with, the different options within the farming system. Change may be influenced by development of appropriate technology, and by policy decisions involving production incentives.

Thus while increased production of food legumes may be the ultimate objective, methods of attaining this are complex and diverse. Some aspects influencing the achievement of increased production are discussed in later sections.

Socioeconomic Factors — Overriding Influence?

Information presented to the Workshop clearly indicated that government policies in the Asian region generally favour increasing production of cereal grains. These policies reflect the importance of the cereal grains in human nutrition, and have been highly successful in certain countries which are now either self-sufficient or even net exporters of cereal grains. Commonly, the policy is to support cereal production via subsidies on inputs, price support schemes and other incentives aimed at increasing local production. Cereal growers also may have favoured access to credit facilities, which again fosters cereal production. In many cases the most experienced and talented research scientists are attracted to the major cereal crops by a perception of improved career prospects.

Despite their importance in human and animal nutrition, and to the stability of farming systems, food legumes have not received the support afforded to cereal production in Asia. The fostering of cereal production, together with many other factors, has led to the situation in which food legumes are regarded as secondary crops, which further discriminates against their development and improvement.

Numerous factors influence the decision by an individual farmer to adopt a particular farming system and cropping strategy. These include assessment of profitability and risk, as well as sociological factors. Policies similar to those developed for the cereal grains may be effective in stimulating local production. However costs of production in Asia are relatively high, and prices of some major food legumes, such as soybean and peanut, are relatively low because they are dictated by world supply and demand. Thus, price support and incentive schemes are unlikely to be viable in Asia unless productivity can be increased, costs of production reduced, or both.

In some Asian countries, food legumes are now receiving higher priority in national development and research as a result of the attainment of self-sufficiency in cereal grains. Diversification of programs of research and development away from the cereals and to the food legumes is a logical response to the large imports of food legumes for human food and animal feed uses. However the viability of such a program of diversification requires demonstration to planners, researchers and farmers that food legumes can respond profitably to inputs and improved management.

Private industry may have a significant future role in the processing and manufacture of human food and animal feed products from food legumes. The diversity of traditional end-uses for legumes in Asia was seen as a positive factor encouraging increased interest in, and production of, these crops.

It is apparent that a complex of socioeconomic and technical factors has interacted to constrain food legume production despite the increasing demand for vegetable protein sources in most Asian countries and despite clear demonstration of the capability to increase production of other crops in those countries. There is a common perception that food legumes are inherently low yielding, high risk crops, and this perception is central to the problem of stagnant production. Indeed, the problem is somewhat centripetal and reflects a fundamental gap in communication between planners, research and extension workers, and farmers. Policies and programs which address the primary constraints to production are necessary. In this context, it is significant that research has demonstrated that many food legumes traditional to or with potential in Asian countries have very high yield potential under favourable management. While this suggests that a major increase in food legume production is possible through modification of farming systems, positive policies and programs to encourage this are necessary.

Markets/Quality/Utilisation and New Crops

Discussion on these topics provided an interesting insight into country attitudes. In general, scientists from those countries actively involved in the export of the food legumes well appreciated the difficulties of developing and maintaining export markets, and the problems of meeting the often stringent quality requirements of the importing countries: for example, sprouting quality in mungbeans. By contrast, scientists from countries in which food legumes are grown and consumed locally tended to consider that questions of quality, market specifications and utilisation were secondary to the problems of production. While this dichotomy of attitude to quality is understood, the point needs to be made that if the quality problem involves a toxic principle, such as aflatoxin in peanuts, which can adversely affect human health, it needs to be addressed and resolved irrespective of whether the product is being exported or consumed locally. Equally, while high product quality may open markets which offer a high economic return, failure to attain that quality forces reversion to alternative uses of lower value. An effective understanding of market implications is inseparable from proper definition of the factors limiting the role of food legumes within farming systems.

The organisers hoped that this Workshop would be a catalyst for increased research and development leading to greater production of the food legumes. However a consequence of any substantial increase in production would be a surplus in some countries, creating the need to develop new local uses and/or export markets for the seed. A number of speakers stressed the need for research and development programs on food legumes to embrace market and quality studies to ensure that plant improvement programs take cognizance of special market requirements. In this respect the food legumes pose particular difficulties because of the diversity of their end-use and the differing consumer preferences for taste, colour, cooking time, size, texture, etc. In general, quality becomes more important as the usage moves from local to national to international markets. International competition is such that strict quality standards and continuity of supply are necessary. It is particularly important during times of oversupply that an exporter have some margin of quality over competing products.

Diversification of end-use was seen as an important way of utilising increased production of the food legumes. Substitution of an imported product with a local product may appear particularly attractive at a time when many Asian countries are experiencing foreign exchange problems. Several examples were cited, including substitution of pigeonpea for soybean in tempe production in Indonesia and the possible use of pigeonpea for animal (particularly chicken) feeds in Thailand.

The introduction of 'new' food legume crops involves an additional dimension of problems. While the crop may be 'new' in that country or area, it may simply involve a different application of an existing crop. Where the demand for that food legume arises from the development of 'new' markets, a policy and research/extension infrastructure appropriate to that need is likely to be implemented. Conversely, new developments in production technology are unlikely to be adopted by farmers unless viable markets for the product also are established.

Several strategies were suggested to encourage food legume usage and meet the needs for research on quality. These included:

- national efforts to improve the acceptability and quality of traditional products made from food legumes;
- establishment of national programs to assess and develop the potential of food legumes new to an area, and to develop new products from currently grown food legumes;
- close collaboration between processing technologists and those responsible for the research and development programs on food legume production. This collaboration was deemed necessary from the outset of the production program.

Research Strategy

The question of an appropriate research strategy for food legume crop improvement evoked some of the most spirited discussion of the Workshop. Aspects of this discussion are reported in the following sections.

PHILOSOPHY OF RESEARCH

Two apparently conflicting strategies were proposed. The first, dubbed the 'crop potential strategy', advocates an approach to crop improvement based on the initial determination of the yield potential of that crop species within the particular production system. Following the identification of the primary limitations to production, research is directed appropriately to develop genotypes and cultural practices which permit a step-wise approach to the known crop potential in that production system.

The second strategy, dubbed the 'farmer's field strategy', is directed to improve productivity by overcoming in turn the various limitations to yield identified in the farmer's field.

The 'crop potential strategy' was considered by some delegates to typify the approach by some international and national institutes in that research is directed at breeding and agronomic manipulations designed to attain near-maximum yields. This will often involve extensive cultivation to assist crop establishment, supplementary irrigation, appropriate fertilisation and control of weeds, pests and disease. A number of Asian scientists expressed the strong belief that the results of such carefully manicured research are unlikely to be relevant to the typical Asian farm situation, where food legume production currently is typified by poorly prepared seed beds, low seed quality, poor establishment, moisture stress, inadequate weed control, little or no fertiliser application, and no pest control.

The advocates of the 'farmer's field strategy' claim that it is unlikely that the typical Asian legume farmer will ever be able to afford significant inputs of agricultural chemicals or achieve high standards of land preparation. Therefore, they advocate the development of low-cost improvements to cultural practices and the development of genotypes which give the highest and most reliable yields under suboptimal growing conditions. By contrast, the advocates of the 'crop potential strategy' considered that it is only by determining the potential productivity of the environment that the effects of particular constraints and management inputs can be quantified. That knowledge can then be used as a rational basis by the farmer, research and extension workers, and the policy makers to define appropriate production systems and research programs. In the absence of a basic understanding of the potential of the crop for yield, and of the economic cost of various manipulations, objective decision-making by all parties is impossible. Given the high value of food legumes in Asian markets, relatively modest improvements in yield through the use of improved technology and management may greatly affect the economics of their production.

We have considered the arguments presented at the Workshop for these two strategies. While they appear to be basically in conflict, they are in fact not mutually exclusive. Indeed, much of the disagreement between the opposing advocates arises from misunderstanding of the basic objectives of the strategies, and of their implications. The 'crop potential strategy' does not necesarily advocate a high input–high output farming system. Rather, it is simply a strategy through which the potential of an environment for productivity can be demonstrated and its particular constraints quantified, so that a range of applications for that crop in alternative farming systems can be defined. Central to this philosophy is the belief that a proper understanding of the factors influencing crop growth and development will enable more objective decisions by the farmer and by researchers, and permit effective extrapolation of such understanding across a range of production environments.

The ultimate success of any crop improvement program is determined by results at the farm level. The evidence from other crops is that Asian farmers have been prepared to invest in inputs if appropriate incentives and policies exist. Thus the farm constitutes a dynamic production environment and the research strategy must accommodate and anticipate changes in production practices. While there can be genuine concern that genotypes developed under the 'crop potential strategy' may not perform well under the current typically low-input conditions, there must be equal concern that selection under the 'farmer's field strategy' will fail to identify genotypes able to respond to conditions of high potential productivity.

A further difficulty in reconciling the two strategies is that their implementation tends to involve different time frames. The 'crop potential strategy' is basically 'strategic' or long-term in its approach, while by contrast, the 'farmer's field strategy' is largely 'tactical' or short-term. Scientists operating at the local level commonly are under pressure to provide a rapid identification of constraints and to develop solutions appropriate to those contraints in that situation. It is to be expected that research for resolution of immediate local needs may differ substantially from that required to address problems of more general consequence at the national or international level.

Thus we consider that these two philosophies of research strategy are compatible and complementary, forming a continuum in the overall process of crop improvement. It is essential to establish the genetic potential of genotypes in particular environments and farming systems in order to identify and quantify the effects of particular inputs in management and to define genetic constraints. However it is equally necessary to evaluate the genetic material and proposed cultural practices in a wide range of conditions typical of current and potential farmers' fields.

Research resources are limited, and there is a need for a strategy which is sufficiently flexible to meet the needs of both the low- and high-input systems. In general for most food legumes, the genetic potential for seed yield is substantially greater than that now attained by most farmers. Consequently the specific requirements for improvement of productivity within traditional farming systems may be quite different from those arising from intensification of production. Strategies of improvement must reflect the overall policies for development, and a phased program of improvement may be appropriate. Thus it would be pointless to seek improvement in seed yield through quantitative breeding for low-input farming systems where yield is constrained by fundamental limitations such as disease and insect attack or moisture stress. Conversely, optimisation of response to fertilisation and irrigation may be highly appropriate research for intensive production systems.

Some objectives, such as improved disease and insect resistance and the ability to establish an effective symbiosis in acid soils, may be of more general importance across the entire range of farming systems. Thus a dichotomisation of research objectives into those which are largely independent of the production system (production system-neutral objectives) versus those which are dependent on the type of production system adopted (technology-dependent objectives) may assist in the development of an appropriate and flexible overall strategy of crop improvement.

Most production of food legumes in Asia occurs in traditional, low-input low-output systems, and research to improve productivity in these systems is necessary. However as with other crops, significant increases in the production of the food legumes are most likely to result from the adoption of improved technology and management. Restriction of the research strategy to traditional uses would effectively deny Asian farmers access to new technology for these crops, and permanently reduce their ability to compete with those elsewhere who adopt improved technology for their production. It would also stifle the continued development of these crops as crucial components of stable farming systems within Asia.

MULTIDISCIPLINARY TEAMS

It was recognised by delegates that unilateral contributions in particular disciplines could have major impact on productivity and adaptation of food legumes in particular situations. However there was general agreement that the growth and development of these crops is influenced by a complex of factors which differ in timing, duration and intensity between production environments. As a result, there was unanimous support for the concept of a multidisciplinary approach to crop improvement.

Delegates considered that a team approach requires careful and flexible management with strong leadership. Just as productivity is a function of the direct effects and interactions of many factors, the effectiveness of multidisciplinary research depends on the establishment of a coordinated framework relevant and responsive to the needs of the target production environment. An appropriate reward structure which ensures professional satisfaction was seen as vital to success. Achievements of the team should be reflected on all members, and individual contributions to the team should be recognised. The current professional reward systems in most Asian countries were considered to be biased towards individual contribution, rather than the accomplishment of overall objectives.

CENTRALISATION VS DEVOLUTION

The sheer number of legume crops and the diversity of their use within farming systems in Asia militates against the formation of teams for individual crops and/or farming systems. Resources are limited and must be carefully organised and managed to achieve the greatest impact.

The current research and extension infrastructure in the Asian region includes components from local, national, regional and international agencies. Each of these sectors was represented at the Workshop. The effectiveness of the overall investment in crop improvement depends on the accuracy with which primary limits are identified and addressed by staff of the individual agencies, and of the degree of effective collaboration between the agencies.

Duplication of research activity by different agencies can, on occasion, be creative. However, more generally, efficient use of resources dictates some allocation of responsibility for specific areas of work to individual groups, complemented by close interaction between the groups. A multi-institutional network of agencies with shared responsibilities in planning, research and extension is likely to lead to the more effective allocation and utilisation of resources.

In many cases, it may be appropriate to centralise the research on particular limits to production within one or more groups where that work can be conducted efficiently and adequately for the entire network. The responsible group may be at any level within the network. Many examples of this already exist, such as the establishment and maintenance by international or national agencies of germplasm collections which can be exploited by all research groups, and the fostering of exchange of information and genetic material through appropriate networks, workshops and conferences. Similarly, research by a national agency into a particular disease which is of economic importance only in a particular country or region may be an effective contribution to the entire infrastructure.

The guiding principle for establishment of such a multi-institutional network is that regional devolution of research is justified only when effective general models through which the results can be extrapolated to the environments are unavailable. Also, that research into problems of only local interest must be conducted in situ. Unnecessary duplication of research across agencies and sites can be avoided where effective general models to extrapolate results to a range of environments are available. In these instances a lead institute (be it national, regional or international) can conduct research relevant to the environment where a crop is grown. However there are other instances where research on problems of local importance must be done in situ.

A system of coordinated research networks may act as a model through which the diverse needs of the food legume crops can be addressed effectively with limited resources. The setting of the research priorities in these networks (which may range from local to international in character) should involve planners, research and extension workers and farmer representatives. The responsibilities of each organisation in the network must be identified at establishment of the collaboration. This must include the sharing of results.

In this context, it may be particularly appropriate to consider centralisation of research on those characteristics which are production-system-neutral i.e. which are of generalised impact and importance, and which relate to fundamental mechanisms and processes. Such characteristics may include resistance to major insects and diseases, mechanisms to attain improved water use efficiency, tolerance of acid soils, etc. Such programs must, however, be complemented by effective adaptive research and extension in order to maintain relevance and evaluate benefits.

This concept of interactive research networks and centralisation/devolution of research was discussed at length at the Workshop. While the potential benefits were recognised, particularly for the food legume crop complex, some delegates considered that sufficiently interactive networks were impractical. Others were concerned that, in practice, centralisation as a concept inevitably implied in-depth research only at major international or regional centres. We believe that the network concept is feasible and offers real promise for improving the efficiency and effectiveness of research in food legumes in Asian farming systems.

SELECTING TEST ENVIRONMENT

There was general acceptance by delegates that the ultimate objective of research must be to identify genetic differences or management options which will increase productivity in the farmer's field. However there was active debate regarding the nature of the environment appropriate for selection and testing, which may range from one involving a high level of management to the farmer's field. Aspects of this were discussed in an earlier section.

The environment used for selection and testing should emphasise the specific factor(s) under study by the scientist, and the discrimination among genotypes in that test should not be confounded by other environmental variables. Thus the environment appropriate for the test may vary greatly depending on the specific objective of the research, and is likely to involve the use of management inputs to avoid the effects of confounding factors and to reduce error. This may be particularly necessary in the selection phase. The fundamental purpose of selection and testing is to enable effective discrimination among alternatives, and this implies precise definition of the objective(s) and intervention by management as necessary in order to ensure that they are addressed efficiently. In some cases, this may be done most efficiently in totally artificial environments, such as screening for disease resistance in a glasshouse. For others, field testing is appropriate and necessary. Regardless, evaluation in the farmer's field ultimately is necessary to validate the relevance and effectiveness of the strategy of discrimination.

Information and Its Accessibility

Delegates agreed that the development and use of data bases was an important component of scientific agriculture and of agricultural research. This was particularly so for the improvement of production of food legumes because of the restricted infrastructure for their research, the relatively limited scientific knowledge of their production, improvement and use, and the complexity of their application within Asian farming systems.

Computer-based systems for data storage, retrieval and analysis are becoming increasingly available to scientists of the region. Delegates considered that the efficient use of such facilities in planning, research and extension was necessary and should be encouraged. This would constitute an important aid in communication among farmers, scientists and policy makers, and would contribute to the effectiveness of multi-institutional research/extension networks.

A need was perceived for increased activity in the development and use of dynamic production models in food legume improvement, in conjunction with the various data bases. The development of a capability to evaluate, via simulation, the implications of particular genetic modifications and management factors within specific farming systems was seen as particularly valuable. This, together with associated field experimentation, could contribute to more objective design of government policies and strategies of plant improvement for the region.

Conclusions and Recommendations

D.E. Byth, E.S. Wallis and I.M. Wood

RESPONSE of the delegates to the Workshop, and the interest shown by others since then, indicates that the Workshop was a successful scientific meeting. However, the Organising Committee had more fundamental objectives. The fact that production of food legumes in Asia is stagnant or declining despite an increasing demand for vegetable protein was considered to be symptomatic of a long-term problem in crop improvement, and a matter of serious concern. It was considered that major change was necessary if the potential and important role of food legumes in Asian farming systems was to be realised. With this in mind, the Workshop was structured around a theme of integrated food legume crop improvement through the identification and resolution of the primary limitations to productivity and adaptation.

The influence of the Workshop in this context remains to be determined. Accomplishment of increased production, improved productivity and wider adaptation of the array of food legumes grown in Asia is a long-term challenge which will require significant changes, in governmental policy and research strategy as well as in farm practice. While these are matters largely beyond the control of most delegates to the Workshop, we hope that the meeting will prove effective in crystallising the issues and in catalysing the actions required to implement the necessary changes. We have derived certain conclusions from the contributions to the Workshop and these, together with specific recommendations for action, are presented below.

• *This Workshop avoided specific crop, country/region or discipline emphasis.* Rather it centred upon improvement of food legumes in the farming systems of Asia by addressing the limitations to production, improvement and use of these crops. This approach required and encouraged delegates to concentrate their efforts on the central justification for their activities (crop improvement), to act as a multidisciplinary team to identify and characterise the primary limitations, and to identify strategies for their resolution through research and policy change.

Recommendation 1: that countries and organisations involved with production of and research into food legumes accept and foster the principle that an holistic approach to their improvement is necessary to achieve increased production. The approach requires close collaboration between all sectors involved in production, improvement and use of food legumes.

• *The establishment in many Asian countries of policies and mechanisms designed to stimulate cereal production has inadvertently inhibited productivity and production of food legumes.* The associated relegation of food legumes to the status of secondary crops grown in more marginal agricultural situations with limited management has reinforced the perception of these as low yielding, high risk crops, and has inhibited establishment of programs for their improvement. In fact, research has demonstrated that many food legumes have a high yield potential under favourable management. Fundamental change, including government policy and research/extension strategy as well as improved communication between policy makers, research/extension workers and farmers, is required to encourage their production.

Recommendation 2: that governments develop and adopt, as a matter of urgency, policies and strategies to encourage production of food legumes and research into their improvement and use.

• *Improvement of food legumes in Asia is inhibited by the large number of species of current or potential importance, the limited scientific knowledge of these species, and the great diversity of their use in farming systems in the region.* Resources in research and extension are limited, and an ability to generalise research findings across species and production systems is necessary. This requires an improved scientific understanding of the major limitations to productivity and adaptation. Reorganisation of the research effort is required to emphasise an integrated and multidisciplinary attack on the primary objectives and an efficient allocation of resources.

Recommendation 3: that local, national, regional and international sectors actively seek to increase the level of coordination of programs for legume crop improvement. A primary objective of coordination would be to delineate the specific roles of each sector in research and extension activity, and to establish effective networks between the various research/extension groups and industry.

Recommendation 4: that organisations involved with research and extension on the food legumes accept and develop the multidisciplinary team approach. Systems of management should adequately recognise and reward the achievements of both the team and the individual.

• *Traditional uses of food legumes within farming systems account for the majority of the production in Asia, and this is likely to continue in the short- to medium-term future.* It follows that crop improvement within such systems (generally characterised by landrace varieties, little or no inputs and limited management) is important. While major improvement of productivity under these systems is unlikely, increased stability of production could be attained through incorporation of genetic resistance to the major biotic or other stresses. In the longer term, significant increases in production are most likely to result from adoption of improved systems of management. Therefore research into improvement of food legumes under more intensive management is required as a matter of priority.

Recommendation 5: that the objectives of research in the food legumes be defined carefully and precisely in relation to the production systems of current and potential importance. Both traditional and improved production systems justify attention. The research strategy should encompass an appropriate mix of production system-neutral and technology-dependent objectives.

• *Although the irrigated and dryland (rainfed) farming systems within Asia represent, at their extremes, fundamentally different systems of management, there is a continuum between them.* With relatively few specific exceptions, food legumes within this range of production systems are confronted with a similar array of limitations to productivity and adaptation. Therefore separate research initiatives for the improvement of food legumes in irrigated and dryland (rainfed) farming systems are not justified except for a few specific areas. However the differences between low- and high-input systems are more fundamental, and research strategies to address these differences are necessary.

A primary objective in research in crop improvement is the experimental discrimination among alternatives (genotypes, management options, etc.). This is best done in an environment which provides the most effective contrast and, as far as possible, avoids confounding with other factors. Since farm environments differ greatly, evolve over time and commonly are highly heterogeneous, they are unlikely to constitute effective test environments for controlled research.

Recommendation 6: that strategies of research be designed to address the primary limitations in the most efficient manner possible and, where possible, the objectives be generalised across the existing or proposed systems of production. Modification of national policy regarding food legume production will create the need for a progressive phasing of the strategy of crop improvement. Regardless, the strategy must ultimately involve evaluation in conditions typical of current and potential use by farmers.

• *Technological change has been rapid in recent years and has had a fundamental impact on techniques of scientific agriculture.* Aspects of particular interest in crop improvement include crop production models, biotechnology/molecular biology, and postharvest processing. To date, these techniques have not been widely evaluated or applied in food legumes, particularly in Asia. However they may have particular relevance in this situation because of the diversity of crop species and their use, and may roster integration across disciplines in crop improvement.

Recommendation 7: that advances in technology be evaluated and, where appropriate, actively exploited in the improvement of food legumes within Asia. Dynamic crop production models should receive attention immediately because they are likely to provide the most effective contribution to crop improvement in the short-term. While technology transfer is possible in some crops and situations, Asian scientists must accept primary responsibility for technological advance in those food legumes largely of interest to Asian countries.

• *There is limited understanding of the socioeconomic factors involved in food legume production, marketing, processing and use, both within Asian countries and as export commodities.* In general, national statistics on costs of production of the various crops in different production systems are either not available or limited and inconclusive. As a result, no firm bases exist to guide formulation of governmental policy, business investment, research planning or decisions by farmers.

Recommendation 8: that research into the socioeconomic factors influencing the production, marketing, processing and use of food legumes within Asian farming systems be expanded as a matter of urgency.

• *Stresses induced by biotic factors (diseases, pests, weeds) were identified as major causes of low productivity of food legumes throughout Asia.* Resolution of these problems is central to any improvement of the productivity of these crops in farmers' fields, in both traditional and intensified production systems.

Recommendation 9: that increased activity in research and extension into crop protection be implemented as a matter of urgency. Government policy also should foster the implementation of appropriate systems of crop protection.

• *Effective systems of exchange of information among policy makers and research/extension workers are necessary to foster increased food legume production.* Scientific journals and specialist newsletters (crop-based, discipline-based, etc.) provide a satisfactory medium for formal technical communication. However, there is little opportunity for effective communication in other areas of concern; for example, for technical observations on minor crops, for publication of negative results, for communication regarding agricultural policy and trade, etc.

Recommendation 10: that a general newsletter devoted to food legume crop improvement and the role of these crops in farming systems should be established and published by an international agency or consortium of agencies, to complement the current scientific journals and technical newsletters.

Food Legumes in Farming Systems

Food Legume Crop Improvement: Progress and Constraints

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THE focus of this workshop is the improvement of the summer-growing tropical and subtropical food legumes (including both pulses and oil-bearing legumes) which are an important component of the farming systems in developing countries throughout the south India, Bangladesh and Nepal and Southeast Asian regions (including China and hereafter referred to as the Asian region).

Food legumes are still relatively minor crops (Fig. 1) despite their role as a source of protein and oil in the diet of peoples throughout the developing world, and their importance as a component of animal feeds and as a major source of biological nitrogen in cropping systems.

Production of pulses in the developing world in 1984 represented only 3.7% of cereal production and the annual rate of growth of 1.3% over the last decade is low compared with the 3.7% growth recorded for the major cereals (FAO 1985).

An important explanation for the apparent low status of food legumes in the developing world, despite their tropical or subtropical evolution and adaptation, is the tendency to underestimate the role of these crops in farming systems around the world. They are often grown as a second or third crop in the dry season when few other crops will produce and they play an important role in crop rotation. Many are grown as opportunity crops for consumption on-farm. Consequently, their production is not fully represented in the official statistics.

Another reason is that, until recently, there has been little investment in the improvement of these crops. In general, they are grown without irrigation, and as with other rainfed crops, they have been neglected by researchers and governments in favour of the irrigated sector.

In this review both the role and productivity of the summer-growing food legumes in the Asian region are examined along with factors limiting the expression of their genetic potential for yield. The need and scope for expanding the production of these crops against their sociological and economic background in the region, now and in the future, are also explored.

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Food Legumes in the Asian Region

Role of Food Legumes

Food legumes represent a vital component of the diet in the countries of this region. They provide a concentrated source of high quality protein (protein content varies from 20 to 35%) and are a valuable supplement to the cereal based diets, especially in

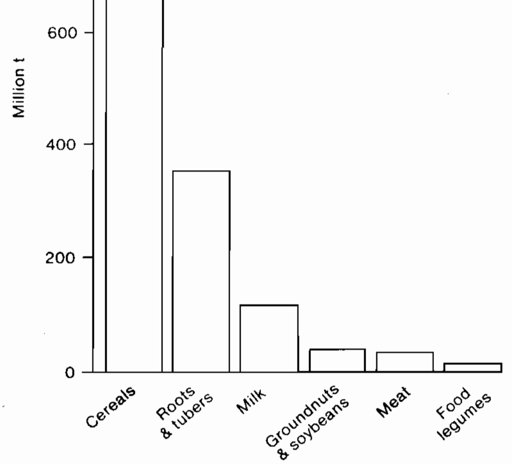

Fig. 1. Major food groups — developing countries

areas where animal protein (milk, meat and fish) is less available. Peanuts and soybean are also important sources of vegetable oil and the residue or cake remaining after oil extraction provides valuable high protein concentrate for animal feed. The growth in demand for vegetable oil and livestock products is a major reason for the concern expressed in recent years by some governments (e.g. India and Indonesia) about the low level of production of these crops throughout the region.

The recent report of the FAO/WHO/UNU Expert Consultation on energy and protein requirements of the human diet set the required level for good quality digestible protein at 0.75 g/kg per day for both sexes. These levels can be satisfied by wheat and rice-based diets for adults over a wide range of energy requirements and body weights, provided sufficient cereal is consumed (e.g. 300 g rice per day). The addition of legumes to the diet reduces the requirement for cereals and provides a more concentrated and better quality protein. As well it adds variety to the diet.

Food legumes also play a valuable additional role in the rice-based farming system of the region. They are cultivated over a wide range of environments from semi-arid to humid tropics — mostly as rainfed crops on a small scale by smallholder farmers — and are grown in rotation with rice, usually following the rice crop. They rely largely on stored moisture and usually have to tolerate water stress during the latter stages of growth. Further discussions on the roles of the food legumes in the farming systems of Asia are found elsewhere in these proceedings (Wood and Myers; Myers and Wood).

The capacity of food legumes for symbiotic nitrogen fixation may reduce the requirements for nitrogen fertiliser, but there seems to be considerable variation in the nitrogen contribution from this source. Other advantages of growing legumes are to break the cycle of cereal cropping and reduce the incidence of soil-borne diseases, and use of their residues after harvest as a valuable source of animal feed.

Despite these advantages the aggregate area sown to food legumes in the Asian region averages only 10.5% of the harvested crop land, ranging from 15% in India (due to the importance of food legumes in human diets) to only 4–5% in the other regions of the lowland tropics in Southeast Asia (CGIAR 1985). The contribution by legumes to the total value of the crop production in much of the region is less than 2.5%, although the value for India (10%) is considerably higher (CGIAR 1985).

Production of Food Legumes

During the last decade pulse legume production in the Asian region, which accounts for about half of the world's production, increased by only 2.1 million tonnes. This represented an increase of only 1.7% per year and resulted in a decline in per capita availability of 2% per year (Singh 1984).

Individual yield data are not available, as separate statistics are not kept, but average yields of pulses in the region (excluding China) over the last decade increased from 489 to 553 kg/ha, whereas the area harvested increased from only 26 million ha in 1974–76 to 27 million ha in 1984. The average yield figures for China are higher but the area devoted to pulse legumes has declined by one million hectares (Table 1).

Soybean and peanuts have fared better. There has been almost a 50% increase in production of these crops over the last decade in the entire Asian region, including China, representing an increase of 4.5% per year. This has come from an increase in the harvested area and in the yield per hectare (FAO 1985).

The growth rates for the pulses are in sharp contrast to the increase in production of cereals in the whole Asian region. The latter grew by 222

TABLE 1. Harvested area and production of food legumes in the Asian Region (including China) over the period 1974–76 to 1984[a].

Region	Crop	Harvested area (10^6 ha)		Production (10^6 t)	
		1974/76	1984	1974/76	1984
Southeast Asia	Pulses	2.8	3.2	1.7	2.1
	Soybean	1.1	1.1	1.0	1.1
	Peanuts	1.3	1.4	1.2	1.7
South Asia	Pulses	23.5	23.9	11.2	12.9
	Soybean	0.1	0.8	0.1	0.8
	Peanuts	7.1	7.3	5.7	6.9
China	Pulses	5.8	4.8	6.3	6.2
	Soybean	7.0	7.5	7.2	9.7
	Peanuts	1.9	2.4	2.2	4.9

[a]FAO 1985.

million tonnes in the decade to 1984, representing an increase of 4.5% per year (FAO 1985). In India over the last decade there has been an equally dramatic increase in cereal production from 119 to 169 million tonnes, whereas pulse production increased from only 10.9 to 12.6 million tonnes in the same period.

Food legumes in Asia are likely to maintain their role as important supplements to cereal-based diets, providing a low-cost alternative to animal protein as well as a limited source of green vegetables. They will also be used as animal feed (essentially the by-products), fuelwood (principally pigeonpea) and soil nutrients through biological nitrogen fixation and disease control in cereal/legume rotations.

The past and future trends in production and consumption of food legumes are given in Table 2. The trends in production through the 1970s indicate that Southeast Asia has maintained steady gains of 2–3% per year in the production of pulse legumes and the oil-bearing legumes, soybean and peanut. With the exception of soybean, which has shown rapid expansion from a low level of production, South Asia experienced negative growth in pulse production, and only a minor increase in peanuts. A similar situation existed for China, except that rapid growth has been experienced in peanut production.

As with production, the upward trends in consumption have been most evident in Southeast Asia in both the pulses and the oil-bearing legumes. In South Asia the strongest growth in consumption has been in soybean and peanuts, with declining or low demand for pulses.

Demand for the food legumes as a group is expected to keep pace with population growth in the region, which for Southeast Asia will have to be around 2.6% per year and somewhat higher (3.6%) in South Asia (Table 2).

The higher demand for soybean and peanut compared to the pulses as a group reflects their price and yield advantage over other crops. At the same time there is a strong demand for certain pulse crops, mung bean and pigeonpea, in the Southeast Asian region (CGIAR 1985). As there is little prospect for any major increase in the total area of arable land, increased production must arise mainly from increased productivity and/or increased cropping intensity. The latter can be achieved through increasing the proportion of legume represented in multiple cropping systems under irrigation and as intercrops and relay crops in the rainfed areas where legumes are the preferred crop. Increased productivity can be sought by removing constraints and by improving the genetic yield potential.

Improvement

Until recently the investment in breeding and improvement of food legumes for the developing world has been limited, relative to the cereal crops. Over the last 20 years the international agricultural research centres belonging to the CGIAR have developed research programs in all of the major food legumes. The value of this research effort in 1984 totalled $US14.4m, representing 15.6% of the CGIAR's research budget (CGIAR 1985).

By contrast, there has been a relatively long history of investment in the breeding and improvement of soybean and peanut in the developed industrial countries, such as USA and western Europe, where a large proportion of these two crops are now produced. As a result, average yields of these two crops in the USA are two to three times the yields reported for the developing world (Table 3). Although improved cultivars of soybean and peanut from these programs can be and are being used to improve the yields of these crops

TABLE 2. Production and consumption trends of food legumes in developing countries of Asia[1] (per cent per year).

Trends	Crop	South Asia	Southeast Asia	China
Production trend (1969/71–1979/81)	Pulses	-0.8	2.8	0.2
	Soybean	10.0[2]	2.0	0.2
	Peanuts	0.3	3.1	5.4
Projected production trends (1979/81–2000)	Food legumes	3.3	2.8	n/a
Consumption trends (1969/71–1979/81)	Pulses	-0.7	2.6	0.6
	Soybean	22.1	6.5	2.3
	Peanuts	1.3	2.6	5.0
Projected demand (1979/81–2000)	Food legumes	3.6	2.6	n/a

1. CGIAR 1985.
2. Based on low level of production (250 000t).

elsewhere, their lack of adaptation to low latitudes and the more stressful cropping conditions of the tropics have reduced the potential gains from this approach.

The lack of improvement in food legume yields is in sharp contrast to the situation with cereals. The improved short-strawed varieties of wheat and rice now produce annually an extra 50 million tonnes more than the varieties they replaced (Breth 1985). The food legumes grown in the same regions, and often in rotation with the improved cereals, as yet have shown little or no increase in area harvested or in yield. The current average yields of food legumes in the developing world, and more specifically in the Asian region, are about one third of that achieved for the major cereal crops grown in the same region (Table 3). Even in the developed world (represented by North America) the average yields achieved for food legumes are still well below those of leading cereals. Although the yields of the food legumes in the developed world are substantially above those for the same species grown in Asia, relative to the cereals the yield gap is about the same (Table 3).

However, these statistics should be interpreted with caution. Comparison of cereal and legume yields in Asia may not be realistic because legumes in the developing world do not compete with cereals. In most situations they fill a niche in space and time that cannot be filled by cereals, and act as an insurance crop in poor seasons.

Constraints to Production

Most food legumes have a long history of domestication, almost as long as cereals, and during this time have been subjected to conscious and unconscious selection for improved adaptation and yield. Large seeds, lack of germination inhibitors, non-shattering pods and freedom from toxic compounds are all retrospective evidence of modification by man (Zohary and Hopf 1973).

Despite this, the yields of food legumes in both the developed and developing world fall well short of the yields obtained for the major cereals, wheat, rice, maize and sorghum. Although simple dry weight underestimates the dietary contribution of legumes by 25–35% because of their higher calorific content of protein and oil, it is of interest to explore the reasons for the apparent difference in the genetic yield potential of these two important crop families.

The factors underlying the yield gap are numerous and complex. They relate to the inherent difference in crop architecture and development patterns which allow cereals to intercept more light and remain insensitive to daylength and sustain a much higher concentration of inflorescences and grain per unit land area than legumes. Also, the poor quality of the seed of many food legumes leads to germination failure and often poor establishment.

The greater susceptibility of legumes to pests and diseases reduces their yield to a greater extent than cereals, and the difficulty associated with harvesting legume crops because of the disposition of the seed pods represents an additional cost in production.

TABLE 3. Average yield of food legumes and some major cereals in the Asian region and in the developing and developed world[1].

Crop	Average yield (kg/ha)			
	Asian region	Developing world	Developed world (USA)	Experimental
Mungbean	490[9]	496[9]	1000[10]	2500[10]
Cowpea	571	241[9]	—	4201[3]
Pigeonpea	689[2]	684[2]	2222[2]	4210[4]
Chickpea	642	663	1031	4000[5]
Dry beans	429	559	1597	2637[8]
Soybean	960	1564	2420[6]	5560[6]
Peanut	1003	1056	3270	5400[7]
Total food legumes	553	610	1654	—
Rice	2441	3106	5520	10000+
Maize	1430	2120	6692	10000+
Wheat	1772	2056	2608	10000+
Total cereals	1842	2162	4378	—

1. FAO 1985.
2. FAO 1981a.
3. Wein and Summerfield 1984.
4. Wallis et al. 1985.
5. Saxena 1984.
6. Shibles et al. 1975.
7. Duncan et al. 1978.
8. Laing et al. 1984.
9. FAO 1981b.
10. Lawn and Ahn 1985.

All these factors have contributed to the lower status of food legumes and help to explain their use as secondary crops. Such factors also have important implications for the productivity of food legumes and their role as food crops in developing countries. Thus, despite the important role played by legumes in supplementing the rice and wheat-based diets in Asia, the social and economic factors relating to risk, and lack of incentive as a result of low prices and poor market opportunities, limit the area sown to food legumes and the investment by the public sector in their improvement.

Some of the more important socioeconomic and biological factors limiting the yield potential of Asian food legumes are discussed below and will be further evaluated in later papers in these proceedings.

Social and Economic Factors

Some of the later presentations in the proceedings provide detailed consideration of the social and economic factors that constrain or may constrain the role of food legumes in Asian farming systems. This paper takes a broad view of such factors, avoiding both regional and technical economic detail. At such a broad level, two statements can be made. First, food legumes do not suffer from any overriding sociocultural constraints such as the religious taboos pertinent to some livestock products. The more pertinent social constraints for food legumes are those of poverty, tradition, fashion, social status, ignorance, lack of experience and such like. None of these social factors has the inflexibility or permanence of religious taboos. They are all subject to influence via economic factors such as prices, information and policies. Likewise, they can all be analysed and appraised in economic terms. This is not to say that all economic analysts would reach the same conclusions as to their importance or the costs and benefits of alleviating them — after all, questions of poverty, tradition, fashion, etc. relate strongly to individual welfare which, by its nature, will be judged differently by different analysts.

The second broad statement that can be made about constraints is that they reflect current economic reality and that any change to them involves costs and benefits. This statement of course applies generally, not just to food legumes in Asia. Its pertinence here lies in its general importance and the fact that it is often overlooked. On the one hand, national welfare is endangered if economic reality is denied over the longer term; on the other hand, only if net benefits from constraint alleviation are satisfactorily distributed to the parties (i.e. the farmers or politicians) involved, will changes to constraints be attractive and acceptable. In this sense, there is an overriding economic dimension to the physical and biological constraints discussed in the next section. They constitute a very significant part of economic reality and the acceptability of their alleviation is consummated (or otherwise) by the relevant benefit-cost equation.

Moving from such philosophical heights to more prosaic levels — what are the economic constraints facing food legumes in Asia? Put another way, and taking a production and farmer-oriented focus — what influences (over and above the biological constraints) constrain food legumes from being more economically attractive to Asian farmers than they are?

A most important factor is the subsidiary status of food legumes (Sharma and Jodha 1982). To both farmers and governments in Asia, food legumes have generally lacked priority relative to cereal staples. Only in recent years have countries such as India, Indonesia and Thailand attained self-sufficiency and export potential in their staple food crops and their governments have now begun to pay some significant attention to pulses in their development planning. Governments have to date given the cereal staples by far the major share of their attention in terms of price policies and investment in infrastructure, research, extension and development — with some justification. However, the food legumes have largely been ignored by governments. Reasons for this are easy to postulate. First and foremost, food legumes are not staples for the bulk of the population, nor have they had the lobbying power that comes with the revolutionary and handsomely viable new technology, generated exogenously and promoted vigorously by its international supporters. Second, food legumes constitute a diverse array of crops with strong characteristics of location specificity whose niche, under current technology, for both agronomic and economic reasons lies largely in the farming systems of semi-subsistence farmers in poorer unirrigated areas. In consequence, compared to rice or wheat, the food legumes constitute a motley group of little significance on the political stage of most nations. It is no wonder that governments have only begun to pay attention to them under the stresses generated by such factors as staple oversupply (leading to desires for a more diversified agriculture) and increased meat consumption (leading to animal feed needs that might be satisfied by domestic production rather than by 'expensive' imports).

From the farmers' view, food legumes are generally subsidiary in that cereals receive priority as the staple, and this is particularly so for the subsistence farmer. Food legumes also do not have a major role with many farmers as a cash crop, in part perhaps because of lack of market access due to the relative isolation of growing areas or other market problems. Also, because of the ability of many food legumes to make relatively better use of a deficient resource base, farmers tend to allocate them to the more marginal agricultural areas.

Other constraints to food legume production often mentioned are their riskiness in the eyes of farmers, the fact that they are typically part of a multicrop farming system, a lack of demand and a price structure that provides no incentive.

The evidence pertaining to riskiness is limited, but what is available (Jahnke and Kirschke 1983; Jodha and Singh 1982) does not suggest that food legumes are generally any greater risk for farmers than the cereal staples, despite the fact that the cereal staples have received far more attention in terms of disease and pest control research. Indeed, from a risk point of view, most food legumes probably contribute positively to risk amelioration through their ability to perform better under poor conditions than many other crops, an advantage complemented by their fixation of nitrogen and provision of useful residues.

Likewise, the fact that food legumes are typically grown in smallholder multicrop systems can of itself hardly be regarded as a constraint. Rather, the relevant constraints are the fact that smallholders predominate and the fact that food legumes as yet, with the exception of soybean and peanut in some regions, do not have the technology, yields and demand to lift them out of the smallholder multicrop system mode of production. While research may generate new technology to break the latter constraint in some regions, productive food legumes per se are unlikely to reduce the predominance of smallholders.

Lack of demand and poor prices certainly are strong economic constraints to production. For food legumes, as for other products, so far as they are a reflection of unhampered market conditions, demand and prices are best taken as given. Manipulation of demand and prices by public authorities is best avoided unless government is prepared (as many, to their cost, have been) to suffer the consequences of resource misallocation. Conversely, if existing demand and price conditions are caused by interference with the market, a prima facie case exists for removing the interference.

In summary, in terms of importance and possibility of alleviation, there are two socioeconomic constraints that need recognition relative to food legume production in Asia. The first is the need for governments to redress the balance between the cereal staples and food legumes in terms of research and extension so that the biological constraints on food legume yields can be overcome. The second is for similar action by government in the more general area of agricultural policy.

Physical and Biological Factors

In Asia, where there is little prospect of increasing the area of arable land, increased yield per hectare per crop is the factor that reduces the cost of production, improves profitability for the farmer and contributes to an acceptable price to the producer and consumer.

Although low grain yields of food legumes in Asia result from the combination of some or all of the factors mentioned previously, the improvement in yield when these constraints are removed is ultimately limited by the yield potential as expressed by the genotype of the cultivars and its interaction with production environment.

There is no simple formula for achieving high yield in crops and for this reason the low yield of many traditional crops such as food legumes in developing countries is also complex. Food legumes still retain many of the developmental and reproductive characteristics of their non-domesticated relatives that conveyed fitness in the wild but may not contribute to high yield potential under cultivation. Some of the most important constraints to the adaptation of food legumes and the genetic improvement of yield are as follows:

ADAPTATION

The phenology of annual and perennial food legumes, that is, the sequence of development events, has evolved in response to important environmental variables, especially photoperiod and temperature, in the climate of origin. When grown in a different region, or in the same region but at an unconventional period of the year, there is often a marked genotype x environment interaction expressed as altered phenology which can have a deleterious effect on the yield and adaptation of the crop.

Throughout the developing world, food legumes are grown in marginal areas where yields are uncertain, in rotation or as an intercrop with the primary cereal crops grown during the most favourable season(s) of the year. As a consequence, the legumes usually have to contend with competition for water from the associated crop, or moisture stress during the reproductive phase. This is due to the depletion of the available stored water remaining after the cereal crops.

With the introduction of new high yielding cereal varieties and the adoption of two and three course rotations there is a need for legumes with a greater range of adaptation to photothermal regimes, to fit them into new cropping systems and to minimise stress in the form of chilling, drought or waterlogging. Many of the traditional cultivars are photoperiod-sensitive and flower too late to fit into the shorter rotations required with the more intensive multiple cropping systems. The development of better adapted germplasm has had little or no impact on the yields of these crops. Most of the cultivars still in use are local strains which are low yielding and probably better adapted to the traditional agricultural systems practiced in the region.

AGRONOMY AND MANAGEMENT

Because of a number of factors, including low prices and the perception of food legumes as opportunity crops, there is less attention given to their cultivation and management. The lack of a commercial seed industry limits the availability of improved cultivars when these are available, and there is limited use of agricultural chemicals (fertilisers and pesticides). Other cultural factors that limit the expression of yield potential are poor establishment (often due to low quality or damaged seed), inadequate land preparation, competition from weeds and the necessity of growing the crop at inappropriate seasons of the year (either too wet or too dry during the reproductive period of the crop) to fit into the cereal-based cropping systems.

The extent to which these factors are responsible for poor productivity varies inversely with the importance of legumes in the diet and their role in the cash economy of the region.

PESTS AND DISEASE

Diseases and insects are the major factors causing reductions in yield and sometimes complete failure of food legumes grown in tropics. Drastic reduction in yield can occur in both wet and dry seasons unless resistant cultivars and/or good pest management practices are adopted.

The process of domestication of food legumes has removed many of the natural toxins, such as alkaloids, which probably gave them a greater degree of protection from both pests and diseases. Some form of protection is especially important in tropical legumes because of the favourable conditions for the rapid build-up and spread of plant pathogens and insect pests. In the future, with the development of disease and pest resistant cultivars and the more widespread use of pesticides, the problem will be reduced, but it remains as a constant threat and will require the continuing efforts of the breeders and agronomists to maintain an acceptable level of protection.

BIOLOGICAL NITROGEN FIXATION

The capacity for symbiotic fixation of dinitrogen (N_2) present in all food legumes is an important factor that enables them to grow in a wide range of tropical soils which are usually low in available nitrogen.

In general, tropical food legumes will nodulate effectively with indigenous cowpea-type rhizobia which are widely distributed in the tropics. Problems can arise when introducing new legumes with specific rhizobium requirements into a region, or where adverse soil pH or nutrient deficiencies restrict the ability of the crop to form an effective symbiosis.

The improvement of food legumes such as soybean and peanut over long periods in North America, under conditions of adequate soil nitrogen and indigenous rhizobia, can present a problem when this germplasm is reintroduced into the tropics to improve the locally adapted material. The loss of 'symbiotic potential' may limit the usefulness of this germplasm when used without inoculation on infertile tropical soils.

FLOWER SHEDDING AND EMBRYO ABSCISSION

This represents one of the most widespread responses found in all food legumes and their wild relatives and is another major factor contributing to the reduction of yield potential through the loss of flowers and pods. Although the causes of these losses are not fully understood, they are thought to be associated with limitations in the supply of photo-assimilates and the action of plant hormones such as ethylene (Sheldrake 1984). Flower and pod abscission controls the number of pods per node, and in the case of soybean it is more pronounced for nodes in the lower portion of the canopy where up to 90% of the flowers and pods formed can be lost (Heindl and Brun 1984).

This pattern has been retained in many food legumes which are still semi-domesticated plants and is inconsistent with the requirements of high levels of pod setting and synchronous pod development associated with a determinant growth habit which is the ideotype usually associated with high yield potential in legumes.

HARVEST INDEX

In considering the yield of crops it is necessary to distinguish between economic yield, that part of the crop that has value to the farmer, and biological yield which represents the total dry matter produced by the crop per unit area. In the case of food legumes, the vegetative material remaining after harvest of the seed has a value as animal feed, but for the purposes of this discussion the economic yield will be restricted to seed.

The concept of harvest index (HI) — the ratio of economic yield to biological yield

$$\left(HI = \frac{\text{Seed DM} \times 100}{\text{Total DM}} \right)^{a}$$

is a useful way of integrating many of the plant

[a] Usually restricted to total above ground DM. In the case of legumes, leaf shedding during development can give inflated values of HI.

responses including growth, net photosynthesis, partitioning of assimilates and grain development into a single measure of a crop's efficiency in converting energy nutrients and water into seed.

On this basis there are two ways of increasing seed yield, either by increasing dry matter production or increasing values of HI. The maximum yield is obtained when the two measures are combined at a high level.

In wheat, for example, Jain (1986) has shown that increases in grain yield in India over the last 60 years, and especially in the last 15 years with the introduction of the dwarf Norin 10 genes, have been closely associated with a greater partitioning of dry matter into grain. The 157% increase in wheat yields was associated with a decrease in height from 113 to 84 cm and increase in HI from 17 to 46%. All this was accomplished with no increase in biological yield. Similar results have been shown for tropical rice following the introduction of the Dee-Geo-Woo-Gen dwarfing genes into the tall varieties of indica rice (Asana and Salunke 1971; Jain 1986).

Programs to improve the yields of peanut in southern USA over the last 40 years have more than doubled the economic yield potential of this crop. As with cereals this has resulted in no increase in biological yield but an increase from 23 to 51% in HI (Duncan et al. 1978). They claim that this partitioning of assimilates into seed and vegetative parts to give a high HI has been the physiological process that has explained most of the yield increase over this period. A similar result has been obtained for soybean (Gay et al. 1980) and for pigeonpea (Wallis pers. comm.). A summary of the data on HI for cereals and legumes is given in Table 4.

TABLE 4. The effect of crop improvement on Harvest Index and yield of legumes and cereals.

Variety	Released (year)	HI (%)	Yield (t/ha)
Peanut[1]			
Dixie Runner	1943	23	2.5
Early Bunch	1973	51*	5.5
Pigeonpea			
Tall Traditional[2]	—	15-20	0.7
Hunt[3]	1983	50*	3.0*
Soybean[4]			
Dorman	1952	23**	1.8
Essex	1972	50**	3.3
Wheat[1]			
P6 8A India	1910	17	2.2
Arjun India	1980	46	5.7
Rice[1]			
Peta (tall traditional)	—	22	2.2
IR 32 IRRI	1974	41	5.2

1. Jain (1986).
2. Sheldrake (1984); Singh and Kush (1981).
3. Wallis, pers. comm.
4. Gay et al. (1980).

* Based on total dry weight less shed leaves, hence, HI tends to be overestimated.

** Relative HI based on DM measured m^{-2}.

Prospects for Improving the Productivity and Role of Food Legumes

The demand for food legumes, largely for human consumption in the developing countries of Asia (Kim 1982) is projected to grow at an annual rate of 2.6% for Southeast Asia and 3.6% for South Asia (mainly oil-bearing legumes). This aggregate demand does not take into consideration the unfilled or potential demand based on the nutritional requirements of the population. One can assume that this 'real' demand would be significantly higher, and this adds further pressure on the need to improve the production of food legumes in the region.

This gain can be achieved in a number of ways: (1) through investment to improve production technology and to make available the necessary inputs including quality seed, thereby encouraging greater use of food legumes; (2) improvements in the agronomy associated with their production; and (3) programs to increase seed yield, especially when legumes are grown as sole crops within the cereal-based farming systems of the region.

Coupled to inputs, there is also a need to provide greater incentives to small farmers to produce and consume food legumes through the development of pricing and marketing policies that recognise the value and future potential of these crops.

Socioeconomic Factors

Reflecting an increasing interest among both international and national researchers and policy analysts, recent years have witnessed a spate of publications focused specifically on food legume production and prospects in Asia — see, e.g., APO (1982), CGPRT (1985a, b), ICRISAT (1984), Kaul (1985), Kim (1982) and Sharma and Jodha (1982). Such heightened interest augurs well, some would say, for overcoming the bias towards the cereal staples evident over recent decades among Asian policy makers, planners and research administrators. Yet, it is unproven (and probably unprovable since welfare tradeoffs between different community groups are involved) whether or not the heavy emphasis to staple cereals was justified.

Prima facie, given the dominance of the staple cereals, it is clear that they deserved at least major emphasis historically. However, the extent of success in yield and production of the staple cereals in contrast to other crops, including food legumes, suggests at least a marginal if not greater degree of unjustified attention has been given to rice and wheat.

Looking to the future, again the judgment is not clearcut. On the one hand, the basis for ongoing research and development into the staple crops has been established. It could be said that for rice and wheat only investment in research and development of a maintenance nature is now justified, while crops such as food legumes still need basic investment in research and development. On the other hand, however, rice and wheat will remain dominant as staples and, given expected population increases, will still require substantial investment in research and development if an adequate supply of the staple is to be assured. The answer perhaps lies, as indicated by current tendencies in both economic and political markets, in a more discriminatory approach in which food legumes are not seen as a group but are differentiated in terms of regional and market importance. Thus, soybean and peanut, as sources of oil and protein for human food, animal feed and industrial uses, might be seen as justifying more attention than those pulses that are merely food legumes. Likewise, pigeonpea and chickpea might justify greater emphasis because of their particular significance in semi-arid areas.

Utilisation of food legumes, to varying degrees among them, follows three tracks; (1) direct human consumption; (2) use as animal feed; and (3) industrial utilisation. Overall, industrial utilisation of food legumes is limited and cannot be expected to expand significantly in the short term.

Despite their importance as a source of protein in human nutrition, the expectation is that without improved production technology, average per capita consumption of food legumes in Asia will decline due to lack of competitiveness with wheat and rice. Similarly, although the use of some food legumes, particularly soybean, as animal feed is increasing rapidly, the difficulty is for domestic production to be price competitive with imported animal feed, particularly soybean from the USA and Brazil. Action to increase productivity and/or decrease cost of production of food legumes is necessary.

Improving the Yield Potential

It is believed by many farmers, scientists and agricultural administrators that legumes have an inherent low yield potential by comparison with cereals. This has tended to discourage investment in their improvement, but there is good evidence to suggest that higher yield potentials can be achieved.

Some of the experimental yields achieved with various food legumes around the world are presented in Table 3. The figures quoted are possibly rather conservative; for example, some values for seed yield of pigeonpea under optimal conditions were in excess of 8000 kg/ha. This indicates quite clearly that, given high-yielding cultivars and favourable cultural conditions with proper management, seed yields can approach those of cereals in the developed world. This suggests that there is considerable unexploited yield potential in all of the food legumes. These aspects are further discussed in other papers in these proceedings.

Under present conditions in the developing world, and under those likely to exist through to the end of this century, it is unlikely that many major agronomic improvements will be implemented generally throughout Asia. It is likely that higher income countries will be able to improve fertiliser practice (phosphorus + trace elements) and the use of pesticides to control insect pests. For most subsistence farmers, however, food legumes will remain secondary crops, and improvements will have to come largely from genetic resolution of the constraints characteristic of the current farming systems, e.g. disease and pest resistance, tolerance of acid soil conditions, resistance to moisture stress. Experience with soybean suggests that substantial increases in productivity at the farm level can be accomplished in the food legume. Average yields of soybean in the USA in 1924 were 760 kg/ha (Luedders 1977) lower than the current average yields in Asia. Productivity in the USA now averages around 2000–2200 kg/ha, which represents a threefold increase in 60 years. Improvement in seed yield in soybean in the USA has ranged from 0.7 to 0.9% per year since the 1930s (Luedders 1977; Boerma 1979). These increases are a little lower than those recorded for cereals (Evans 1983). However, as in cereals, the increases have been stepwise and are the result of both improved cultural conditions and an increase in genetic potential (Jensen 1978; Boerma 1979). In view of the current reluctance of subsistence farmers in Asia to apply inputs to food legumes, increases in seed yields there are likely to be more limited. It is clear that achievement of a doubling in the realised yield of pulse and oil-seed food legumes in Asia will require major investments to improve cultural conditions and agronomic management of the crops. This will include timely provision of better quality seed and inputs such as fertiliser and pesticides as well as improvement cultivars, coupled to a more informed and effective extension service.

There is a clear need to increase investment in selection and breeding of more suitable cultivars. The national programs in the region with the international agricultural research centres and other institutions should collaborate to gain access to advanced technology and a wider range of genetic material.

There are a number of important objectives in any such improvement program to develop better-adapted, higher-yielding cultivars for use in rotation with lowland rice or as sequential and relay crops in association with upland cereals. Some of these are:

- development of the appropriate daylength and temperature responses, including daylength-insensitive cultivars, to enable the crop to adapt its life cycle to the available cropping season;
- selection of cultivars with improved tolerance or resistance to the major diseases and insect pests;
- improvement of stress tolerance, especially in relation to water deficit and improved water use efficiency in peanut (Hubick et al. 1986);
- evaluation of the potential for wet soil culture of soybean in rotation with lowland rice (Troedson et al. 1983);
- development of cultivars, particularly of soybean, that are symbiotically promiscuous, nodulating with the indigenous rhizobia so that they are capable of forming an effective symbiosis without inoculation;
- exploitation of other developments in molecular biology, including the engineering of *Rhizobium* to increase N_2 fixation (Gresshoff and Delves 1986); supernodulation and nitrate-tolerant symbiotic mutants (Caroll et al. 1985);
- improvement in flower and pod retention to increase the potential for yield increases, using approaches such as selection for an independent vascular supply to flowers as demonstrated in faba bean (Gates et al. 1983) and for more synchronous pod development in a determinate growth background;
- change in the architecture and development of the legume plant to produce a determinate type; shortened stature achieved through response to photoperiod (Byth et al. 1981) or insensitivity to photoperiod; tolerance of high plant population (500 000 plants/ha; Wallis et al. 1985) and high LAI; earlier flowering for better adaptation to farming systems; synchronous pod development and self destructive senescence (Sinclair and de Wit 1975); maximum utilisation of light energy and improved photosynthetic activity to prevent sink limitations and increased partitioning of assimilates to developing grain to maximise harvest index.

These objectives and other factors are discussed in other papers in these proceedings.

Conclusions

Nearly fifteen years ago Norman Borlang, in opening a conference sponsored by the UN Protein Advisory Group, called for a 'protein revolution' in the developing world for pulse and oil-seed legumes. He claimed in his paper that 'the pulses remain at a low yield level and production is either stagnant or dropping'. Also, because of the lack of high-yielding varieties and improved technology, 'part of the land that once grew pulses has shifted in winter to wheat and in summer to rice or maize' (Borlang 1973).

On the surface nothing very much has changed in the intervening years, but in fact investment in research to improve the productivity of food legumes has increased, both in the international centres and in the national programs. Improved legume cultivars are now becoming available for use in Asia and in other parts of the developing world.

This research has clearly demonstrated that there is a great deal of variation available within the gene pools of these species, and that the yield potential can be significantly increased through breeding and improved cultural conditions. The successful use of improved genotypes of soybean and peanut developed in the West to recombine with local tropically adapted cultivars, is a good example of this approach.

The realisation of this additional yield potential will depend, to a great extent, on the additional incentive provided by these new cultivars and systems for production for the small resource poor farmer. Unless adequate extension and the necessary inputs to grow the improved legumes are available, and unless sound pricing policies and market opportunities are developed, there is little prospect that they will be widely adopted, despite the growing demand for food legumes throughout the region.

The prospects for greater investment in food legumes are improving in view of the projected demand, stemming from population growth in the developing world (population is expected to double to 6.6 billion in the next 40 years), the growth in income causing a shift in demand away from the traditional cereals, and the increasing trend towards urbanisation, which is providing new market opportunities.

By the year 2000 Asia will contain almost half the population of the developing world (of which 10% will suffer from serious undernourishment). Present growth rates of both cereals and food legumes, along with other basic food commodities, will have to be increased in line with population growth. In this respect, cereals and food legumes should be seen as complementary, in that they are essentially synergistic components of Asian farming systems. Also, the value of food legumes in sustaining the productivity of tropical soils and providing feed for animals may be as great as their contribution to the food resources.

The available evidence suggests that there is scope for further improvement in the yield potential of all food legumes, and there are indications of greater support for the development of these crops to complement the more intensive cereal production systems in the region. In the future, the marriage of biotechnology to plant improvement and a more enlightened agricultural policy environment should, in Borlang's words, help to speed up the 'slow runner' and contribute to better balanced farming systems for Asia.

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Food Legumes in Farming Systems in the Tropics and Subtropics

I.M. Wood and R.J.K. Myers *

LEGUMES have been components of farming systems since the days of the Roman Empire and their reputation as restorers of soil fertility is well established. However, it has only been during the past century that their effect on soil fertility has been demonstrated to arise from the symbiotic activity of nitrogen-fixing bacteria in nodules on their roots. The family Leguminosae, which contains all the food legumes, provides the most outstanding examples of this feature. The ability to fix nitrogen (N) has a number of important consequences: it enables legumes to make good growth in soils deficient in mineralised soil N; it leads to the food legumes producing seed with a protein content of up to 40%; and it leads to a high concentration of N in the tops and roots, which can either decompose in the soil to produce plant available nitrogen, or in the case of the tops be used as animal feed. The contribution of legume residues to the nitrogen balance of the soil and to the nitrogen nutrition of following crops has established their reputation as restorers of soil fertility.

It was pasture and green manure legumes that established the reputation of legumes and it has almost been an act of faith among agricultural scientists that the food legumes must also be valuable components of farming systems. Scientists need to question this assumption and seek to identify the role that the food legumes do play in farming systems.

In this paper the food legumes are examined in terms of their roles in farming systems in the tropics and subtropics and, in the N cycle. Ways in which they affect the productivity of farming systems are discussed. Emphasis will be on the farming systems of Asia and, given the location of the workshop in northeast Thailand, local examples are used as far as possible.

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Production and Markets

A number of the food legumes, such as peanuts and soybeans, are major world crops that are used for human and animal nutrition and as sources of vegetable oils. These are important in world trade but the greater part of world food legume production is consumed in the country of origin. In 1984 the percentage of total world production entering world trade was only 6.7% for the pulses (food legumes other than groundnut and soybeans) and 5.0% for groundnuts (FAO 1985a). World soybean production in 1984 of 89.9 million tonnes was almost twice that of all pulses, and 28.7% of this was exported. This reflects the dominance of soybeans among the food legumes, a dominance that can be attributed largely to their use as a source of both vegetable oil (15–20%) and protein (35–40%) and the ease with which they can be harvested and transported.

Details are given in Table 1 of the main centres of production of those food legumes that are grown in the tropics and subtropics. It will be seen that while some of these, such as peanuts and soybeans, are widely grown, others such as mungbean and black gram are much more restricted in their areas of production. This reflects both the influence of local eating preferences and the absence of large-scale international trading in most of the food legumes. The extent of local usage and the importance of the food legumes in those countries with developing market economies are illustrated by the statistics of Table 2. Clearly the question of markets must be an important consideration in any attempt to increase the production of food legumes. This may well require special national and international promotional programs to foster the consumption of the food legumes.

Food Legumes in Farming Systems

The food legumes of the tropics and subtropics (Table 1) are largely grown in developing countries with predominantly agriculture-based economies. In

TABLE 1. The major food legumes of the tropics and subtropics and their main centres of production (adapted from Wood and Russell 1979; FAO 1985b).

Specific name	Synonyms	Common names	Main centres of production
Arachis hypogaea		peanut, groundnut, goober	India, China, USA, Indonesia, Senegal, Burma
Cajanus cajan	*Cajanus indicus*	*pigeonpea, red gram, cajan pea, Congo pea, non-eye pea*	*India, Kenya, Uganda, West Indies, Burma*
Cicer arietinum		chickpea, chick gram, common gram, gram, Bengal gram, Egyptian pea, Indian gram, garbanza, garbanza bean	India, Turkey, Pakistan, Burma, Mexico, Ethiopia
Cyamopsis tetragonoloba	*Cyamopsis psoraloides*	guar, cluster bean	India, Pakistan, USA
Macrotyloma uniflorum	*Dolichos uniflorus, Dolichos biflorus*	horse gram, horse grain, kulthi bean (Indian)	India
Lablab purpureus	*Dolichos lablab* *Lablab niger* *Lablab vulgaris*	lablab bean, hyacinth bean, bonavist bean, seim bean, lubia bean (Sudan), Indian bean, Egyptian bean	India, Sudan, Burma
Glycine max	*Glycine soja*	soybean, soya bean	USA, Brazil, China, Argentina, Canada, India
Lens culinaris	*Lens esculenta* *Ervum lens*	lentil	Turkey, India
Phaseolus lunatus	*Phaseolus limensis*	lima bean, Sieva bean, butter bean	
Phaseolus vulgaris		haricot bean, kidney bean, common bean, French bean, dwarf bean, bush bean, runner bean, climbing bean, snap bean, navy bean, pinto bean, white pea bean, dry bean	Brazil, USA, Mexico, Yugoslavia, Turkey
Psophocarpus tetragonolobus		winged bean, goa bean, asparagus pea	New Guinea
Vigna aconitifolia	*Phaseolus aconitifolius*	moth bean, mat bean, pillipesara, aconiteleaved kidney bean	India
Vigna mungo	*Phaseolus mungo*	black gram, urd, mungo bean, woolly pyrol	India, China, Bangladesh, Burma
Vigna radiata var. *radiata*	*Phaseolus radiatus* *Phaseolus aureus*	mung bean, green gram, golden gram, Oregon pea, Jerusalem pea, moong, Newman pea	India, Thailand, China, Indonesia
Vigna umbellata	*P. calcaratus* *P. sublobatus* *P. ricciardanus* *P. hirtus* *P. pubescens*	rice bean, Pegin beans	Thailand, China
Vigna unguiculata subsp. *unguiculata*	*Vigna sinensis*	cow pea, black-eyed bean, southern peas, poona pea	Nigeria, Mauritania, Niger, Senegal, Burkina Faso, USA, Zimbabwe
Vigna unguiculata subsp. *sesquipedalis*	*Vigna sinensis* subsp. *sesquipedalis*	yard long bean, asparagus bean, asparagus pea	S.E. Asia, West Indies
Voandzeia subterranea		Bambara groundnut	Zambia

Asian countries they are typically grown on small farms as a minor component in essentially rice-dominant farming systems. The food legume is generally grown as a cash crop with the rice being grown for family consumption. The soils are characteristically low in soil nitrogen but the high cost of fertiliser, low income, lack of credit facilities or a high level of indebtedness prevent most farmers from using nitrogenous fetilisers. Leguminous crop species offer to such farmers a cheap and effective way of overcoming the problem of nitrogen deficiency.

The tropical and subtropical food legumes are primarily adapted to areas with a climate classified as semi-arid which approximates to areas having growing seasons of 90–150 days. The food legumes will grow well in humid and subhumid conditions but the problems of land preparation, diseases, insect pests, harvesting and seed quality tend to increase as rainfall increases and the growing season extends beyond about 150 days. They are therefore grown in areas where the major crops are the cereals — paddy and upland rice, wheat and sorghum. A number of other non-leguminous crops including corn, barley, millet, cassava, jute, kenaf, sunflower and cotton are also grown in these areas, and although they are often of local importance they are generally of minor importance compared with the major cereals.

The food legumes are used in many different ways in Asian farming systems. They are frequently grown as main crops during the wet season and, where the pattern of rainfall is bimodal, two crops are often grown with sowings timed to give growth during each of the two wet periods. Where irrigation water is available and there is little or no risk of frost, many of the food legumes can also be grown throughout the dry season. They are also grown opportunistically where moisture conditions are unfavourable for a cereal crop. For example, they are often grown as late wet season crops when poor early rains prevent the sowing of paddy rice on river terraces. A short-duration legume such as mungbean or rice bean is also often sown just before or immediately after a cereal crop to utilise residual soil moisture. As might be expected, seed yields are often low in such opportunistic crops.

The versatility of the food legumes is demonstrated by their capacity to grow in agroecological situations ranging from lowland alluvial areas through river terraces to upland areas, in soils ranging from heavy estuarine clays to light textured sands and in climates giving growing seasons extending from about 50 to 300 days. The food legumes can also be grown as sole crops or in various forms of intercropping. In addition the group embraces species and genotypes adapted to a wide range of temperatures, daylengths and moisture regimes.

The possibilities exist, therefore, for the food legumes to be utilised in a wide range of farming systems under a wide range of ecological conditions. The role and potential of soybeans in tropical and subtropical cropping systems were described by Shanmugasundaram and Sulzberger (1985) and similar considerations for mungbeans were discussed at a symposium in 1977 (AVRDC 1978). Other legumes are described in the proceedings of three international workshops i.e. chickpea (ICRISAT 1980a), groundnuts (ICRISAT 1980b) and pigeonpeas (ICRISAT 1981).

Food Legumes in the Nitrogen Cycle

The role of food legumes in the N cycle of farming systems is discussed in some detail by Myers and Wood (these proceedings). Briefly some of the main features are:

TABLE 2. World production of selected food legumes and food legume groups. The percentages of production in countries with developed and developing market economies, and the percentage of production exported from the countries of origin are also shown (sources FAO 1985a, 1985b).

Crop or crop group	1984 Production ('000 m/t)	Percentage production in*		Percentage exported from country of origin
		Developed ME	Developing ME	
Soybean	89893	58.2	29.2	28.7
Groundnut	20611	10.8	65.0	5.0
Chickpea	6526	1.6	98.4	NA**
Lentil	1538	8.9	89.4	NA
Dry beans	15469	10.7	73.8	NA
Dry broad beans	4039	13.3	29.9	NA
Dry peas	10627	16.3	7.5	NA
Total pulses***	47907	10.6	58.2	6.7

* not shown in the table are the percentages of production in countries with centrally planned economies.

** not available.

*** includes chickpeas, lentils, dry beans, dry broad beans, dry peas, pigeonpeas, cowpeas, vetches and lupins.

- The N in the biomass of a food legume crop (N1) comes either from fixation by the rhizobia (Nf) in the root nodules or by uptake from the soil (Nu). This N is then partitioned either into the seed, which is removed at harvest (Ns), or to the leaves, stems and roots, which are generally left as a residue on the soil following harvest (Nr).
- The balance between uptake and fixation is determined by the growing conditions of the crop, the effectiveness of the *Rhizobium* strain and the level of available soil N. The proportions of N partitioned to the different plant fractions also depend on the growing conditions of the crop but are modified by the genotype. Plant improvement generally seeks to increase the proportion of total dry matter production that goes to seed production, and this has the effect of reducing the proportion and amount of residual N (Nr) from the crop. To this extent plant improvement programs can reduce the residual value of food legumes in farming systems.
- Little of the N fixed by a leguminous crop appears to become available to other plants during the life cycle of the legume. It only becomes available to other plants following the breakdown of tissue and its mineralisation by soil microbes. The amount of N which is taken up from the legume residue by a following crop (Nc) is determined by the proportion which is mineralised (Fm) and the efficiency (E) with which the crop utilises the mineralised N in the soil.
- The proportion of Nr mineralised to N (Fm) is determined by the following factors: the quality of the residue (usually expressed as C/N ratio), temperature and water status of the soil and the duration of decomposition. In general, the rate of mineralisation increases as mean temperature increases and as the C/N ratio decreases; mineralisation is also facilitated by adquate levels of available soil water.
- The efficiency of utilisation by the crop (E) of the N mineralised from the residues is determined by the extent of losses due to denitrification or leaching and by the efficiency of uptake by the crop. Losses of N by denitrification arise from waterlogging and flooding and leaching losses from water flow through the profile. The efficiency of uptake by the crop is determined largely by the growing conditions of the crop and its rooting pattern. Under good growing conditions and where the roots are exploiting most of the soil profile the efficiency of uptake can be very high and efficiency of utilisation is only affected by gaseous or leaching losses.

Clearly soil, climatic, management and cultural factors will all affect the parameters in the N cycle. For example, the use of adapted genotypes will directly affect the level of Nr and may well affect the C/N ratio of the residual biomass. Cultural practices such as cultivation, irrigation, intercropping and grazing will also affect the balance and there will also be important interactions between these factors.

TABLE 3. Estimates of components in the N balance associated with a soybean crop (120 days duration) and a green manure crop of lablab bean turned under at flowering (110 days duration). Data are in kg/ha.

Component	Symbol	Soybean	Lablab bean
Total N in crop at crop at harvest	Nl	404	190
N fixed *	Nf	290	133
N taken up from soil	Nu	114	57
N removed as seed	Ns	296	0
N in crop residue	Nr	108	190
Net change in soil N		−6	+133

*Ratio of fixed to total N in lablab biomass assumed to be 0.70

The effects of two contrasting leguminous crops on the soil nitrogen balance are illustrated in Table 3; the data are from papers by Wood (1983) and Chapman and Myers (1987). The soybean crop was high yielding and almost 75% of the N in the above-ground biomass was removed with the seed. The lablab bean was harvested at flowering and can be taken as corresponding with a green manure crop that is cut and cultivated into the soil. It will be seen that the net effect of the soybean crop was a loss of 6 kg N/ha from the soil; in contrast the green manure crop contributed 133 kg N/ha to the soil. These data clearly demonstrate that while high-yielding food legume crops are capable of fixing quite high amounts of N, most of this is removed with the seed and there is little or no net gain of N by the soil. While this result may seem unsatisfactory for long-term stability, it should be pointed out that a much higher net loss of N could be expected following a non-leguminous crop such as sorghum. Green manure crops can provide a substantial contribution of N to the soil and they have long been used for this purpose in China, Japan and Korea. However, it must be remembered that this N will generally have been obtained at the expense of an alternative cash or food crop.

While the processes involved in the N balance of farming systems involving the food legumes are now recognised, there is unfortunately a paucity of quantitative data. Knowledge is limited on such questions as the amounts of N that the different legumes are capable of fixing, of the quantities of

N that are returned to the soil in residues and of the dynamics of breakdown of legume residues in the soil. There is also little quantitative data on the effects of edaphic and climatic factors on fixation and residue breakdown. Advances in knowledge in these areas will allow the development of systems of management that will optimise the supply of N both to the legume and to associated nonleguminous crops.

Agronomic Attributes of Food Legumes

This section questions whether food legumes have a wider role in farming systems and discusses the various agronomic attributes that either enhance or reduce their value as components of farming systems.

Seed Quality

Low seed quality affects food legumes, particularly soybeans, peanuts and mungbeans. Some of these (e.g. aflatoxin in peanuts and weathering damage in mungbeans) adversely affect their value as food crops. Others, such as the rapid loss of viability and vigour found in soybeans, lead to problems with germination and establishment. Hardseededness and dormancy are common characteristics of many legumes, but there has been a tendency to select against these traits in the development of commercial cultivars of the food legumes. This has been done to achieve an even germination and establishment, but it seems probable that this has increased the sensitivity to weathering damage in mungbeans (Imrie et al. these proceedings) and adversely affected the storage life of soybean seed (Potts et al. 1978). The deliberate incorporation of hardseededness into commercial genotypes and the development of simple techniques for breaking hardseedness just before sowing is a possible strategy for overcoming at least some of the problems of seed quality.

Difficulties are often experienced in obtaining satisfactory stands of the food legumes. The problem is a complex one involving loss of viability and vigour during maturation (mungbeans) and storage (soybeans), inherently poor seed vigour (some pigeonpea genotypes) and a general inability of seedling shoots to grow through high shear strength or crusted soils. The last problem is partly associated with the epigeal pattern of germination, in which the cotyledons are carried above the soil, and partly with the crooked form of epicotyl in those species with hypogeal germination. Arndt (1965) found that the hypocotyls of soybeans tended to break when emerging through a surface crust. B.J. Radford (pers. comm.) found that the emergence of soybeans was reduced when a press wheel was used during sowing and attributed this to the inability of soybean seedlings to penetrate the compacted surface soil.

Insect Pests and Diseases

The food legumes are subject to a wide range of insect pests and diseases (Shepard et al. 1983; Buddenhagen et al., these proceedings; Campbell and Reed, these proceedings) and these are often the major constraints to their production in the tropics and subtropics. In this respect they are more at risk than the cereals. However, the two groups are generally subject to different suites of pests and diseases, and therefore can often be usefully grown in rotation to break pest cycles and reduce the buildup of pathogens.

Disease resistance can be incorporated into food legume cultivars, and notable successes have been achieved in the breeding programs undertaken by the international and national institutes. However, the incorporation of insect resistance into commercial genotypes has proved more difficult. Many noncommercial legumes are relatively resistant to insect attack because of the presence of unpalatable or toxic compounds, but the dilemma for plant breeders is that these would pose a health risk to humans or animals if incorporated into commercial food legumes. Van Emden (1981) suggests that in the case of pigeonpea, plant resistance might be expected to make a contribution of 15–20% to pest management control. A similar contribution could be expected with the other food legumes.

Ecological Adaptation

The food legumes grown in the tropics are generally quantitative short-day plants, and the patterns of growth and development are determined by the genotype, the latitude of the area and the time of the year they are grown. Temperature, level of water availability and nutrition, and plant density all modify the patterns of growth and development. One of the major problems associated with the introduction of the food legumes into a new area or a modification to a cropping system involving a change of sowing date is the need to develop an adapted genotype for the specific environmental conditions. The development of genotypes insensitive to daylength is an approach frequently followed, but insensitivity tends often to be linked with early maturity and this may be advantageous or disadvantageous, depending on the environmental regime.

The food legumes show considerable diversity in their response to water deficits (Lawn 1982; Muchow 1985) and these differences are often reflected in their utilisation in cropping systems. Cowpeas are often grown as dry season crops when the availability of soil water is uncertain, and there is considerable uncertainty about the prospects of obtaining a seed crop. If the crop fails to set seed it may still be utilised for green manure or stock feed. Mungbeans and pigeonpeas are also tolerant of moisture deficits and are grown in locations where there is insufficient water for reliable soybean production.

Soils also greatly influence which food legumes can be grown. Peanut is usually grown on sandier soils where it both grows better and is easier to harvest. Soybean, mungbean, pigeonpea and cowpea can tolerate a wider range of soil physical conditions. The introduction of legumes into paddy rice cropping systems can create problems, since the process of puddling to provide suitable conditions for growing rice often leaves the soil with undesirable physical characteristics, such as low porosity and high soil strength, for the growth of the food legumes.

Effects on Soil Structure

Accelerated soil erosion can be a consequence of growing food legumes. Allmaras et al. (1975) found that soybean roots were less fibrous, were larger in diameter and had a smaller root length per unit volume of soil than corn roots. These observations may explain the findings of Laflen and Moldenhauer (1979) and Alberts et al. (1985) that soil losses were greater with soybean cropping than with corn cropping.

However, there are indications that the roots of some food legumes, such as pigeonpea and lablab bean, are capable of penetrating soils of high soil strength. Growing such crops can lead to improvements in such edaphic properties as water infiltration and porosity, because of the tunnels left in the soil following decomposition of the roots.

Nutrition

Levels of nutrients other than N can be important limitations to food legume production, and this is discussed in the paper by Craswell et al. (these proceedings). Three aspects will be commented on here; the importance of adequate nutrition during the establishment phases; the role of vesicular-arbuscular mycorrhiza (VAM) in P nutrition; and the nutritional problems associated with extremes of pH.

It is generally assumed that seed reserves are adequate to meet the nutritional demands of early growth. However, a number of workers have clearly demonstrated growth responses in leguminous species to additions of N, P and K as early as six days after germination and well before endogenous seed reserves were exhausted (Ozanne and Asher 1965; Asher and Loneragan 1967; Krigel 1967; McWilliam et al. 1970). This finding has important implications. It may explain some of the reports of low seedling vigour in some food legume species. If improved nutrition enhances early seedling growth, it could improve their competitiveness with weeds and reduce their susceptibility to pests and diseases.

Paddy soils in Asia are generally low in P (Kawaguchi and Kyuma 1977) but because P availability increases following submergence, traditional paddy rice varieties do not require additional P fertiliser (Brady 1982). However, widespread responses to P by rice and food legumes grown on upland soils have been demonstrated (Sudjadi et al. 1984). Responses to P by food legumes grown on drained paddy fields could also be expected.

Little has been published regarding VAM in relation to the legume in a cropping system in the tropics. It could well be important in a paddy rice–legume system, since paddy rice is essentially non-mycorrhizal (Bowen 1980), and therefore much depends on the survival of the VAM through firstly, the dry season and secondly, the flooded-rice cropping cycle. Tropical legumes are usually mycorrhizal (Black 1980) and early VAM infection could be important in providing sufficient P uptake for growth and nodulation.

Acid soils are common throughout the tropics. All legumes suffer when the soil pH is too low (<4.5) or too high (>7.5), both with respect to effective nodulation and to other nutrient problems. At low pH, Al and Fe toxicities and Mo and Mg deficiencies are common, whereas at high pH, Fe, Mn and Zn deficiencies may occur.

Inoculation

Legumes lose their unique advantage if they fail to nodulate, and it is fortunate that most of the food legumes nodulate freely and effectively throughout Asia. Cowpeas, mungbeans and pigeonpeas generally do not appear to require inoculation. However, soybeans and chickpeas are more specific in their *Rhizobium* requirements, and on new land inoculation is generally recommended for both crops. *Rhizobium* response trials are necessary when a new legume species is introduced into a region. We are aware of some observations of ineffective nodulation in peanuts in the new areas opened up for development under the Transmigration Scheme in Indonesia and in Burma (Beech these proceedings).

Effective nodulation can be a problem on soils with a low pH, such as the acid sulfate soils, and on these soils it is particularly important to select for adaptation of both the host plants and the *Rhizobium* strain. The anaerobic conditions associated with paddy rice growing can lead to a serious depletion of *Rhizobium* in the soil and responses to inoculation can often be obtained in legume crops grown after paddy rice.

Because the need for inoculation presents special difficulties for the low-input farming systems generally practiced in Asia, it has been suggested that the preferred strategy for plant breeders is to develop genotypes that are compatible with local strains of *Rhizobium* rather than requiring an exotic strain.

One aspect of inoculation that is often overlooked is the time lag of 3–4 weeks after sowing before fixation becomes effective. If the establishing crop is unable to meet its needs for N from mineralised soil N, crop growth can be retarded during this early period of growth. This can affect final yields directly and also indirectly, by reducing the competitiveness of the crop to weeds and by increasing its susceptibility to pests and diseases.

Seed Yield

Yielding ability is clearly one of the most important attributes of a crop species, and the food legumes have the general reputation of giving both lower and more variable yields than the cereals. Published statistics support the contention of lower yields. In 1984 average world yields of paddy rice, wheat and maize were 3.2, 2.3 and 3.5 t/ha respectively; the corresponding yields for soybeans, peanuts and dried pulses were 1.7, 1.1 and 0.7 t/ha respectively (FAO 1985b). However these figures can be a somewhat misleading indicator of true differences in potential, as the different crops are grown under a wide range of cultural and seasonal conditions. In particular, as previously mentioned, the food legumes are often sown opportunistically when poor water availability makes conditions unsuitable for a cereal crop.

It is therefore of interest to examine reported peak yields of the major cereals and food legumes. These are given in Table 4 and again show a general superiority of the cereals in yielding ability. However on the basis of protein the yields of the two groups are much more equitable. A 7 t/ha cereal crop with 10% crude protein produces 0.7 t/ha of protein; a 2 t/ha soybean crop containing 40% crude protein produces 0.8 t/ha of protein and in addition about 0.4 t/ha of vegetable oil. A consequence of the higher protein and/or oil content of the legume seeds is that they generally have a much higher unit value than the cereals, and if they are being grown as cash crops this helps to offset their lower yields.

The claim that the yields of food legumes are less reliable and show a greater variability than the cereals appears to be well founded. This is probably the combined result of their greater susceptibility to insects, diseases and environmental stresses, their production under generally less favourable conditions than the cereals, and the use of poorly adapted genotypes.

TABLE 4. Reported peak experimental grain yields for selected cereals and food legumes.

Crop	Location	Crop duration	Seed yield (t/ha)	Reference
Wheat	Washington, USA	NR*	14.1	Evans (1975)
Paddy rice	Japan	NR	10.0**	Murata & Matsushima (1975)
Maize	USA	130–140 d	22	Fischer and Palmer (1984)
Sorghum	USA	110–120 d	16.5	Pickett & Fredericks (1959)
	Australia	110–120 d	14.3	Fischer and Wilson (1975)
Soybean	Australia	125 d	8.5	Troedson (pers. comm.)
Peanut	Zimbabwe	150 d	6.4***	Smartt (1978)
Pigeonpea	Australia	120–150 d	8.0	Wallis et al. (1983)
Chickpea	India	90–180 d	4.0	Saxena (1984)

* not reported
** brown rice at moisture content of 14%
*** kernel yields

The Farming Systems Approach

The topics of 'farming systems' and of 'farming systems research' have been discussed at length during the past decade (Remenyi 1985) and it should be unnecessary to comment on the need for a holistic and multidisciplinary approach to research on farming systems and particularly the need for agricultural scientists to see farmers as an essential component of the system. Nevertheless, there are still many regrettable examples of research that purport to be conducted on a farming systems basis but which ignore the basic tenets of the systems approach.

If legumes are to have a role in farming systems in Asia they must have clear agronomic and economic benefits and must also be consistent with the social and economic constraints on farmers and with their attitudes and aspirations. In general, the benefits must be tangible to the farmer and must preferably be short-term as well as long-term. This requires that the benefits must be seen in the form of immediate increases in productivity rather than as potential future benefit arising from, say, reduced erosion or an improvement in soil fertility as a result of biologial nitrogen fixation. Technologies that are perceived by smallholder farmers as complex and requiring a higher level of managerial skill or as involving a higher level of risk than their existing systems are unlikely to be readily adopted even if it has been demonstrated that they are more profitable. Farmers, particularly those under smallholder-subsistence farming systems, may recognise the need for conservation practices but they simply cannot afford to or are not prepared to adopt any changes to their farming systems which involve some risk of reduced yields.

Increasing Food Legume Use in Farming Systems

This section outlines two major ecological areas found throughout much of Asia where food legumes could play an important role, and also highlights the difficulties of introducing food legumes into farming systems. Some food legumes that offer promise in Asian farming systems are suggested.

Possible Ecological Areas

The first ecological area considered comprises the upper river terraces and hills that are cultivated widely under the system of shifting (also referred to as swidden) cultivation. Lowland agriculture (as opposed to the highland agriculture practiced by hill tribes) has traditionally utilised the coastal lowlands, floodplains and lower river terraces (i.e. bottomland) for paddy rice production during the wet season. With the rapid increases in rural populations in Asia during the past 30 years the area of bottomland has become increasingly inadequate for local communities. Farmers have therefore been forced either to supplement their paddy production by growing upland crops on the adjacent higher river terraces and hills, or in many cases have established their homes in these areas and become totally dependent on upland crop production.

Initially the upland areas were cropped under a rotational system in which each year a portion of the bush was slashed and burnt and the crop sown directly into the ash and loose surface soil. Following the crop harvest, the land was allowed to revert to bush to allow restoration of the fertility of the soil which had been depleted by the crop. The period of bush fallow was ideally at least 10 years, but population pressure in recent decades has gradually reduced the fallow period. In the more populous areas the land is now being being cropped each wet season. There has been a decline in soil fertility, and problems of soil erosion and pest and weed buildup are becoming increasingly apparent. Nitrogen is the main limiting nutrient, and the incorporation of food legumes into the farming system could help to overcome this deficiency of N.

The second ecological area consists of the coastal lowlands, river floodplains and deltas of Asia (Cox 1968). It includes the large river systems of the Mekong (Kampuchea and Vietnam), the Chao Phya (Thailand), the Irrawaddy (Burma) and the Ganges and Brahmaputra (India and Bangladesh). It also includes large areas in Indonesia — the coastal lowlands along Sumatra's east coast, the southern, western and northern coasts of Borneo and the southern lowlands of Irian Jaya (Pons et al. 1982). The soils in these areas are a complex series but all originated from river sediments deposited into coastal tidal swamps. The soils derived from these sediments fall into two main types.

The first consists of soils laid down under a dense mangrove swamp vegetation under reducing conditions which gave rise to a build up of pyrite (FeS_2). If the acid-neutralising capacity of such high pyrite soils is low, subsequent aeration, such as by drainage, leads to the oxidation of the pyrites, the formation of sulfuric acid and a drop in the pH of the soil below 4.0. The acidity of these soils, which are termed 'acid sulfate', presents serious difficulties for their agricultural development.

The second consists of soils derived from fluvial sediments deposited along coastlines under conditions of rapid accretion (Pons et al. 1982). Under these conditions there was little buildup of pyrites. The soils derived from these sediments are not subject to acidity and are much more suitable for agricultural development.

In the tropics, large areas of both these soil types are inundated during the monsoon season and rice is the only crop that can be grown at that time. However, following the retreat of the floodwaters and the maturation of the rice crop there are good possibilities for growing food legumes on the residual moisture in the non-acid-sulfate soils. If irrigation water is available, there is also the possibility of growing crops during the dry season on such soils. The agricultural utilisation of acid sulfate soils requires either that they be used in a waterlogged condition for rice growing, or that they be drained and treated to remove or neutralise the acidity produced by the oxidation of the pyrites (Rorison 1973).

In Thailand the possibilities for year-round utilisation of the soils on the floodplain of the Chao Phya River were examined between 1966 and 1972, under the Thai-Australian Chao Phya Research Project at the then Chainat Agricultural Research Centre. Since then staff of the Department of Agriculture have continued the studies (Department of External Affairs 1968; Department of Foreign Affairs 1970; Judd 1973). While rice continues to be the favoured dry season crop, the studies have indicated the potential and the problems of a number of the food legumes including mungbeans, soybeans and peanuts when grown on these generally heavy-textured and slow-draining soils. There appears little doubt that if the market prospects were satisfactory, genotypes of many of the food legumes that would grow well on these soils could be developed. The results of the research conducted in Thailand are relevant to many areas of Asia. These areas are so large and important that an international workshop solely to review the potential and problems of growing food legumes in these areas is strongly recommended.

Cropping Possibilities

In Asia many of the cultural operations are undertaken manually, and this increases the possibilities for incorporating the food legume into farming systems. It can be grown as a main crop, as an intercrop with, e.g., upland rice or maize or, as now widely practised in Taiwan, as a relay crop sown either before or after the main wet season crop. Very promising results have been obtained in studies incorporating peanuts, soybeans and mungbeans into the upland farming systems of northern Thailand (Royal Thai Government, Ministry of Agriculture and Cooperatives, Department of Land Development 1985).

Many of the current farming systems in Asia involving legumes have evolved over many years and have developed to their present form in response to climatic, biotic and soil factors and to local food preferences and market demand. It is important to respect local systems that have withstood the vagaries of climate, pests and diseases. Implementation of change must be with care because such systems often represent a delicate balance between the factors involved in the production of the legume and the other components of the system.

There are a number of possibilities for incorporating food legumes into the farming systems of Asia and for improving food legume production where these are already a component of the local farming systems. Clearly the improvement of the food legume in an existing system offers the most immediate prospect for success, as it mainly involves establishing the key limitations in the system and then seeking to resolve these. Analyses of local agroecosystems such as those reported in the KKU-Ford Cropping System Project (1982a, 1982b) identify not only the technical problems limiting agricultural development in an agroecosystem but do so in the context of the social and economic situation. This can be particularly important when trying to decide on an appropriate solution to a technical problem. For example if a particular farming community has a high level of indebtedness it is unlikely that a solution that involves further borrowing will prove acceptable to the general community.

The introduction of new food legumes into an area or the incorporation of existing food legumes into new farming systems presents many more difficulties and may require major changes to the production system. Such changes can be complex and will often require demonstration and education programs to obtain farmer acceptance, the development of appropriate market infrastructure, the provision of credit facilities and an ongoing research program to resolve any technical problems that arise. Clearly, a multidisciplinary approach involving social scientists, agricultural scientists and often marketing and financial institutions is essential if radical changes are to be made to existing systems. However, quite dramatic alterations to practical farming systems are possible, as demonstrated by the adoption of both kenaf and cassava in Thailand.

It is very easy for agricultural scientists to believe that they can resolve the problems of a rural community by means of technical solutions. For example, pigeonpea is a food legume with many excellent characteristics, both as a crop and as a food. It is a crop that is very well adapted to large areas of the tropics and subtropics but is little grown outside of India where it is one of the major pulse crops. Why then isn't it grown in say northeast Thailand where there is no doubt that it would grow well? The difficulty is that pigeonpea is a new crop to the region and is not a local food crop. Experience has shown that it is not easy to change local eating habits, and rural populations tend to prefer to grow those food crops that they can and do consume, even if that crop is being grown primarily as a cash crop.

Fortunately there are good prospects for developing an export market for pigeonpea, but it will require the development of adapted genotypes and appropriate cultural practices, demonstration of the viability and profitability of the crop, establishment of a program of farmer education and establishment of an infrastructure for purchasing, processing and marketing the crop.

Other food legumes with promise for Thailand include chickpea as an irrigated dry season crop and guar as a wet season crop. Guar is a source of the commercial gum, galactomannan, which is used widely in industry as a flocculant, binder, lubricant and filtrant and in the food industry as a stabiliser and thickener (Jackson and Doughton 1982). Guar could be expected to grow well on the lighter textured soils of northeast Thailand. A very early maturing species, *Cyamopsis senegalensis*, is also a source of galactomannan and could be useful in areas with a short growing season or in rotation with early-maturing upland crops such as upland rice (Strickland and Ford 1984).

A comparatively recent demonstration that yields of soybean can be increased substantially by growing them under saturated soil conditions offers considerable promise for Asia (Nathanson et al. 1984; Troedson et al. 1984; Troedson et al. 1985). Soybeans grown on beds with a water table maintained at a depth of 3–15 cm below the soil surface have given yields 10–30% greater than with conventional furrow irrigation. The technique currently under test at several locations in Thailand appears to be particularly suitable for the very large lowland areas capable of being irrigated during the dry season, or where there is adequate water control during the wet season to maintain a fixed water table. It also appears to offer particular promise for the areas of acid sulfate soils. However, an extensive plant improvement program may be necessary to develop genotypes and rhizobia tolerant to low pH and high levels of iron and aluminium.

Conclusions

In this paper and in the paper on the role of the food legumes in the N cycle (Myers and Wood, these proceedings) the relative proportions of the fixed N that are removed in the seed crop or left in the crop residue are examined. While data are limited, it seems clear that with well adapted high-yielding cultivars the bulk of the fixed N is removed in the seed crop and there is little or no net gain in soil N. Clearly the primary role of the food legumes in farming systems must be seen as the production of seed. Agronomic and plant improvement programs should be directed towards this end. One of the major objectives will need to be the development of improved genotypes, adapted to the specific environmental conditions of particular sites and hopefully incorporating resistance to the local pests and diseases.

Scientists need to question the effectiveness of current research efforts on farming systems and the associated component research. The social as well as the technical and economic aspects of farming systems must also be accounted for. Too often agricultural research programs are primarily discipline-based, with the selection of research topics based on subjective judgment. This research is conducted with little or no regard to the other components of the system. A feature of biological systems is the interaction of their components, and it is important that any component research be undertaken in a farming systems context (Remenyi 1985). In recent years, developments in systems analysis and the increasing availability of computers has made it feasible to apply the approach to agricultural systems (Loomis 1986). The utility of the systems approach has been clearly demonstrated in secondary industry and it is unfortunate that its application in agricultural research has been so slow. The systems approach not only provides a more rational basis for setting research priorities, but it also provides an opportunity to simulate the time course of production and to predict the responses to changes in nominated inputs. While predictions must necessarily lack precision initially, comparisons of the model predictions with field performance will identify those areas of the models requiring modification.

Crop growth models are now available for rice, wheat, maize and sorghum, the major cereals grown in the tropics and subtropics, whereas soybean and peanut are the only food legumes that have been modelled. However, a properly structured food legume model should be amenable to simple modification to provide adequate simulation of the growth of alternate species such as cowpea, mungbean and pigeonpea (see for example the soybean model of Sinclair (1986) and Muchow and Sinclair (1986)).

A range of models exists for soil N transformations and some have been incorporated into cereal crop growth models (Godwin and Vlek 1985; Vanderlip and Myers, unpubl.) There are still few proven legume crop models that include an adequate simulation of N fixation. It is, however, technically possible to connect up such N transformation and crop growth models to model the N dynamics of a legume–cereal rotation system, but this work is in its early stages. There has been no known attempt to develop simulation models for the intercropping situation. Again it should now be technically feasible to do this by combining the simulation models for the component crops.

Inevitably, the indepth studies which provide us with the basic understanding of soil processes are performed only at a few locations on a limited number of soil types. The extrapolation or transfer of results to other locations or other soils presents difficulties. It is strongly recommended that in appropriate experiments agricultural scientists endeavour to make the critical measurements (i.e. minimum data set) that will permit extrapolation of their results to other soil types and to other locations with different seasonal conditions. Some of these critical measurements have been indicated in this paper.

There is currently a large gap between average on-farm yields and experimental yields, and constraints to the attainment of potential yields are to be found in all facets of production. Research must therefore be multidisciplinary and must address all the components in the production system. Research leading to quick and spectacular increases in yield is unlikely. Instead, an integrated research program producing steady but small incremental increases in yield is envisaged. Marked improvement in yields is also unlikely in those situations where the food legume is being grown as an opportunistic crop under adverse conditions of soil moisture, soil texture etc. While the food legumes are capable of high yields, these will only be achieved, as they are with other crops, under good growing conditions and with good crop husbandry.

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Food Legumes in the Nitrogen Cycle of Farming Systems

R.J.K. Myers and I.M. Wood *

WHENEVER a legume and a non-legume are grown together in a cropping system, the legume is expected to provide most of its nitrogen (N) through symbiotic N fixation, and also to supply some of the N requirement of the non-legume crop. Thus it may substantially reduce the input of fertiliser N required to grow the non-legume crop. The following are typical of the results reported in the literature.

Clegg (1982) found that sorghum grown after sorghum required 55 kg/ha of fertiliser N to achieve the same yield as sorghum grown after soybean. Giri and De (1980) found that pearl millet produced more grain after groundnut, cowpea or pigeonpea, compared with pearl millet after millet, but there was no response after a mungbean crop. The groundnut was equivalent to 60 kg N/ha as fertiliser, compared with 30-60 kg N/ha for cowpea, and 30 kg N/ha for pigeonpea. Doughton and Mackenzie (1984) observed that previous crops of black and green gram increased sorghum yield by as much as a fertiliser application of 68 kg N/ha. However, in none of these reports was the quantity or N content of the legume residues reported. Giri and De (1980) removed all above-ground residues, thus their crop response was due to an unknown quantity of roots, nodules and litter. Doughton and Mackenzie (1984) reported sufficient data to allow the quantity of above-ground residue to be calculated, but the quantity of below-ground residue was not reported.

There is little point in listing the many reports like this that are to be found in the literature. Instead it is proposed to examine what happens to the N fixed by a leguminous crop and the factors that determine the amount of this N that becomes available to a following crop. The aim is to provide an understanding of the processes involved, to suggest a means of analysing the results of such experiments, and to suggest some directions for future research.

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The N fixed by a leguminous crop can be considered as having two distinct but overlapping roles: to provide adequate N to meet the demands of the leguminous crop itself, and to provide N to an associated intercrop or a following crop. While it is recognised that the legume also affects some of the transformations of soil native N, these effects are not considered in this paper.

Meeting the Requirements of the Legume Crop

A great deal is expected of the food legume and its symbiotic N-fixing bacteria. The legume is expected to produce a high yield of high protein seed. The N-fixing bacteria are expected to fix sufficient N to ensure that the crop is not deficient in N at any stage of growth. A further expectation that is sometimes expressed is that N fixation should not be unduly inhibited by the presence of soil nitrate. These expectations may not be realistic on several scores. Firstly, it is possible to argue logically that, so long as the energy cost of nitrate assimilation and reduction is less than that for N fixation, an additional supply of mineral N to the plant should always increase growth since less energy would then need to be transferred to the nodules to support fixation. Secondly, a number of workers (Krigel 1967; McWilliam et al. 1970) have shown that legume seedlings require N from the growing media within ten days of germination, and that this N leads to greatly improved early growth. It seems unrealistic to expect that N-fixing bacteria could meet these early demands for N. Thirdly, the legume can meet its needs for N either by uptake of soil nitrate or from fixation. It is known that the presence of soil nitrate will increase the uptake of N from the soil and decrease the level of fixation. The possibility of modifying the genetic constitution of rhizobia to facilitate N fixation in the presence of high levels of soil nitrate is the subject of considerable research, particularly in soybean (Carroll et al. 1985). Another major objective in research is to maximise the amount of the N that is fixed into useful product, that is, to maximise the proportion of N that is removed in seed, which is referred to as the harvest index for N (NHI). Later it will be shown that this is in conflict with another important research objective. Measuring the amounts of N fixed by food legume crops in the tropics presents problems that are being addressed by ACIAR-sponsored research in Thailand and Malaysia.

Provision of Fixed N to Another Crop

The transfer of N fixed by a leguminous crop to other plants during the life cycle of the legume is probably rather small. It appears that transfer of fixed N must await the end of the legume crop cycle, and for death and then substantial breakdown of tissue to occur before mineralisation by soil microbes makes N available.

In the past, an agronomic approach has been used to determine the provision of fixed N to another crop. In this approach, the N-supplying ability of the legume is estimated by comparing the yield of the non-legume following the legume and the yields obtained from a range of levels of N applied to the non-legume following some reference non-legume crop. Heichel (1985) concluded that such assessments are likely to overestimate the contribution of symbiotic N, owing to several invalid assumptions.

The transfer of N from a leguminous crop to a following crop will be examined using a simple, static conceptual model:

$$N_c = N_l * P * (1 - NHI) * F_m * E$$

where N_c is the amount of N derived from the previous crop taken up by the following crop, N_l is the amount of N in the previous legume crop, P is the proportion of the legume N derived from fixation, NHI is the N harvest index (ideally defined as the ratio of N in seed to N in total plant biomass usually at maturity, where total plant biomass includes roots and shed leaves), F_m is the proportion of residue N that is mineralised and E is the efficiency of utilisation of this mineral N.

To maximise the contribution of N to the next crop, it is necessary to maximise N fixation, minimise NHI, maximise N mineralisation from the legume residues and maximise efficiency of utilisation. Clearly these requirements are in conflict with the optimum requirements for the food legume. For example, to maximise N fixation it would be necessary to grow the legume at the time of year that would result in the highest yield. However, this is not always possible or desirable. In northeast Thailand and many other parts of Asia, the most favourable growing period for many food legumes is the wet season, and this is usually reserved for rice. The food legume is often grown under the much less favourable conditions of the late wet season or dry season following the harvest of one or two rice crops. N fixation is also less than maximum when the legume is grown in an intercropping situation (Ofori et al., in press), which is frequently the case in Asia and Africa. Under good conditions, food legumes in the tropics can fix up to 300 kg N/ha in one growing season, but under less favourable conditions fixation levels of less than 50 kg N/ha can be expected (Table 1). The data of Table 1 were obtained mostly by the ^{15}N dilution procedure which, like other field estimation procedures, is prone to error (Witty 1983), and the conditions promoting such errors are prevalent in the humid tropics. Nevertheless, estimates in some instances were supported by other measurements which confirmed their accuracy.

Where the legume is grown primarily for its seed production, it is desirable to maximise the harvest index (i.e. the ratio of seed yield to total biomass at maturity), which will in turn maximise NHI. Naturally the higher the value of NHI, the lower the proportion of fixed N that will be left in or on the soil for the next crop. Within food legumes the NHI varies considerably between species, with soybean tending to be higher than other species (Table 2).

TABLE 1. Some examples of N fixation estimates by legume crops in the tropics.

Crop	N fixed (kg N/ha)	Reference
Peanut	240–260	Dart and Krantz (1976)
Chickpea	120–140	
Soybean	250	Boddey et al. (1984)
Cowpea	47–188	Eaglesham et al. (1982)
Soybean	290–312	Chapman and Myers (1987)
Green gram	112	
Sesbania	126–141	
Soybean	93–138	Vallis et al. (pers. comm.)
Black gram	55–72	
Soybean	9–33	Sisworo et al. (pers. comm.)
Lablab bean	66–208	Wood (1983)

TABLE 2. Harvest index for N of food legume crops

Crop	Harvest index for N	Reference
Cowpea	0.42–0.73	Eaglesham et al. (1982)
Soybean	0.80–0.90	
Soybean	0.51–0.89	Chapman and Muchow (1985)
Green gram	0.69–0.81	
Black gram	0.41–0.65	
Cowpea	0.53–0.69	
Lablab bean	0.48–0.56	
Pigeonpea	0.52–0.62	

Variation also occurs due to growing conditions, particularly water supply, with water deficits lowering the NHI. The harvest index values in Table 2 take no account of below-ground parts or of shed leaves. Presumably similar variation occurs in below-ground material, but very little information exists. Dart and Krantz (1976) estimated that for chickpea at Hyderabad roots and nodules contained about 13 kg N/ha whereas Chapman and Myers (1987) found approximately 40 kg N/ha in the roots and stem bases of several food legumes.

Data reported by Chapman and Myers (1987) for soybean, green gram and sesbania crops will be used to illustrate the fate and distribution of the N fixed by a food legume crop (Table 3). The first three columns, where the seed produced is harvested, will be considered, with later discussion on the case of green manure (column 4). In this study, the proportion of N derived from fixation and the quantities of N derived from the soil and from fixation were determined by an isotope dilution procedure. Much of the N was removed in the seed; 73, 52 and 30% for the soybean, green gram and sesbania, respectively. This left 83–141 kg N/ha in crop residues, of which 54–98 kg N/ha was attributable to N fixation by the legume.

Next, the proportion of residue N that was mineralised (F_m) and made available for crop uptake was determined. Four important factors are involved: the C/N ratio of the residue; soil water status; soil temperature; and duration of the period of mineralisation. For this simple static model, uniform conditions will be assumed. In fact, these four factors will vary over time, but this variation can only be taken into account in an integrative dynamic model. In the case of temperature, considerable variation has been noted in the rate of decomposition of plant residues according to the mean temperature at the site (Ladd et al. 1985). Thus the rates of residue decay in England, South Australia and Nigeria were in the ratios of 1:2:4 respectively. However, it is possible that these results were partly influenced by the different residues used at the three locations. Temperature should be taken into account whenever attempting to extrapolate research findings from temperate to tropical regions.

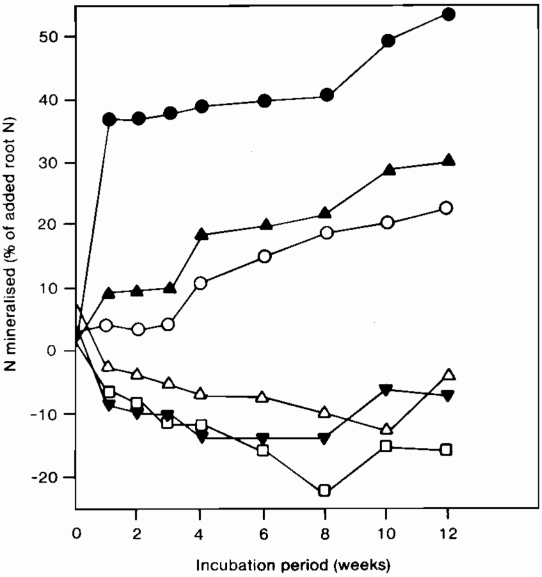

Fig. 1. N transformation from addition of legume roots to unlimed fallow soil. ● Bambara groundnut; ▲ cowpea cv.'NEP593'; ○ lima bean; △ soybean; ▼cowpea cv.'Ife Brown'; □ pigeonpea. (Nnadi and Balasubramanian 1978)

TABLE 3. Distribution of fixed N from a legume to the subsequent cereal crop. Actual data (bold type) from Chapman and Myers (1987). Estimated values (standard type) using the algorithm described in the text.

	Soybean	Green gram	Sesbania	Soybean gr. manure
		kg N/ha		
Amount of N fixed	**290**	**112**	**141**	**290**
Amount of soil N taken up	**114**	**60**	**61**	**114**
Thus, total crop N (N_t)	**404**	**172**	**202**	**404**
and proportion of total from fixation (P)	**0.72**	**0.65**	**0.70**	**0.72**
N removed in seed	**296**	**89**	**61**	**0**
Thus N left in crop residue	**108**	**83**	**141**	**404**
Thus N from fixation (Ndff) in residue	**78**	**54**	**98**	**290**
Ndff mineralised (assuming 20% of fixed N mineralised (F_m))	16	11	20	58
Ndff taken up by next crop (N_c) (assuming 80% efficiency of utilisation (E))	12	9	16	46
Fertiliser N required to provide same result (assuming 30% utilisation of fertiliser N)	42	27	53	155

With respect to C/N ratio, Nnadi and Balasubramanian (1978) observed that, with a 12-week incubation at constant temperature and moisture, root residues containing 1.5% N or less (C/N ratio >25) immobilised N, whereas those with 2% N or more (C/N ratio <20) mineralised N with the proportion mineralised being related to the initial concentration of N. Examination of these data (Fig. 1) suggests that had the incubation proceeded longer, net mineralisation from the low N residues would have eventually occurred. In the highest quality material (Bambara groundnut 3.9% N), over 50% of the N was mineralised within 12 weeks. Because plant materials with different C/N ratios release mineral N in different ways during decomposition, it is probable that an even better understanding of this would come from being able to consider the residue N as consisting of two components (McGill et al. 1981), viz., structural N with a high C/N ratio of ≈ 150 and metabolic N with a lower C/N ratio of ≈ 5. For a high quality material such as Bambara groundnut it is estimated that approximately 4% of the N would be structural and 96% metabolic, compared with 85% structural and 15% metabolic in the material containing 1.5% N. This helps explain the very fast release of N from Bambara groundnut (Fig. 1) as being due to rapid decomposition of readily decomposable material. By contrast, Lima bean and NEP593 show what is essentially a slow decomposition of lignified, less readily decomposable material. The effects of water status and duration of the decomposition period will not be discussed here.

A similar picture is seen in the data of Frankenberger and Abdelmagid (1985). They examined the rate of breakdown of stems, roots and foliage of four legumes — lucerne, Egyptian clover, cowpea and soybean — and observed that %N, C/N ratio and lignin content were important modifiers of the rate of N mineralisation from plant residues. One anomaly in their data was the net immobilisation of N by soybean stem residues containing 2.39% N. All other data were consistent with the concept of net N mineralisation occurring in material containing >1.73% N, approximating a C/N ratio of 24. Frankenberger and Abdelmagid (1985) used first-order kinetics to describe the time course of mineralisation, and derived values for the mineralisable $N(N_0)$ in their residues and for the rate constant (k). Mineralisable N correlated well with total N, but k varied considerably between the different materials. This supports the authors' suggestion that the data are better explained in terms of a two-component residue model.

These two papers, combined with the two-component model, can improve understanding of the conflicting results reported in the literature and suggest reasons for the apparent discrepancies. In studies of mineralisation and utilisation of N in plant residues, cereal crops are frequently reported to utilise no more than 20% of the N in the residues (e.g. Ladd et al. 1981). Occasionally there is a report of a much higher proportion being utilised, and in these cases it appears that the legume crop has been a green manure crop containing most of its N in a readily available form (e.g. Nnadi and Balasubramanian 1978).

To further proceed in the distribution of the original legume N, it will be assumed that the food legume crops had an N concentration of 2% (Chapman and Myers 1987), and that approximately 20% of the N was mineralised prior to and during the growth of the following crop (Nnadi and Balasubramanian 1978). Thus expected mineralisation from the fixed N in the crop residues would be 11–20 kg N/ha (Table 3).

Finally, the efficiency of utilisation of this mineral N by the crop needs to be considered. This has two aspects — losses from the mineral N pool (via denitrification or leaching) and efficiency of uptake of available N by the crop. It can be assumed that where soil N is at moderate or low levels (that is, where there is just sufficient N for plant growth, or where N is deficient), efficiency of uptake by the crop would be very high. Exceptions to this may occur where there are weeds or where there is inadequate soil moisture or poor root development. The major cause of low efficiencies of utilisation would generally be gaseous or leaching loss. Unfortunately quantitative data are not available. However, two pieces of evidence emphasise the importance of the concept. Williams and Finfrock (1962), working with paddy rice, observed that when decomposition of incorporated residues was delayed by dry conditions the value of the residues was unimpaired, whereas with favourable moisture conditions nitrate was produced and subsequently denitrified after flooding. Singh (1984) noted that much of the N released from green manures could be lost by leaching during the period between residue incorporation and the sowing of rice.

It can be reasonably assumed that 20% of the N was lost in some way, and therefore that efficiency of utilisation would be about 80%. Thus 9–16 kg N/ha derived from fixed N in the crop residues would be taken up by the cereal group (Table 3). This is higher than Chapman and Myers' (1987) estimate of 10% of the N in legume residues utilised by the following rice crop, which was equivalent to 5–10 kg N/ha of fixed N. They argued that denitrification may have reduced the efficiency of utilisation, which would suggest that the authors' estimate of 20% loss may have been too low.

Thus, of the original 112–290 kg N/ha fixed by the three legumes, only 9–16 kg N/ha would be utilised by the following crop. One further calculation can put this into context. As a rough generalisation, the efficiency of utilisation of fertiliser N in the tropics is about 30% (Firth et al. 1973, Myers 1979, 1983, R.J.K. Myers unpubl.). Thus the 9–16 kg N/ha provided from fixation by the previous legume is equivalent to 27–53 kg N/ha provided as fertiliser (Table 3).

Impact of Management on the N Cycle

Three important aspects of farm management which affect the N cycle are:

Green Manuring

When a green manure crop is grown, the entire crop is returned to the soil. The quantity of N returned and the N concentration will be higher than when seed is removed. The possible impact of this, seen in Table 3, suggests that the N value of such material is potentially very high. Unfortunately, Chapman and Myers (1987) did not have an exactly comparable treatment in their experiment, so field confirmation of this estimate is lacking.

Intercropping

With a food legume intercropped with a cereal, it is to be expected that the growth and N fixation of the legume will be less than if it were a sole crop. There is little information on the proportion of N in the legume that is fixed. Eaglesham (1980) and Ofori et al. (in press) found that the proportion was unaffected when cowpea was intercropped with corn. It is well recognised that the cereal should be fertilised specifically, so that the N fixation is not inhibited by the presence of available N from fertiliser in its root zone.

There is little to suggest that the cereal component derives much N from the legume component of an intercropping system during the same season (Ofori et al., in press). Rather, any transfer of N from legume to cereal appears to come from decomposition of residues. Similar principles apply here as for the legume–cereal sequence of sole crops discussed previously. However, some special considerations apply where above-ground crop residues are left on the soil surface. Following intercropping, such crop residues are a mixture of low C/N legume residues and high C/N cereal residues. Their behaviour during decomposition will depend partly on whether they are physically mixed or remain as discrete components in the soil. If mixed, the cereal residues could influence net N mineralisation by preventing any rapid initial mineralisation and delaying the onset of slower net mineralisation following immobilisation. A further implication is that the net mineralisation of N derived from residues will be available to both cereal and legume components, whereas ideally it should be directed to the cereal. More efficient use of this N could occur if in consecutive years the sites of the legume and cereal plants were transposed.

Effect of Large Herbivores

Two ways in which large herbivores influence the N cycle are considered. It is a widespread practice in Asia for crop residues to be cut and fed to herbivores tethered in the villages. This practice has an effect similar to that of raising the value of the N harvest index and thus reduces the residual N. If this occurred for the crops considered in Table 3, then the amount left as below-ground crop residue would be only about 40 kg N/ha, and repeating the calculations on this basis leads to only 4–5 kg N/ha contributed by N fixation to the next crop, equivalent to only 14–15 kg N/ha fertiliser N. If, however, the dung from the tethered animals is returned to the field, an additional contribution of N to the crop will occur. No estimate of this contribution is made here.

Alternatively the field may be grazed. Powell (1986) has reported apparently large benefits from the presence of cattle on cropland, with increased uptake of N by corn in excess of the quantity of N estimated to have been applied in dung. The additional benefit was assumed to be due to urine, but no estimate of this was given.

The grazing animal can influence the transfer of N from legume to cereal crops in several ways. Firstly, grazing is selective so that the higher quality (i.e. higher %N) material is grazed preferentially, leaving lower quality materials as crop residues. This will mineralise more slowly than the higher quality material. Secondly, there is a small net loss of N from the system through removal of animal products. Thirdly, there is usually a substantial loss of N from the system by volatilisation from dung and urine.

At the same time, however, the urine-N that is not lost is in a form that is readily available to the crop. For example, using the previous estimates for residues from food legume crops (Table 3), N from fixation left after seed removal is 54–98 kg N/ha. If the grazing animal consumes half of this (27–49 kg N/ha), the other 27–49 kg N/ha remains as crop residue. These residues will then contribute 4–8 kg N/ha to the next crop. However, the grazing animal will return about 23–42 kg N/ha of the originally fixed N as dung and urine. Of this, 10–19 kg N/ha can be assumed lost by ammonia volatilisation and 10–19 kg N/ha mineralised, so that 8–15 kg N/ha would be taken up by the next crop. Thus the grazed crop residues will eventually contribute 12–23 kg N/ha to the next crop. This figure is in excess of the 4–5 kg N/ha obtained when residues were cut and removed without grazing and of the 9–16 kg N/ha when residues were left in situ.

This analysis has many assumptions that undoubtedly will be questioned. It does, however, raise the possibility that grazing of residues, whilst encouraging greater losses of N from the system, could enhance the transfer of N from legume residue to cereals. It also raises the question as to whether the system of removal of residues for feeding to tethered animals is an efficient one with respect to N economy. There is also the question of how best to manage the animal residues from such a practice. However, this simplistic analysis has ignored the possibility that such removal does not include N in senesced leaves. Since the quality of senesced leaves is expected to be low, owing to transfer of N from leaves to seed prior to senescence, this contribution is probably quite small, although leaf drop is known to be substantial in mungbean and soybean.

Studying the Dynamics of Soil N in Rotations

The two most important techniques (in conjunction with a good sound field experimental technique) are the use of ^{15}N as a tracer to provide the means of identifying legume residue N and fertiliser N, and the use of appropriate data analysis. Regrettably, ^{15}N is very expensive to use. The cost factor comes through the need for expensive mass spectrometers (from $A150 000) and ^{15}N-labelled compounds ($A150 per g ^{15}N). The recent development of automated mass spectrometers brings with it the hope that some large research institutions may be able to set up central facilities for ^{15}N analysis at a moderate price.

Modelling provides another potentially powerful research tool. The results of much past research apply only to the location and conditions of that particular experiment, and cannot be extrapolated to other sites and conditions. Modelling, combined with appropriate measurements for carefully conducted experiments, offers a means of avoiding the ad hoc nature of past experimentation. Models may therefore be extremely useful in bringing order to apparently conflicting results. The authors' simple static N decay model is one example of how this might be done through using other research data to help understand the results of agronomic experiments. Such a descriptive model is a short step (conceptually) from a predictive model.

Conclusions

In this paper the role of legumes in the N cycle of cropping systems has been in term of the changes that occur in the various components involved in the N balance of such systems. In doing so, the shortcomings of the empirical approach has been demonstrated and a procedure developed that could be used in the planning and analysis of studies of legumes in cropping systems. The value of such a procedure lies in the fact that it ensures consideration is given to the important components of the system and that appropriate measurements are made to quantify the changes taking place over time.

This static modelling approach is not seen as the ultimate solution. Its obvious shortcoming is that it is a static description of a dynamic system. The necessary approximation in the static model of the dynamic effects through time of soil, water and temperature could lead to significant errors. A more complete analysis and understanding of the system would require the use of dynamic simulation modelling. Such modelling could take the form of a soil process model that estimates the N supply to the crop in relation to moisture and temperature, or eventually it may be possible to combine crop growth and soil process models to simulate the whole system. Such models would not only provide powerful tools for planning research, but could be used to optimise N use in specific cropping systems.

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Limits to Productivity and Adaptation

Food Legume Production in Asia: Past Trends and Future Prospects *

P. Parthasarathy Rao and M. von Oppen **

Food legumes — pulses, groundnuts, and soybeans — are an important source of protein and fat in the diets of people, especially in low income countries. From the early 1980s, Asian food legume production, particularly pulse output, has stagnated and declined relative to cereal production (Fig. 1). For instance in India, per caput cereal availability has increased from 403 g/day in 1971 to 450 g/day in 1984, while pulse availability has declined from 65 g/day to 41 g/day in 1984 (Government of India 1975 and 1982-84.)

The objective of this paper is to assess the prospects for increasing food legume production in Asia. This assessment is based on estimates of market parameters, the analysis of recent trends, and the results of several related studies. The expected improvements in pulse yields and in trade and processing technologies are grounds for optimism that the future of food legume production in Asia is bright. Before initiating this outlook assessment, the role of food legumes in Asia is briefly described in the next section.

Importance of Food Legumes

Food legumes account for only a small portion of the world's area and production. In Asia, pulse production (including drybeans, broadbeans, drypeas, lentils, cowpeas, vetches and pigeonpeas) amounted to only 3% of total cereal production, but 6.5% when soybeans and groundnuts are included. However, their higher value is reflected in pulse:cereal price ratios around two. Those favourable price ratios mean that food legumes are often viewed by Asian farm households as cash crops.

Nutritionally, pulses provide almost 10% of total protein intake per caput per day in Asia (Table 1). In Asia and Africa, vegetable protein sources contribute 80% of total protein intake.

The world production of food legumes in 1982-84 consisted of 57% soybean, 30% pulses, and 13% groundnuts. In Asia, pulses are proportionally more important. They account for 48% of food legume production while groundnuts and soybeans contribute 27 and 25% respectively (Table 2). Different food legumes are produced in different countries, indicating location-specific advantages (Table 3).

In Asia, the compound growth rate for production of pulses from 1970 to 1984 was 0.8% and for area under pulses 0.6%, while cereal production grew at 2.9% and cereal area at 0.6% (Table 4). In India, the major pulse producer in Asia, the rates of growth of production (0.4%) and area (0.3%) were lower than in Asia. From 1970-84, among the important producing countries, pulse production increased only in Turkey, Burma, and Thailand. By contrast, soybean production in Asia

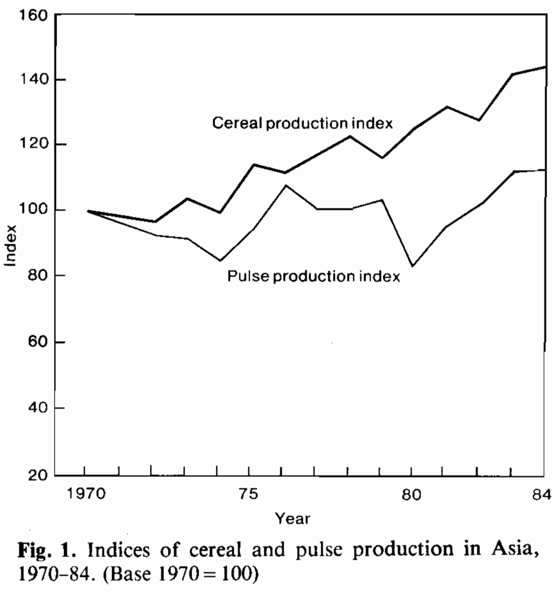

Fig. 1. Indices of cereal and pulse production in Asia, 1970-84. (Base 1970 = 100)

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has rapidly expanded. Area under soybean grew at a rate of 3.3% per annum from 1970 to 1984; soybean production grew even faster at 5.9% per annum. Area under groundnuts is slowly increasing, with a growth rate of 0.3%; production is increasing at a faster pace, by 1.4% per annum. Statistics for China have been excluded from calculations, since time-series data for China are erratic.

Demand and Supply of Pulses

Pulses are of moderate importance in Asia, and the overwhelming evidence of stagnating pulse production leads one to ask the extent to which pulse production is constrained by weak demand or by farmers' lack of responsiveness to rising market prices signalling increased demand. To examine whether demand or supply considerations are more important in conditioning output, estimates of market parameters for pulses are compared to those for other commodity groups. Comparison is restricted to India and Bangladesh where pulses are traditionally grown in large quantities and where thorough demand studies (Murthy 1983; Pitt 1983) have been conducted.

Demand Elasticities and Projections

Like other commodities, food legumes have economic characteristics which are reflected in consumers' decisions conditioned by changes in prices and incomes. These responses are measured in the form of elasticities, i.e. the percentage change in quantities demanded, given a 1% change in price or income.

In this section the income and price elasticities of demand of pulses are compared with other commodity groups for low- and high-income rural households in India and Bangladesh (Tables 5a and 5b). For India, the elasticities are reported separately for chickpeas and for other pulses as a group.

With regard to changes in income, pulses occupy a position of preference similar to rice and wheat. A 1% change in income or consumer expenditure results in about 1% increase in the quantity of pulses consumed for the lower income households in India and for the lower and higher income households in Bangladesh. For higher income rural households in India, the demand for 'other pulses' behaves like most food commodities — responsiveness declines

TABLE 1. Protein consumption per caput/day in different regions of the world (1977).

Region	Consumption (g)	Proteins from[1]: Pulses (%)	Proteins from[1]: Total non-animal sources (%)
Africa	59	10	79
North Central America	93	4	39
South America	67	11	56
Asia	58	10	80
Europe	97	2	45
World Total	69	7	65

[1] Figures are percentage of column 1.
Source: FAO 1980.

TABLE 2. Distribution of area and production of food legumes in Asia compared to the world (1982–84 average).

Crop	Area (m ha): World	Area (m ha): Asia	% share of Asia in world	Production (m t): World	Production (m t): Asia	% share of Asia in world
Drybeans	25.4	12.6	50	14.8 (10)[1]	6.7 (14)	45
Broadbeans	3.3	1.9	58	4.2 (3)	2.5 (5)	61
Drypeas	8.0	1.9	24	10.2 (7)	2.4 (5)	24
Lentils	2.4	1.9	81	1.6 (1)	1.3 (3)	80
Chickpeas	9.9	9.2	93	6.5 (4)	6.0 (13)	92
Other pulses	17.3	7.1	40	9.3 (6)	3.9 (8)	44
Total pulses	66.3	34.6	52	46.6 (30)	22.8 (48)	49
Soybeans	51.0	10.3	20	87.2 (57)	12.0 (25)	14
Groundnuts	18.5	11.3	61	19.3 (13)	12.7 (27)	66
Total food legumes	135.8	56.3	41	153.1 (100)	47.6 (100)	31

[1] Figures in parentheses indicate percentage contribution of different food legumes to world and Asian production.
Source: FAO 1984.

as income rises. In general, the demand for pulses is not as strong as the demand for 'other food' and nonfood commodities in India and is weaker than the demand for milk, mustard oil and potatoes in Bangladesh. Therefore, as income increases in rural South Asia the demand for pulses is expected to rise but not as fast as for several other agricultural and nonagricultural commodities.

The elasticity estimates in Table 5a for India also indicate that consumer preferences may be markedly different for different pulses. The income responsiveness to chickpea is much less than for 'other pulses' (mainly comprised of pigeonpea). For higher income rural households, a proportional 1% increase in consumer expenditure is accompanied by less than 0.1% increase in demand for chickpea. The relative inferiority of chickpea as a pulse is not surprising. It is often grouped with cereals because flour is its most important end use. Hence, chickpea is considered as a substitute to cereals, while other pulses are viewed as complements to cereal consumption. The cross-price elasticity between the price of rice and wheat as a group and demand for chickpea is 0.411; it is −0.229 for other pulses for low income rural households in India. For high income rural households the elasticities are 0.12 and −0.07 respectively.

In India, the price elasticities of demand for rice and wheat and 'other pulses' are about the same and suggest a fairly high degree of responsiveness to changes in price, particularly for lower income households. Price elasticities of demand for pulses are also similar between rural households in India and Bangladesh. A 1% increase in pulse price leads to 0.5–0.6% fall in pulse consumption. In India, household consumption is more sensitive to changes in the price of nonfood commodities and in Bangladesh to fluctuations in the price of potatoes and rice than to changes in the price of pulses. In the short run, an increase in the supply of those commodities would likely result in a less steep fall in relative price than an equivalent increase in the supply of pulses. In any case, the estimated price elasticities of pulses in Tables 5a and 5b are not too low; thus, we do not have to be too concerned that a sharp increase in supply caused by abrupt technical change will result in an abrupt decline in prices to producers. Marketing research by Raju and von Oppen (1982) also shows that pulse markets, at least in India, are reasonably well-integrated; hence, the national market should be capable of absorbing regionally increasing supplies derived from locationally specific technical change.

TABLE 3. Average production of legumes in Asian countries 1982–84.

Country	Pulses	Soybeans	Groundnuts
India	53[1]	5	51
China (Peoples Rep)	27	79	34
Pakistan	3	—[2]	—
Turkey	6	—	—
Burma	2	—	5
Thailand	1	—	1
Indonesia	1	5	6
Japan	—	2	—
Korea (DPR)	—	3	—
Total	93	94	97

[1] Figures are percentage of total Asian production for each commodity.
[2] Negligible amount.

TABLE 4. Compound growth rates (%) for cereals, pulses, soybeans, and groundnuts for important growing countries in Asia (1970–84).

	Area				Production			
Country	Cereals	Pulses	Soybeans	Groundnuts	Cereals	Pulses	Soybeans	Groundnuts
India	0.5	0.3	5.5	0.2	2.8	0.4	5.3	1.3
Pakistan	1.4	0.1	—	—	3.9	-1.2	—	—
Turkey	0.1	6.1	—	—	3.4	5.8	—	—
Burma	-0.8	2.1	—	-1.2	5.2	2.0	—	0.6
Thailand	2.9	8.1	5.4	-1.0	3.1	4.4	6.0	-2.9
Iran	1.5	3.4	—	—	3.0	2.9	—	—
Indonesia	0.8	-2.1	-0.1	2.4	4.9	1.3	1.4	4.8
Korea (DPR)	-0.7	-0.1	-2.4	—	4.5	2.6	3.9	—
Bangladesh	1.0	-0.6	—	—	2.7	-1.9	—	—
Syria	1.8	-0.8	—	—	6.1	1.9	—	—
Nepal	1.6	2.4	—	—	0.7	2.1	—	—
Japan	—[2]	—	4.1	—	—	—	5.5	—
Korea (Rep)	—	—	-3.9	—	—	—	0.1	—
Total Asia[1]	0.6	0.6	3.3	0.3	2.9	0.8	5.9	1.4

[1] Total Asia area and production data does not include China (Peoples Rep).
[2] - = rate not calculated, values too small.

Aside from income and prices, population growth is the other important demand shifter. Demand for pulses in India is estimated to increase by 3-3.8% per annum from 1984/85 to the year 2000, depending on the assumptions regarding total expenditure growth. According to estimates by the World Bank (1981), demand in India for pulses by the turn of the century would be 20-25 million tonnes. The projections by the National Commission on Agriculture (Government of India 1976) are similar, indicating a demand in the year 2000 of 23-28 million tonnes.

Production of pulses in 1983-84 was 12.6 million tonnes. To satisfy demand, production will have to double in 20 years.

Supply

An analysis of district data for India from 1956 to 1975 on production response to changes in relative commodity and input prices indicates that the supply elasticities of pulses during that period were about 0.4, implying a price increase of 1% would be followed by an increase in production of about 0.4% (Bapna et al. 1984). From the own-price (nominal prices) elasticity estimates in that study, farmers were about as responsive to changes in pulse prices as to changes in the prices of rice, wheat, sorghum, and groundnut.

Estimates for India as a whole indicate greater price responsiveness. A recent study by Anuradha (1986) shows that pulse supply response at the national level is larger than the district estimates. The output supply elasticity of pulses with respect to real prices was estimated to be 1.1. Further, the elasticity of output with respect to yields of pulses relative to cereals was found to be 1.2, i.e. if yields of pulses (relative to cereals) increase by 1% then pulse output wil increase by 1.2%. Based on sampling of evidence it can be inferred that farmers are responsive to price changes in pulses. This will be shown for pigeonpeas in the next section.

Price and Related Area Trends

The elasticity estimates on demand and supply suggest that pulse:cereal price ratios will rise over time and that farmers will be able to respond to that economic incentive by planting more pulses. Those hypotheses are examined with emphasis on pulses, looking at trends in pulse: cereal price ratios and changes in pulse area and production.

Pulse:Cereal Price Ratios

In Table 6, the pulse:cereal price ratios from 1970 to 1984 are shown for a number of major pulse-producing countries in Asia. The average ratios are

TABLE 5a. Income and price elasticities of demand for different commodity groups for low and high income group rural households in India.

	Income elasticity		Price elasticity	
Commodity group	Low income households	High income households	Low income households	High income households
Superior cereals	0.81	0.34	-0.69	-0.39
Chickpea	0.47	0.07	-0.81	-0.20
Other pulses	1.04	0.46	-0.63	-0.48
Edible oil	1.03	0.96	-0.46	-0.61
Other food	1.60	0.69	-0.82	-0.55
Non-food	1.23	1.60	-0.66	-1.00

Source: Murthy 1983.

TABLE 5b. Income and price elasticities of demand for different commodity groups for low and high income group rural households in Bangladesh.

	Income elasticity		Price elasticity	
Commodity group	Low income households	High income households	Low income households	High income households
Rice	1.19	0.94	-1.30	-0.83
Pulses	0.84	1.04	-0.68	-0.51
Mustard oil	1.03	1.31	-0.09	-0.72
Milk	2.52	1.91	-1.08	-0.25
Potatoes	1.61	1.88	-1.68	-0.96

Source: Pitt 1983.

highest in Turkey (3.1) followed by Thailand (1.86), while in Asia, the average ratio is 1.6.

For most of the pulse-producing countries in Asia, a period of decreasing or stagnant price ratios during the 1970s was followed by a period of consistently increasing price ratios from around 1980 onwards. The exception is Turkey, where the price ratios were already high during the 1970s.

The price data on general food items, such as 'pulses' or 'cereals', are highly aggregated and hence do not convey much information on the relative profitability of crops in specific farming systems. It may, therefore, be of interest to examine price trends of specific competing cereals and pulses over the same period. Trends were examined for India, where detailed data are available. The price ratios of pulses:coarse grains, pigeonpea:sorghum, pigeonpea:maize, chickpea:wheat, groundnut:pearl millet and rabi groundnut:paddy are shown in Table 7. A pattern is discernible in the behaviour of the pulse:cereal price ratios: a declining trend during the 1970s, a sharp rise around 1978/80 (the years 1978, 1979 and 1980 were agriculturally adverse, with overall decline in foodgrain production and price rises more rapid for pulses than cereals) and a subsequent drop and another increase since 1982. Since the mid-1970s cereal production has been increasing, and stagnating supplies have caused cereal price increases to taper off while pulse prices keep rising.

TABLE 6. Price ratios of pulses:cereals for important pulse-growing countries in Asia, 1970–84.

Year	India	China	Pakistan	Turkey	Burma	Thailand	Asia
1970	1.2	1.3	2.4	1.7	1.8	1.6	1.4
1971	1.2	1.3	1.6	3.0	1.9	2.0	1.7
1972	2.0	1.3	—	5.1	1.9	1.9	1.7
1973	1.7	0.8	2.4	4.2	1.5	1.3	1.3
1974	0.7	0.8	1.4	2.8	1.5	1.6	1.4
1975	0.6	0.9	0.9	1.5	1.3	1.4	1.1
1976	1.3	1.1	1.4	3.1	1.4	3.0	1.8
1977	1.7	1.3	—	4.0	2.0	2.5	2.1
1978	1.6	1.2	1.0	3.6	1.6	1.7	1.6
1979	1.9	1.0	1.1	3.9	1.3	1.7	1.6
1980	1.5	1.5	1.3	2.9	1.1	1.5	1.5
1981	1.3	1.9	1.3	2.5	1.3	1.6	1.6
1982	1.4	2.6	2.2	2.4	1.5	2.1	1.9
1983	1.4	2.4	2.1	—	1.9	1.9	1.7
1984	1.6	2.8	2.1	2.5	2.1	2.1	2.0
Average	1.4	1.6	1.6	3.1	1.6	1.9	1.6

Source:FAO 1970–84.

TABLE 7. Price ratios of selected grain legumes to competing cereals in India, 1970–84.

Year	Pigeonpea: sorghum	Pigeonpea: maize	Rainy-season pulses: coarse grains	Chickpea: wheat	Groundnut: pearl millet	Postrainy season groundnut: paddy rice
1970–71	1.5	1.5	1.6	1.1	2.2	2.1
1971–72	1.3	1.7	1.9	1.3	2.2	2.1
1972–73	1.4	1.6	2.0	1.8	1.7	3.1
1973–74	1.3	1.5	1.7	1.6	2.2	2.4
1974–75	1.4	1.4	1.4	1.3	1.8	2.1
1975–76	1.2	1.3	1.4	1.1	1.5	2.2
1976–77	1.1	1.5	1.7	1,3	2.1	3.0
1977–78	2.1	2.2	2.2	1.7	2.6	2.3
1978–79	3.0	2.6	2.8	1.6	2.3	2.4
1979–80	2.5	2.3	2.9	2.1	2.6	2.6
1980–81	2.4	2.2	2.5	2.1	2.5	3.0
1981–82	2.0	2.1	2.1	1.5	2.8	2.9
1982–83	2.3	2.1	2.2	1.4	2.7	3.0
1983–84	2.8	2.4	2.4	—[1]	3.0	—[1]
Average	1.9	1.9	2.1	1.5	2.3	2.6

[1] - = data not available.

Source: Government of India 1968–1981, 1982–1984.

Area Response to Changes in Price Ratios

To see how prices may have affected supply response over time, the data on pulse:cereal price ratios in Table 6 are presented graphically in Figs 2 and 3, with information on pulse area sown by region or country from 1970–84. Both the price ratios and the area estimates are presented in index numbers, with 100 equalling the simple average of the 15-year period. In Burma and Thailand, upward moving pulse prices appear to coincide with an expansion in area. For Turkey, Pakistan and India, and for Asia as a whole, movements in the cereal: pulse price ratios are not highly correlated with shifts in pulse area.

For India, indices of price ratios of competing food legume and cereal crops with their respective area indices of food legumes are shown in Figs 4 and 5. The area of rainy season pulses has increased in tandem with its relative price ratio. In particular, pigeonpea area has steadily increased after 1980. In contrast, area planted to chickpea, a postrainy season crop, shows no discernible upward trend. In recent years, chickpea:wheat price ratios have declined. That trend in relative chickpea prices partially supports an earlier finding on the low income elasticity of demand for chickpeas. Rainy season groundnut area is stagnant despite a favourable price ratio compared to pearl millet, while postrainy season, irrigated groundnut area has increased since the mid 1970s as the groundnut:paddy price ratio has also risen.

The data in Tables 6 and 7 and Figures 2–5 do not make a compelling case for stating that food legume:cereal price ratios have unambiguously increased and that such changes (where they have occurred) have been accompanied by a response in area planted to food legumes. Still, some food legumes, like pigeonpea and postrainy season groundnut in India, have recently gained ground. Part of their expansion in area is undoubtedly due to the more favourable relative price environment of the 1980s.

Future Prospects

There are several reasons to believe that the past trend of stagnating pulse area and production of 1970s is giving way to a moderately improving trend documented in the early 1980s.

1. Scientists expect that improved technologies in pulse production will be developed which increase yields. A Delphi study was conducted among ICRISAT scientists to assess their views on yields of

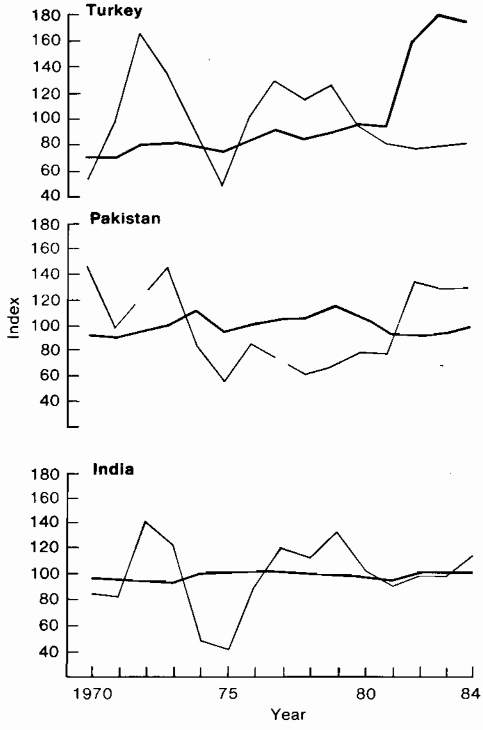

Fig. 2. Indices of price ratios of pulses to cereals and indices of pulse area in India, Pakistan and Turkey, 1970–84. (Base 1970–84 avg 100)

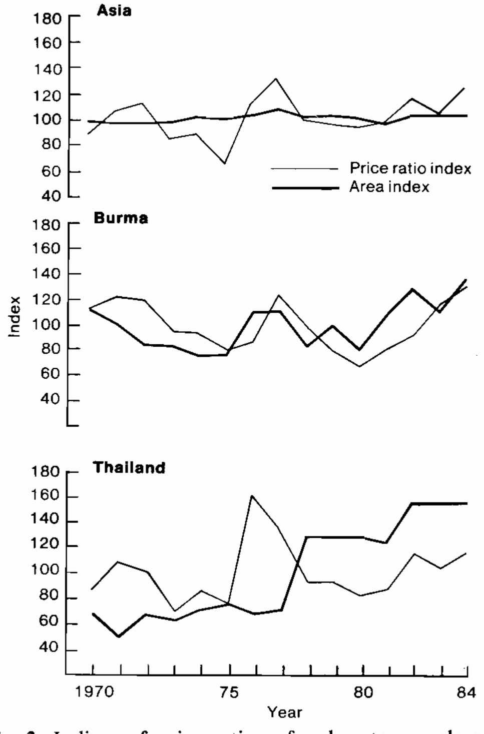

Fig. 3. Indices of price ratios of pulses to cereals and indices of pulse area in Thailand, Burma and Asia, 1970–84. (Base 1970–84 avg 100)

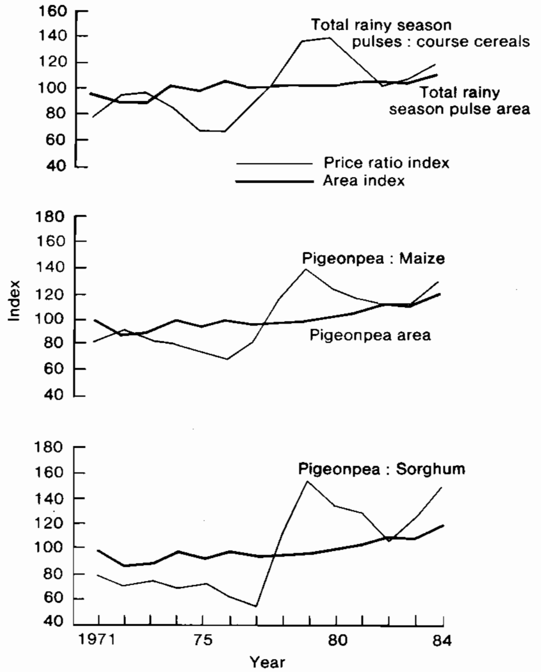

Fig. 4. Indices of price ratios of competing pulses to cereals and indices of pulse area in India, 1971–84. (Base 1970–84 avg 100)

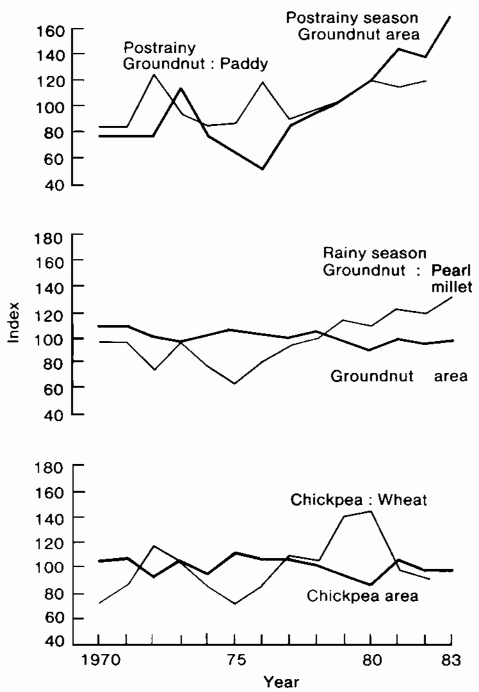

Fig. 5. Indices of price ratios of pulse and groundnuts to cereals and indices of grain legume area in India 1970–84. (Base 1970–84 avg 100)

mandate crops. The study involved a questionnaire survey in two rounds. In the first round, scientists' assessment of yields of particular crops for 1990, 2000 and 2010 were obtained. After a summary analysis of the first round, the questionnaire was recirculated, summarising the findings and offering the scientist the option to revise their earlier estimates. The results show that with current levels of resource allocation, yields in farmers' fields in India in the year 2000 will increase: pigeonpea from 880 to 1510 kg/ha (70%), chickpea from 660 to 1470 kg/ha (120%), and groundnut from 840 to 1815 kg/ha (116%). These expectations give predicted compound growth rates of 3% for pigeonpeas and 4% for chickpeas and groundnuts (von Oppen and Subba Rao 1985).

2. Trade in pulses at the world level has almost doubled from about 1.8 million tonnes in 1966–68 to nearly 3.1 million tonnes in 1982–84, i.e. from 5 to 7% of total production. This general trend of increasing pulse trade is also observed in Asia, where pulse trade (exports) increased from 0.4 million tonnes in the 1960s and 1970s to 1.1 million tonnes in 1982–84. Imports of pulses by Asian countries have increased to similar extent (Table 8). While these increases are small compared to total production, it is important to note that this trend is very recent (since 1980) and is consistent with increased production. This increase in world trade is probably a reflection of increasing commercialisation of pulse production in many producing countries and a growing demand for pulses in countries where income is rising. In contrast to pulses, 53% of soybean production entered world trade in 1984 (36% in 1976) of which 42% was traded in the form of oil. Asia is a net importer of soybean. In 1984, it imported 18 million tonnes, or 150% of local production, of which 10 million was in the form of oil.

Pulse production is location-specific; different countries have specialised in the production of particular pulses. For instance, within Asia, China produces 96% of broadbeans and 83% of drybeans. India accounts for 82% of total chickpea production (Table 9). Also, within a country pulse production varies markedly from region to region. For instance in India, pulse production is highly diverse. A single state or a few states account for bulk of the area of particular pulse crops (Sharma and Jodha 1984). If several regions specialise in the relatively best suited crops, then aggregate production from all regions should rise. Regional efforts in plant breeding, pest control, and crop management programs are likely to accelerate this specialisation. Furthermore, improvements in trade and marketing channels support regional specialisation.

A modelling exercise (von Oppen 1978) revealed that, compared to cereals, pulse production in India is more affected by restrictions in interregional trade. The model was based on data representing the following hypothetical case. In the three Indian states of Andhra Pradesh, Madhya Pradesh, and Maharashtra, three crops, namely rice, sorghum, and chickpea were grown, and all three crops competed for the same locally available resources, particularly land. In the model, yield per acre was assumed to restrict supply, so that the total use of land for all three crops could not exceed its limits in each state. Supply was further restricted by a linear function of area response to price multiplied by yield. The initial elasticities of supply were derived from available estimates. The model also incorporated demand as a linear function of price, using available elasticities. Transportation costs between regions corresponded to official rail freight rates.

The model results showed that larger proportions of chickpea (38%) enter free interregional trade compared to rice (15%) and sorghum (19%). A trade restriction is then imposed on each of the crops, such that quantities traded will not exceed 10% of the quantities traded without restrictions. In that situation, total production of rice remained unaffected, sorghum production declined by 5%, but chickpea production decreased by 13%. Total output of all foodgrains together decreased by 2%. Over time Indian state governments have lifted many of these trade restrictions. Freer interstate trade should reinforce aggregate productivity gains from regional specialisation.

The location-specificity of pulse demand may also limit international trade. Populations in different regions are accustomed to the consumption of particular pulses, and given their consumption preferences they cannot easily switch to other protein sources. Those food legumes which are consumed in processed form (e.g. soybeans) have a relatively wide international market. As pulses are increasingly processed and consumed in the form of flours, instant foods, snacks or other preparations, it is likely that interregional and international trade will grow.

3. Pulses, in contrast to wheat, coarse grains or even rice, generally require more elaborate and costly processing before human consumption, e.g. in India pigeonpeas, chickpeas, and other pulses are dehulled and split before they are cooked. Processing is done in specialised mills. All quantities marketed and traded outside the village (about 40–50% of production in India) pass through these mills, which operate with considerable economies of scale. For instance, the cost of processing

TABLE 8. Development of pulse imports and exports for major pulse trading countries in Asia.

Country	Exports ('000t) 1966–68	Exports ('000t) 1974–76	Exports ('000t) 1982–84	Country	Imports ('000t) 1966–68	Imports ('000t) 1974–76	Imports ('000t) 1982–84
China (Peoples Rep)	126	85	102	China (Peoples Rep)	25	36	102
Thailand	68	104	221	India	3	6	93
Turkey	33	67	540	Pakistan	0.1	0.2	97
Burma	73	32	76	Japan	184	175	197
Syria	41	18	32	Malaysia	—	28	53
				Singapore	20	23	35
				Sri Lanka	75	13	17
				Saudia Arabia	9	12	37
Asia total	462	396	1045		470	441	889
World total	1843	1787	3088		1843	1787	3088

Source: FAO 1968, 1976, and 1984.

TABLE 9. Average production of pulses in Asian countries, 1982–84.

Country	Dry beans	Broad beans	Drypeas	Chickpeas	Lentils
India	49[1]	—[2]	14	82	40
China (Peoples Rep)	27	96	83	—	—
Pakistan	1	—	—	7	2
Turkey	3	3	—	5	46
Thailand	4	—	—	—	—
Burma	3	—	—	3	—
Total	87	99	97	97	88

[1] Figures are percentage of total Asian production for each commodity.
[2] Negligible amount.

chickpeas into split peas is reduced by 20%, from Rs 25 to Rs 20 per tonne, when the capacity of the processing unit is increased from 22 to 40 t/day (Gangwar et al. 1983).

Investments into larger mills will not be attractive as long as the industry is facing highly unstable and generally stagnant supplies from farmers. Millers have difficultly in discerning trends when the variability (measured by the coefficient of variation) in production of crops such as pigeonpeas and chickpeas is as high as 25-60% at the district level. For comparison, estimated coefficients of variation for rice production at the district level have a much narrower range were 15-30% (the coefficients of variation were calculated for important growing districts (10 for each crop) with production data from 1956 to 1979).

Once expansion has been recognised, market processors and traders are likely to invest because profits from large mills can be considerable. Market competition will force traders and millers to share these costs advantages with the farmer, and this in turn will accelerate the supply response of farmers.

The development of India's soybean industry is a good case in point. Growth has been exceptionally rapid and parallels what happened in Brazil in the 1960s. The rapid adoption of a new crop is proof of farmers' responsiveness to market demand and of the processing industry's ability to convert to profitable enterprises (von Oppen 1982).

4. Recently, policy-makers in many Asian countries have become aware of the negative welfare implications of high pulse prices to poor consumers and have begun to implement programs to boost pulse productivity (Asian Productivity Organization 1982). In several Asian countries this concern stems from achieving cereal self-sufficiency at the cost of oilseeds and pulses. Governments in India, Indonesia, and Thailand have now begun to pay more attention to pulses in their development planning (McWilliam and Dillon, these proceedings).

Summary

Over the past 15 years food legume production in Asia, except for soybean and to a lesser extent groundnuts, has been stagnant. The production of pulses has declined in several Asian countries. Nonetheless, there appear to be indications that the downward trends in pulse production passed their lowest point in 1980/82 and that the upward movement observed in recent years may continue. This assessment is based on the following observations: pulse prices (relative to cereals) are rising for some species; improvements in marketing and processing facilities should increase response to market demand; national and international trade in pulses is increasing; scientists are optimistic regarding the possibilities for increasing yields in farmers' fields; and policy-makers have expressed concern for the welfare implications of decreasing relative pulse production. To substantiate and evaluate the consequences of these emerging trends, more information is needed on commodity demand and supply estimates and on cost of production between pulses and competing crops.

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Limits Imposed by Management in Irrigated Farming Systems

V.R. Carañgal *, M.V. Rao ** and B. Siwi ***

FOOD legumes are an important component of the production systems in small farm holdings, but they are generally considered to be secondary crops. The most important in terms of hectarage are chickpea, mungbean, soybean, peanut, cowpea, black gram, faba bean, pigeonpea, lentil and lathyrus. Lathyrus, chickpea and lentils are important in subtropical areas of northern India, Bangladesh, Burma, Nepal, Pakistan and Afghanistan. Faba bean is grown mainly in China and to a certain extent in northern South Asia. Soybean is very important in China, Indonesia, Vietnam and Thailand, and its cultivation is expanding in Sri Lanka, India and the Philippines. Black gram is grown in India, Nepal and Pakistan.

Yield levels of the food legumes are generally low because they are grown in marginal areas or on residual moisture, under rainfed situations with very low management. The traditional system is to broadcast legumes (mungbean, cowpea, lathyrus, soybean, chickpea) after harvesting rice. In upland areas, legumes are grown during the rainy season, when weeds, insects and diseases are major problems, and during the dry season when drought is an added problem.

The area of food legumes under irrigation is very limited, with most irrigation systems constructed for major staple and export crops such as rice, wheat, oil crops and cotton. The amount of water in these irrigation systems will determine what other crops can be irrigated. In areas with limited water, food legumes with high market value are grown.

Two-crop systems involving legumes are common in irrigated areas and 3-crop systems are becoming widespread because of earlier maturing varieties. The most common cropping systems in irrigated areas are cereal-legume, cereal-cereal-legume, legume-cereal-cereal, legume-cereal-legume. In northern Thailand, rice-soybean and rice-peanut are important cropping patterns. With the rice surplus in Thailand these two patterns have increased and the rice-rice system has decreased in the Chiang Mai Valley. A new cropping system being promoted in northern Thailand is mungbean-rice-soybean. In southern Taiwan, the most popular systems are rice-rice, rice-rice-soybean and rice-rice-red bean. With the rice surplus in Taiwan, research stations are now looking at substituting soybean and corn for either the first rice or second rice crop. The most popular cropping pattern in Pakistan is rice-wheat. Rice-chickpea is also popular, although the area cultivated is similar because of disease (Ascochyta blight) and the popularity of basmati rice. Resistant varieties are now available, and two promising cropping patterns are rice-sunflower and rice-chickpea. In India the recommended cropping patterns in irrigated areas involving legumes in light textured soils are: a) early rice (July-Sept), groundnut (Oct-Jan), rice (Feb-May); b) jute (May-Sept), groundnut (Oct-Jan), rice (Feb-May). In medium-textured soils the recommended systems are medium rice (July-Oct), corn (Nov-Feb), mungbean (March-May), medium rice (July-Oct), pea (Nov-Jan) and rice (Feb-May). In medium or heavy textured soils, rice (July-Nov), black gram (Nov-Dec) and rice (Feb-May), jute (April-Aug), rice (Sept-Dec), pulses and rice (July-Nov), chickpea (Nov-Feb), rice (Feb-May) are the recommended patterns. In large irrigated areas with limited water for the third crop of rice, such as in the Philippines, Indonesia and India, rice-rice-mung bean is recommended. Soybean or cowpea are recommended after two rice crops in the same area.

In the non-rice areas, limited areas of food legumes are grown under irrigation, except in China. The major cropping systems in northern China under irrigated conditions are corn-wheat-soybean relay intercropping and corn-wheat-soybean, depending on latitude. In the relay cropping system,

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wheat strips of 4–6 rows are planted with 0.33 m between strips. Corn is the relay crop on the vacant space between strips, sown one month before harvesting wheat. After harvesting the wheat, 2–3 rows of soybean are grown between the corn rows. Soybean-wheat is a major cropping system in Hui, Yellow and Yontze river valleys in China. Most of the valleys have good irrigation systems.

Limits to Productivity

The average yields of food legumes in Asia are very low compared to yield potentials calculated for developing countries. Difference ranged from 50 to more than 500%. These observations are true, not only for food legumes but also for other crops including rice and wheat. Crop yields are generally lower when the crop is a component of a cropping pattern, especially intercropping and relay cropping. Since most crops are developed as monocrops, there is a need to develop varieties and management techniques to increase the productivity of grain legumes in cropping systems for various environments.

The potential yields of various systems were evaluated in several parts of India under the Model Agronomy Trial Project. The total yields of the 3-crop patterns involving legumes were 9.55 t/ha for rice-rice-groundnut, 10 t/ha for rice-wheat-mungbean and 14.70 t/ha for maize-wheat-chickpea. In those trials, the yield of groundnut was 4.57 t/ha, mungbean was 1.30 t/ha and chickpea was 1.80 t/ha. In the All India Agronomic Research Project, data on production potential of different cropping systems also showed very high yields (Table 1). The yield of the legumes varied depending on the location. The yield levels of these crops in farmers' fields were very low. There was a wide gap between the farmers' yield and potential yields identified in many demonstration trials.

Pandey (1986) reported that experiment station yield was 3.7 t/ha, researcher's yield in farmers' fields was 2.8 t/ha, and farmers' yield was only 0.80 t/ha (Fig. 1). He suggested that the gap between experiment station yield and researcher's yield in farmers' field was caused by environment and soil factors, and the gap between researcher's yield and farmer's yield was due to technical resources and social factors.

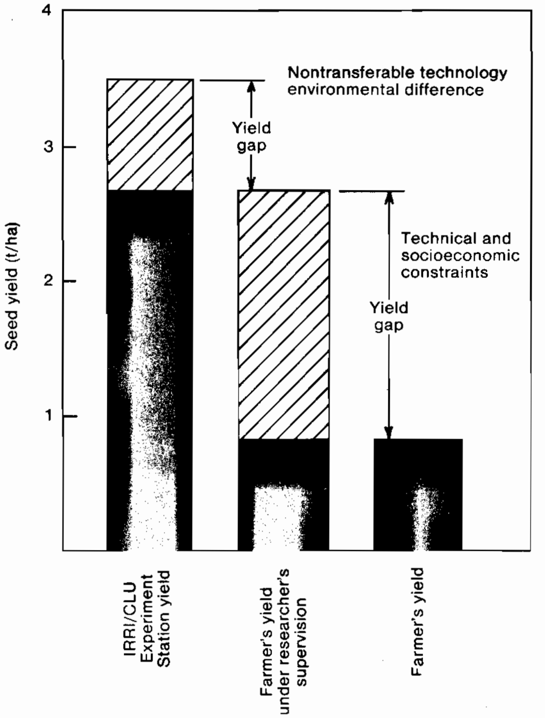

Fig. 1. The yield gap between experiment station yields in the Philippines.

TABLE 1. Production potential of high-intensity crop rotations and their relative economics (promising crop sequences from selection locations) (AICARP data pooled over 1979–80 to 1981–82).

Location	Crop Sequences			Yield (kg/ha)			Total grain yield including pulses and oilseeds (kg/ha)	Net returns (rupees/ha)
	Kharif	Rabi	Summer	Kharif	Rabi	Summer		
Pantnagar	rice	wheat	cowpea + maize (F)	3818	4293	29333*	8511	10835
Faizabad	rice	potato + wheat	green gram	4388	12732	625	8433	21024
Varanasi	rice	wheat	green gram	4748	3434	1060	9242	10592
Rudrur	rice	groundnut	black gram	4200	2061	920	5120	13774
Karjat	rice	wheat	green gram	3416	2012	540	5968	6245
Thanjavur	rice	rice	groundnut	6040	3528	2175	9568	16464

* Green fodder yield.

The reasons for yield differences between potential and farmers' average yield levels can be summarised as follows:

1. lack of suitable varieties for different growing conditions;
2. seeds of recommended varieties not readily available to farmers;
3. use of zero to minimal tillage for the legumes, especially after lowland rice;
4. dependence on conventional draught power, resulting in poor tillage and poor plant stand;
5. poor stand due to inadequate plant population, poor seed viability and poor crop establishment;
6. shifting planting dates due to unreliable environment;
7. non or minimal use of fertiliser;
8. most crops are grown in marginal areas with very low management, especially in areas with soil stress like low pH, salinity, pest and drought;
9. poor nodulation and rhizobial nitrogen fixation;
10. lack of adequate moisture, even under irrigated conditions;
11. poor water distribution resulting from poor water management, causing water logging and moisture stress;
12. problems of weed infestation;
13. technology unsuitable for different cropping systems;
14. problems of insect infestation and disease infection;
15. scattered and small land holdings that prevent efficient adoption of technology;
16. low incentive associated with share cropping and other land tenure systems;
17. high risk in applying agricultural inputs to increase yield;
18. lack of capital resulting from low income of smallholder farmers;
19. unreliable marketing systems;
20. agricultural inputs not readily available;
21. inadequate extension service for different cropping systems.

The constraints mentioned from items 1-14, focusing on cultivars and cultural management with suggestions on research emphasis, are dealt with here. Other limitations are discussed elsewhere in these proceedings.

Cultivars

Many food legume cultivars are identified by various national programs as high yielding in comparison to the existing farmers' cultivars. These cultivars went through a series of trials in several experiment stations and to a limited extent in farmers' fields. Several cultivars were identified in national programs and recommended for use in production programs. The adoption rate is generally low for grain legumes compared to the two major staple crops of rice and wheat.

Food legumes are grown in many different environments such as upland and lowland conditions with varying moisture regimes, different soil characteristics and different time of planting as they fit in cropping systems. Most of the breeding activities are limited to environments in the research station which are often not representative of actual growing conditions. There is a need to reorient the breeding objectives to include different characteristics for various major environments where food legumes are grown. This will allow identification of varieties for different major soil types and growing conditions. The major objective of breeding should not only be high yield potential but stable yield for different growing conditions. Evaluation should be done in the environment where it is grown. For example, mungbean in Southeast Asia is grown in the upland during the wet and dry seasons as a monocrop and an intercrop; after rice on residual moisture; before rice; under lowland and upland irrigation, etc. Selection is usually done under one environment, although testing is done in several locations. Recommendations are for all environments. Several characteristics are common across these environments and breeding objectives should include characteristics such as stable yield, medium to early maturity, drought resistance, tolerance to diseases and insects, early seedling development, etc.

Varietal evaluation in Asian countries follows the regular steps: preliminary yield trial, general trial, then advanced or standard trials. Most trials are conducted in experiment stations, but some of these trials should be conducted in farmers' fields and evaluation should be done for specific environments. The most promising cultivars after the advanced trial must be tested in farmers' fields in typical cropping systems before such cultivars are released.

Lack of Improved Seeds

Many cultivars recommended for farmer use have passed through a series of varietal trials for several seasons. After the cultivar is approved for release, seed production is intensified using different seed schemes; breeder seed, foundation seed and registered/certified or good seed. The breeders are responsible for breeder seed, government stations for foundation seed, private and government sector for the remainder. The seed production scheme for food legumes is very poor and often seeds are not readily available to farmers, especially for crops that are grown in only one season of the year. There is a need to modify the seed production scheme to make quality seed of food legumes available to farmers. The scheme should be different from that of cereal crops, since legume seeds lose their viability faster.

Farmers tend to use improved seed of the same cultivar for several seasons. The common system of seed distribution is from farmer to farmer, which leads to mixtures, and thus purity of the cultivars deteriorates.

Seed storage is a major problem that leads to low germination. Legumes are planted once a year and farmers have to save seeds for the next planting, involving storage for 4–6 months. There is a need to identify practical and better storage techniques for small farmers. Seed storage is a problem for both the smallholder farmers and the seed producer.

Tillage

Food legumes are grown using zero, low, minimum or high tillage. The most common practice, especially in lowland rice areas, is zero tillage for mungbean, black gram, cowpea, lathyrus, soybean, chickpea, etc. Zero tillage significantly reduces the risk of crop failure due to drought and results in savings of labour and energy in land preparation; but yield levels are very low. The seed is broadcast before or after harvesting rice. However, plant density is low because of poor seed germination and low management, and several studies have been conducted to improve productivity. One technique is to dibble the seed at the base of rice stubble. This is common practice in rice–soybean in Thailand and rice–rice–soybean in China, Taiwan and Indonesia. The other technique is to use simple equipment to plant the seed in rows, to improve the stand and have better soil-seed contact. The rolling injection planter and the inverted T-planter modified and developed by IRRI can plant food legumes using zero tillage. However, these techniques are good in light to medium textured soils, but poor in heavy clay soils.

Minimum tillage is also practiced, especially in medium- to heavy-textured soils both in lowland and upland fields. Seeds are planted by drilling in the row or behind the plough. Germination is generally better than for broadcast seeds. However, low management with little or no fertilisation and limited insect control produce low yields.

For legumes, high tillage is practiced in upland and lowland fields, but land preparation is poor. Most farmers use native plough and harrow for land preparation. Fields are not uniform. Yields are higher because of better management and more available moisture. In lowland irrigated areas, high tillage is practiced because water is assured during the legume-growing period, which coincides with the dry season. Yields are higher because of better management.

Several reports on tillage experiments are conflicting. In general, if water is limiting, zero tillage is used to take advantage of residual moisture. In areas with a plough pan, high tillage is generally better, and it is also better than zero tillage in irrigated areas with good water. A study in Thailand on tillage using zero and high tillage indicated that for soybean after rice with irrigation, high tillage is better than zero tillage (Tongdee 1983). Crop yield in high tillage was increased with ridging, mulching and handweeding (Table 2).

TABLE 2. Zero tillage compared with land preparation following rice.

Treatments	Yield (kg/ha)	No. of pods per plant	100-seed weight (g)	Weed[1] score
Rice stubble	835	15	18	3.44
Straw burning	821	16	18	3.56
Tillage	991	20	18	3.44
Ridging[2]	1200	21	19	4.00
Mulching[2]	1148	19	18	4.38
Hand weeding[2]	1307	19	19	1.94
Alachlor[2]	863	17	19	3.50
No weeding[2]	775	16	18	4.63
F. Ratio	**	**	**	
L.S.D. (5%)	88.69	2.2	0.9	
C.V. (%)	16.0	4.2	6.9	

[1]Weed score 1–5.
[2]These treatments were given in addition to tillage.

Research on tillage should focus on better establishment of food legumes by using low-cost farm implements and machinery. There is a need to improve the existing implements and to test improved implements developed by different research organisations in more environments. Tillage techniques for upland crops should be studied in different soil types.

Plant Population

Optimal plant density is a key to realising high yields. Generally, a farmer's plant population of different legumes is low compared to the optimal plant population recommended by research, due to poor seed viability, lack of seed, poor planting methods, stress, environment, etc. Several studies in South and Southeast Asia have varied plant densities at different row spacing. For cowpea, spacing of 0.5 m between rows, with two plants per hill at 15 cm proved best. Maintaining two plants per hill provides insurance against crop failure from pests and diseases. Plant population and spacing vary, depending on soil texture, available moisture, plant type, cropping systems and growing season. In cowpea, the determinate type with high population is better before rice, and the indeterminate type is better during the dry season.

Plant population is higher during the dry season than in the rainy season. Studies in north India indicate that 300 000–400 000 plants/ha from determinate early-maturing varieties and 200 000–300 000 from the indeterminate spreading types, produced the highest yields. In mungbean, plant population can be increased during the dry season, especially after rice, and this is also true in peanut. In Khon Kaen, plant spacing of 30 cms for peanut is better than 50 cms with a corresponding increase in plant population. In chickpea, yield increased with increased population up to 50 plants/m^2 under irrigated conditions.

Research efforts should focus on plant densities for different cropping systems, soil types and cultivars to identify the optimal plant population. Recommendations should be for a specific environment rather than the general recommendation commonly practiced by national programs.

Planting Time

Planting time is very critical for increased yield, especially for crops that are photoperiod-sensitive, like soybean. When planted after rice in the Philippines, it encounters short days for completion of the vegetative and a portion of the reproductive stages, resulting in reduction in plant size and branching. Yield is less than 1 t/ha. However, when planted in January with irrigation, yields are very high, attaining 3.2 t/ha in a maximum yield experiment (Pandey 1986).

Yield of food legume is low because it is grown before or after the staple crops, or intercropped with other crops. Planting time for food legumes is often dictated by the preceding cropping systems. If planting of the main crop is delayed, then planting of the succeeding legume crop is also delayed and corresponding yield reduced. In a rice-based system, the use of early-maturing varieties of rice opens up more opportunities for planting food legumes before and after rice. The yield of legume after rice is improved because planting can also be adjusted. In many places planting of food legumes results in increased cropping intensity of irrigated rice areas, from rice–rice to rice–rice–legume or rice alone to rice–legume.

There were many studies on planting dates for different crops. Researchers have identified suitable planting time in several environments. These studies should continue especially with new cultivars being developed for different cropping systems. Breeders should intensify their breeding programs for early maturity with high stable yield. Planting can then be shifted according to the environment, with minimum risk of yield reduction.

Fertilisation

Farmers generally apply zero to minimal amounts of fertiliser to food legumes, especially when grown in marginal areas and on residual moisture. More fertiliser is applied in irrigated areas, whether water is sufficient or not. A well-nodulated legume crop can meet the nitrogen requirements through symbiotic nitrogen fixation. For example, soybean can fix between 14 and 300 kg N/ha depending upon its yield potential, the availability of soil N, and the genetic interaction between the host genotype and the *Rhizobium* strain. Other legumes can also fix large amounts of N. Several reported experiments showed that artificial inoculation of the soil with elite rhizobia did not increase seed yields of grain legume. Similarly, in many soils nitrogen fertilisation did not improve seed yields of cowpea, peanut, chickpea, soybean and mungbean. This is specially true in soils with high organic matter content. In chickpea, for example, no response has been obtained on soils of relatively better fertility status. However, in sandy and sandy loam soils with poor organic matter there is positive response to nitrogen dressing of 15–25 kg/ha. In areas where nodulation is very poor or absent, significant response to increasing rates of nitrogen has been reported.

Considerable attention is given to response of grain legumes to phosphorus. Studies in cowpea indicates that phosphorus is critical in cowpea production. Singh and Lamka (1971) reported that application of 40 kg P_2O_5 in low phosphorus soils increased the grain yield of cowpea. In chickpea, positive response to phosphate application from 50 to 75 kg P_2O_5/ha has been obtained in Delhi, Kampur and Jabalpur, India. The soils in the study had low phosphorus content. In other studies in India, several authors reported no response to phosphorus application even in soils with medium to low phosphorus level. Even with different methods of application, including soil incorporation or deep placement, there was no effect on chickpea grown in low phosphorus soil (Saxena and Sheldrake 1976). In soybean, application of phosphorus in areas with low phosphorus soil increased seed yield (Singh and Saxena 1973; Agustin et al. 1985).

There is a need to better understand why there is response in some soils and none in others. Researchers conducting these kinds of experiments should characterise the soils and environment to better understand the interactions. This will help researchers refine recommendations for different soil types and cropping systems. Small farmers should take advantage of the nodulation capacity of legumes. Varieties with better nodulation should be developed for different soil types. This will reduce the use of fertiliser and the cost of production.

Efficient use of fertiliser is very low for upland crops. There is an urgent need to study fertiliser use efficiency for different soil types, especially for zero and minimum tillage. Studies should be conducted to determine the best time of irrigation to increase fertiliser use efficiency. There is a need to study the method of fertiliser application using the farmer's own implements and the improved farm implements and equipment. Engineers should develop better implements to uniformly and efficiently apply fertiliser.

Irrigation and Water Management

Plants grow well and yields are higher when the soil in the root zone is well supplied with water. Vegetation can then evaporate water at the rate approximate to its potential, which varies depending on the kind of food legume, stage of crop growth and the environment. To increase legume production in Asia there is a need to provide adequate water for growth, especially during the dry season when most of the legumes are grown, but irrigation of these crops is low priority in comparison to the major staple crops. Table 3 shows the percentage of irrigated area of different major crops in India. It can be observed that less than 10% of peanut area, 15.4% of chickpea and 8% of other pulse is under irrigation. Irrigated areas for rice (41.6%) and wheat (65.2%) are very high. This is true throughout Asia except in China and Taiwan. In most countries, food legumes are grown in marginal areas and on residual moisture. In areas with irrigation there are several problems in water distribution and drainage. Often the systems do not provide adequate water. Crops suffer from waterlogging and drought. For other legumes 2–4 irrigations are needed. The most important growth stages to have water are at planting time, at vegetative stage and at pod filling stage.

Crop-water needs of food legumes should be met in order to attain the potential yield. Water required by different legumes varies depending on the crop, its life cycle, evaporation demands of the atmosphere, crop characteristics, soil characteristics, etc. There are several studies available on water requirements of food legumes. For soybean there are many reports of seasonal water use of 40–60 cm with a peak daily water use of 7–8.9 mm. For mungbean, the total water requirement (in the absence of stress) was about 375 mm. Under upland conditions acceptable yield of mungbean was achieved with 306 mm of water. In general, water requirements for mungbean ranged from 3.2–5.0 mm per day when water supply was sufficient for the whole growing season.

High yields and cropping intensity were observed in areas with irrigation. Table 4 shows the percentage of irrigated food legumes and average yields in different states of India. Better yield trends in states with a higher proportion of irrigated area can be observed in the case of peanut and pulses, but the effect is less clear for chickpea. For example, in Orissa, Haryana and Punjab where 10–17% of groundnut area is under irrigation, the yields are above 1200 kg/ha, while in states like Madhya Pradesh, Rajasthan, Gujarat and Maharashtra the areas under irrigation range from 0.2 to 4.9% and the yields from 405 to 774 kg/ha. In the case of

TABLE 3. Percentage irrigated under different major crops and legumes in India (1978–79).

Region	State	Rice	Wheat	Maize	Groundnut	Chickpea	Pulses	All crops
Central	Madhya Pradesh	17.0	25.9	0.4	0.2	7.1	3.1	11.1
	Rajasthan	37.9	77.6	65.6	2.3	17.5	9.0	19.7
	Uttar Pradesh	21.7	90.2	9.5	—	19.3	22.8	43.5
Eastern	Assam	33.8	—	—	—	—	9.3	17.3
	Bihar	34.8	71.9	19.2	—	4.1	1.5	32.6
	Orissa	26.6	61.3	1.5	15.3	—	5.9	19.2
	West Bengal	28.7	40.5	11.8	—	—	5.7	19.6
Northern	Haryana	93.0	89.0	15.7	10.0	25.6	25.4	53.9
	Punjab	96.4	41.7	65.6	17.3	23.6	24.9	83.0
Southern	Andhra Pradesh	94.0	—	18.7	16.7	—	0.3	35.8
	Karnataka	62.7	21.3	80.3	9.6	5.5	6.0	15.4
	Kerala	31.9	—	—	—	—	—	12.3
	Tamil Nadu	92.7	—	81.8	25.5	—	11.8	49.7
Western	Gujarat	39.2	61.0	61.0	3.1	12.1	2.7	18.6
	Maharashtra	26.4	40.8	8.7	4.0	13.3	2.9	11.6
	All India	41.6	65.2	15.5	9.6	15.4	8.0	27.5

Source: Fertilizer Statistics, 1982–83, Fertilizer Association of India, New Delhi.

pulses, the yields in Uttar Pradesh, Haryana and Punjab (where 23–25% of the area is under irrigation) range from 703 to 900 kg/ha; in the rest of the states where areas under irrigation range from 0.3 to 9.3%, the yields range from 292 to 537 kg/ha.

Delivery of water is a major problem in irrigating food legumes. In upland areas, water delivery is either by sprinkler or furrow irrigation. Sprinkler irrigation is too expensive for farmers. The most common system is furrow irrigation. However, water delivery is not efficient because of losses due to poor water distribution and uneven fields. Larger areas are irrigated in lowland rice areas. The most common irrigation is by furrow and flooding.

The irrigation systems should be improved to have better water control for upland crops. Studies should emphasise techniques of water distribution and more efficient water use. Irrigation systems should be categorised depending on available water for upland crops, and technology should be refined to suit the different water regimes in the system.

Weed Control

Weeds are limiting factors in grain production in farmers' fields. Crop yield losses due to weeds have been reported up to 80%; for example, in chickpea losses were estimated to range from 30–50% (Panwar and Pandey 1977). In upland areas there is better weed control because farmers practice mechanical and hand weeding, especially in the early stage of crop growth which is the most critical weed competition period. In lowland rice areas, weeds are a major problem when grain legume is grown with zero tillage and water is inadequate. Farmers have to hand weed to keep the field weed-free for the first 30 days. After 30–40 days, weed infestation no longer affects grain yield.

There are several ways of controlling weeds. The most common practice of farmers is hand weeding, which is very costly. Another common technique is by cultivation at early growth stage, using the native plough or cultivator. However, this is only common in upland areas. In the lowlands, the irrigated crop is generally in beds or flooded. Mechanical weeding is difficult. High plant population and hand weeding are the most popular control measures among farmers.

Chemical weed control is the most popular technique among the scientists for controlling weeds. Several chemicals are already recommended but adoption is very limited. For example in cowpea several pre-emergence herbicides such as butachlor, terbutryne and alachlor including pendimenthalm and butralin are effective in controlling weeds of cowpea. In soybean, the more effective herbicides were alachlor + oxyfluorfur and pendimethalin in the spring season and metolachlor and Galex 500 during the summer season in Taiwan (Sajjapongse and Wu 1983). In chickpea, pre-emergence application of 1.5 kg/ha of nitrogen or 0.5 kg a.i./ha of prometryne were found effective in Kampur (Panwar and Pandey 1977), and 1 kg a.i./ha Basalin showed better weed control on sandy clay loam soils of Pantnagar (Singh et al. 1978). In most studies, no single herbicide is effective for all conditions and the choice of herbicide as well as the rate of application will vary depending on the crop, nature of weed infestation, soil type and cropping sequences, moisture available, etc.

Herbicides are too expensive for smallholder farmers. In many areas the chemicals are not available. Researchers should study less expensive techniques to control weeds, such as better land preparation, mulching, mechanical techniques with

TABLE 4. Yields of food legumes (kg/ha) and percentage irrigated area in different states of India.

Region	State	Yield			Irrigated area (%)		
		Groundnut	Chickpea	Pulses	Groundnut	Chickpea	Pulses
Central	Madhya Pradesh	611	579	436	0.2	7.1	3.1
	Uttar Pradesh	680	860	865	—	19.3	22.8
	Rajasthan	405	696	378	2.3	17.5	9.0
Eastern	Bihar	—	753	537	—	4.1	1.5
	Orissa	1300	513	544	15.3	—	5.9
	Assam	—	—	417	—	—	9.3
	West Bengal	—	578	455	—	—	5.9
Northern	Haryana	1280	903	900	10.0	25.6	25.4
	Punjab	1244	746	703	17.3	23.6	24.9
Western	Gujarat	774	740	481	3.1	12.1	2.7
	Maharashtra	733	350	296	4.9	13.3	2.5
Southern	Andhra Pradesh	634	258	292	16.7	—	0.3
	Karnataka	597	566	490	9.6	5.5	0.9
	Tamil Nadu	811	—	323	25.5	—	1.8

simple implements, better cropping sequences, use of fast growing cultivars, use of high plant population, etc. A better method is to use different combinations of the techniques mentioned above to control weeds, increase yield and decrease cost of production.

Conclusions

The majority of the farmers in Asia have more complicated farming systems than those in developed temperate countries. Researchers in various disciplines must therefore have a better understanding of the existing farming systems of small-scale farmers. National programs of the region must develop better classification of the physical, social and biological environments where legumes are grown. This could guide scientists in defining their research priorities. Research on achieving maximum potential yields, which is the normal objective of researchers, should be complemented with research on maximising the use of limited resources of small-scale farmers. The main thrust of research should focus on increasing production and income of the existing farming systems.

Research funds and trained manpower are too limited in most developing countries to enable more extensive research on food legumes. With the present economic situation, funds are even more difficult. There is an urgent need to increase the support to legume research in order to overcome the various limitations to production. Research on different agroecological environments and production systems should be intensified and appropriate technology developed for specific environments. Since funding is limited in most national programs, scientists in Asia should evolve a scheme to work together to develop technology for different environments. Exchange of research information, technology, methodology and ideas should be undertaken to solve the constraints to production in the region. Better collaboration is necessary so that national programs with very limited resources can benefit from other national programs. The international centres, ACIAR, JICA, USAID, regional centres and others should help in facilitating such collaboration and help national programs carry out food legume research.

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Limits Imposed by Management in Rainfed Farming Systems

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WHEN the Asian Productivity Organization (APO) held a meeting in Chiang Mai, Thailand, in November 1980 to discuss the production of food legumes in Asia, it highlighted that over the previous decade food legume production in the region had remained constant or declined despite growing demand (Suzuki and Konno 1982). The symposium attributed the slow growth in production to slow expansion in the area planted to food legumes, and to low yield per unit area. Poor economic returns and unfavourable government policy towards legumes relative to other crops like rice and wheat discouraged expansion in the area cultivated, while low productivity was blamed on inadequate water (mostly rainfed crops), marginal land, and low production inputs, e.g. fertilisers, disease and insect control. A meeting (organised by ACIAR, ICRISAT, and IRRI) was then held at ICRISAT Centre in December 1985 to review the progress on Asian Regional Research on Grain Legumes (ARRGL) and to develop plans for future cooperation. It was revealed that much of the food legumes are still rainfed and grown on marginal lands. In India, rainfed agriculture represents 75% of the arable land or 108 million hectares, and even if current efforts to bring more area under irrigation were successful, at least 45% of the arable area will remain rainfed by the year 2000 (Guatam 1983). The situation is more or less the same in most Asian countries. Clearly, if a significant increase in food legume production is to be realised, production of the crops in rainfed farming systems will have to be improved.

This paper attempts to give an overview of the limits to food legume productivity and adaptation imposed by management in rainfed farming systems in Asia, factors contributing to such limits, and areas of research needed. Special emphasis is given to the limitations operating at the farm level and in the minds of Asian farmers who make management decisions. As management practices are location-specific and there are several crop species and farming systems involved, discussions are generalised, and specific examples are used only to illustrate the principles which should hold in most Asian countries.

Constraints to Rainfed Food Legume Production in Asia

The major physical and management constraints to rainfed food legume production in Asia have been identified in the APO meeting in 1980 (Suzuki and Konno 1982) and in the ARRGL meeting in 1985. These are listed in Table 1. Erratic and low rainfall is probably the most important physical constraint to rainfed food legume production, and this has several implications for management. Being grown in low fertility soils and on marginal land means the crops are normally faced with nutritional constraints, and fertiliser application and other soil fertility improvements such as *Rhizobium* inoculation are required. Expansion of food legume production into new areas or new cropping systems will place the crops into new and often unfavourable environments, which require not only new crop varieties adapted to such environments but also different management practices. As in other crops, insect pests, diseases, and weeds are the common yield reducers and effective control measures are needed.

With erratic rainfall, drought and excessive moisture are the major environmental constraints affecting both crop growth and crop management. To overcome these constraints, it is helpful to consider when they occur and what are the consequences. These can be seen by examining the periods in the growing season occupied by legumes in the different types of rainfed cropping systems.

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TABLE 1. Major physical and management constraints to food legume production in rainfed areas in Asia.

a) APO Meeting, 1980		
	Physical:	Erratic and low rainfall, Lack of supplementary irrigation, Grown on residual moisture, Marginal or poor soils, Small holding, less than 1 ha.
	Management:	Mainly subsistence level, No suitable varieties or uncertain seed supply, Lack of disease-resistant varieties or HYV, Little use of fertilisers, pesticides.
b) ARRGL Meeting, 1985		
	Physical:	Erratic and low rainfall, Desire to expand into new areas or during off season. Ecophysiological adaptation of existing varieties is poor, Low soil fertility, need for rhizobia, Marginal land.
	Management:	Low inputs of fertilisers, insecticides, Low yield potential, Little attention to cultural operations, e.g. weed control, Lack of quality seeds, Need for short-duration varieties, Poor stand due to low soil moisture.

In areas with short growing seasons, food legumes are normally sown at the onset of rains, when soils are periodically rewetted and the potential evaporation is low, or in the postrainy season when there is very little rainfall and crops are grown on residual moisture (Squire et al. 1986). In areas where rainfall and water-holding capacity of the soils allow a long cropping season, there is a choice of a sequential system of an early rainy season crop and a mid-late or postrainy season crop, or a single long-duration crop like pigeonpea which is sown at the start of the rainy season and is harvested when residual moisture is used up (Willey et al. 1981). In the traditional systems in north India and parts of central India, such long-season pigeonpeas are usually intercropped with one or more different species (Sheldrake 1984). Regardless of the cropping systems, there appears to be three distinct periods in which food legumes are sown, each with different management constraints. These periods are early rainy season, mid-late rainy season, and postrainy season.

When the crops are sown at the onset of the rains, quite often seeds are placed in relatively dry soils resulting in low seed germination and poor crop establishment. Subsequent crop growth is also in the period of erratic rainfall when either drought or excessive moisture may occur, affecting crop growth and development. Weeding is difficult in wet soils, and delayed weeding can cause substantial yield reduction. The crops mature in the period with frequent rains creating difficulties in harvesting and drying. High humidity is also favourable to fungus development on pods causing yield loss and poor seed quality.

In mid-late rainy season sowing, land preparation and seeding are done during the wet period. Excessive moisture makes land preparation and seeding operations difficult, and heavy rainfalls may result in poor crop establishment. Soils are wet during early growth, affecting crop growth and development and causing a delay in weeding. Crops will run into dry soil conditions during late growth stages, and quite often suffer from drought stress.

Postrainy season sowing may involve wet or dry soil, depending on the land and soil type and the preceding crop. In any case, it creates a constraint for crop establishment. Drought stress during the latter part of crop growth is normally more pronounced than mid-late season sowing, resulting in low crop yield.

The above discussion sets the scene for the constraints to rainfed food legume production imposed by environmental and biotic factors. On top of those, food legumes are normally grown by small farmers with limited resources, unable to afford high cash inputs or high risks. These farmers also have several enterprises and will allocate their resources according to priorities in their small holdings. In most cases, food legumes are considered secondary crops which are of low priority in the farmers' view. These are the conditions which scientists have to face in developing improved management practices.

As food legumes are generally grown in association with other crops in various cropping systems, improving management should be considered in the context of cropping or farming systems. These can be done by improving the management of the cropping system components and the management of the entire system.

Components of a cropping system include sowing date, crop variety, crop establishment, plant density, fertiliser application, *Rhizobium* inoculation, weed control, control of diseases and pests, and harvest and postharvest handlings. Limits to management of several of these components are discussed in detail in other papers in these proceedings (e.g. Beck and Roughley, Buddenhagen et al., Byth et al., Crasswell et al., Lawn and Williams). In this paper, discussions will concentrate on the components which have not been covered in other papers, touching briefly on some of the others regarding management issues.

Limits Imposed by Management of Components of Cropping Systems

Sowing Date

As mentioned earlier, under rainfed conditions, drought and excessive moisture are probably the most important factors affecting crop yield. One way to minimise these problems is to adjust sowing date to a period in which the problem is less likely to occur. Numerous date-of-sowing trials have been conducted for food legumes, and the sowing dates for the best crop yields have been identified for many areas. However, in many instances, it is not practical for the farmers to sow on such dates for several reasons.

In areas with a long growing season, double cropping systems are preferred because they are more profitable and pose less risk of crop failure than single cropping. Durations of the two component crops normally cover the full length of the growing season, leaving little room for adjusting sowing date. In many cases, food legumes are grown as opportunity crops to take advantage of the period left over from other crops, e.g. growing food legumes before and after rice. In such cases, the sowing date of the legumes is determined by the duration of the main crop.

Even in areas where monocropping is practiced, farmers normally prefer early sowing at the onset of the rains, even though the crops may suffer from drought stress. This is because the weed population is lower than at later sowing, making land preparation and weeding much easier and thus requiring less labour. Other activities may also affect the choice of sowing date. For example, in an area in Khon Kaen province of northeast Thailand, the sowing date of groundnut varies from year to year depending on the time of rice transplanting. In this area, the land is undulating and rainfall is quite erratic. Rice is grown in the depressions while field crops are grown in the upland portion of the undulating terrains. Rice is grown primarily for home consumption and is considered the most important enterprise. If rainfall is low during the early rainy season, groundnut is sown first and rice transplanting is done later when the heavy rains come. On the other hand, if heavy rains come early and water is sufficient for rice transplanting, farmers will transplant rice first and sow groundnut later. In this case, the sowing date of groundnut is adjusted to fit the labour supply of the farm family which is allocated to different enterprises according to their priorities.

It appears that a major change in sowing date of food legumes is unlikely to be accepted by farmers. However, there are possibilities of adjustments within those limits imposed by the individual cropping systems that will improve the legume yield. This very much relates to the timeliness of sowing to get to the right moisture condition for good crop establishment, and will involve some modifications in land preparation and sowing practices which will be discussed later. In some cases, there is a need to change the variety of the preceding crop so that sowing date of the following legumes could be moved forward to avoid drought stress during late growth stage. This is the case with rice-based cropping systems in which early rice varieties are required. These sowing date adjustments also involve mechanisation to reduce the turn-around time and speed up the seeding operation. More research is needed in these areas.

Crop Establishment

As discussed earlier, food legumes are sown either in the early rainy season, mid–late rainy season, or postrainy season depending on the cropping systems in which they were grown. In all three sowing periods, the soils are likely to be either too dry or too wet and crop establishment becomes a major constraint. For example, in India where chickpea is normally grown on residual soil moisture in the postrainy season, crop stand is poor in the majority of farmers' fields, probably due to early moisture deficit (Saxena 1984). In the rice–soybean double cropping system in Indonesia, farmers broadcast the soybean just before harvesting the rice crop, resulting in poor stand (Syarifuddin and Zandstra 1978).

There are possibilities to improve crop establishment of rainfed food legumes. Work at IRRI on the effects of several cultural practices on soybean establishment under rainfed conditions has shown that drainage a day before rice harvest followed by one rotovation gives the best soybean yield (Syarifuddin and Zandstra 1978). When seeds are sown on residual soil moisture or when the onset of the rainy season is unreliable, the ability of seeds to germinate and establish when the top soil is drying out becomes a major determinant of crop establishment (Lawn and Williams, these proceedings). Deep sowing is an obvious way to reduce the effect of early moisture deficit, and this practice has been used successfully in establishing groundnut grown after rice on residual soil moisture by farmers in Surin province in northeast Thailand (Patanothai 1985). However, seedling emergence and subsequent vigour is dependent on seed quality and genotype. Therefore, the use of good quality seeds and appropriate variety is a prime prerequisite.

In areas where the onset of rains is reasonably predictable, timeliness of sowing is crucial for early and good stand establishment. Detailed analyses of the trend and dependability of rainfall would provide useful information to formulate management strategies (Vermani 1980). Such studies at ICRISAT Centre have resulted in the use of dry seeding on the deep Vertisols which become sticky when wet and prevent a sowing after the onset of the rains (Kampen 1982). On the deep black soils of central India, the most efficient way to grow a postrainy season crop is by means of the simultaneous sowing of intercrops, because this eliminates the necessity of a second land preparation at the end of the rainy season (Rao and Willey 1982).

Appropriate farm implements could also improve crop establishment. Choudhary and Pandy (these proceedings) reported the successful development of a multicrop seeder (invert-T) which would extend the range of field conditions where seeding and crop establishment could be achieved with minimum risk of failure. However, this equipment is good only in light to medium soils but poor in heavy clay soils (Carangal et al., these proceedings).

The above examples indicate that there are several ways to improve crop establishment of rainfed food legumes. However, they are specific to different conditions. As poor crop establishment is an important and widespread constraint, additional research is needed. The major determinants for management practices appear to be soil type and moisture regime. Thus, there is a need to derive a classification of environments based on these two parameters so that research results could be compared or extended to similar conditions. An example is also given to illustrate that there are farmers' practices which give good results. These should be scientifically studied to understand why they are successful and under what conditions, so that the transfer of these practices could be done appropriately.

Land Preparation

Good land preparation is another prerequisite for good crop yield, because it provides favourable conditions for seed germination and subsequent crop growth and also reduces weed population. However, good land preparation takes time and labour, and in some situations needs appropriate farm equipment. Most farmers only have animal-drawn equipment, although some may have small tractors. Small equipment makes land preparation slow and poses some difficulties to farmers when land preparation needs to be done in a short time or on heavy soils.

In some areas, land preparation is done by custom plough with large tractors. In such cases, land preparation is often inadequate, as only one ploughing is normally done. The contractors do not have the harrower, and additional operations would cost more. Quite often, land preparation cannot be done at the time needed because the tractor may not be available.

With all these limitations, many farmers still conduct reasonably good land preparation. There are also cases where land preparation done by the farmers is exceptionally good. For example, in growing groundnut after rice on residual soil moisture in Surin province in northeast Thailand, farmers plough and harrow the fields several times until the soils reach a fine tilth. Such good land preparation is required to conserve moisture to support crop growth for the entire cropping period.

The major problems in land preparation are land levelling and drainage. With the available equipment, land levelling is difficult and drainage furrows are seldom incorporated. As a consequence, small depressions occur in the fields causing water stagnation following heavy rains and reducing crop growth in those areas. Improvement of land preparation, thus, lies in the improvement of farm equipment and drainage management. The equipment should be low-cost so that small farmers could afford to use it.

Seed Quality

Seed quality is another important factor affecting plant stand. As seeds of most food legumes lose viability rapidly or are easily attacked by insects during storage, farmers rarely store their own seeds. Seeds are normally purchased from local merchants shortly before planting. The local merchants procure their seed supply from other areas or sometimes from the farmers themselves. The quality is poor, not only in terms of viability but also in varietal purity. Often, improved variety seeds are not available. Since food legumes are minor crops and self-pollinated crops, no large seed company is interested in producing seeds of these crops. Although there are government seed multiplication programs, the amount produced falls short of the demand. In addition, the seed distribution system is generally inadequate, and most farmers still have to depend on poor quality seeds from local merchants.

Obtaining adequate plant stand is of great concern to the farmers. When plant stand is too low, the farmers may have to prepare the land again and resow, thus losing time, labour, and cash inputs. Sometimes it may be too late for resowing, and this would mean a season is lost. It is not uncommon to see abandoned fields because of poor crop stand. Farmers anticipate these problems by using a high seeding rate to make sure that they get enough plant stand. However, if germination is good, the result is excessive plant stand and clumps of several plants per hill.

Strengthening government seed multiplication programs and improving the distribution system are obviously needed, but these can only serve a fraction of food legume growers. There are, however, possibilities of improving seed storage at the farm level by which the farmers could save their own seeds. Work in Sri Lanka indicates that germinability of mungbean seeds could be retained by storing dried seeds in polythene bags (Sangakkara, these proceedings). A similar technique was also found effective in storing groundnut seeds (Yin-adsavaphan 1985). Improving farm level seed storage practices would be of great benefit to the majority of small farmers, and more research in this area is needed.

Plant Density and Method of Sowing

Plant density and spatial arrangement can have a major effect on the final yield of most legumes, and the general response of yield to increasing population is well documented. Fig. 1 illustrates the types of response reported for many legumes in dryland agriculture.

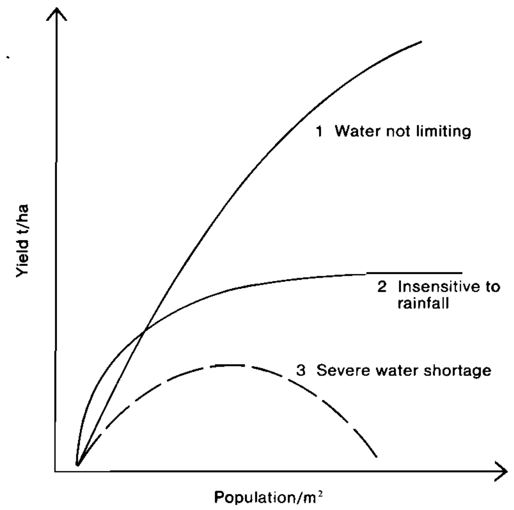

Fig. 1. Three major examples of yield-population responses.

Example 1 illustrates the situation where water deficit is not serious, and the legumes are compact and short, e.g. groundnut and chickpea (Saxena 1980). In such instances, the recommended plant population may be determined by other factors such as cost of seeds or limits of planting practice. The extra early or short season legumes would also fall into this category.

Example 2 represents the legumes like medium- and long-duration pigeonpea where individual plants have the ability to rapidly spread their branches to intercept light between plants and also the ability to remove moisture from deep in the soil profile. For instance, Rao (1986) observed that seed yield of pigeonpea cv. ICP 1 at ICRISAT Centre was virtually constant at 1000 kg/ha over a wide range of plant populations (2–15.6 plants/m^2). The same yield–population response was also reported when pigeonpea was intercropped with sorghum at various sorghum populations.

Example 3 is the most common response typical of many food legumes grown on residual moisture or with severe water shortage (Saxena 1984, for chickpea; Akinola and Whiteman 1974, for pigeonpea). The optimum yield is obtained at populations which enable the plant to extract the maximum amount of available moisture and allowing adequate plant growth for the seed to reach physiological maturity. There are very few reports of how these examples of yield–population responses are modified by the erratic rainfall distribution in many of the rainfed farming systems. In the study of Rao (1986), seasonal variation in rainfall from 650 to 910 mm appears to have no major influence on pigeonpea yield; presumably the response also depends on soil water-holding capacity.

Planting arrangement is unlikely to have a major effect on yield in many situations when plant population is optimum for yield (Saxena and Sheldrake 1976). The main exception is in intercropping where the final yield proportion of the component crops may be predetermined to achieve the full yield of one of the crops. Increasing the population of one component crop will tend to make that component relatively more competitive, especially if it is the dominant crop. The maintenance of a high population of a dominant crop may be necessary to achieve a worthwhile yield contribution (Willey and Rao 1981). Such a combination would result in a higher total plant population, and this is most common in an intercrop which involves crops of vastly different maturity, e.g. sorghum and pigeonpea.

Plant population and planting arrangement are affected by method of sowing. In Asian countries, food legumes are either planted in hills or by broadcasting, depending on specific situations. Practically no seeding machines are used because appropriate low-cost seeders are not available. Hill planting is normally done by hand, using family labour including children, but sometimes with hired labourers. Irregular row and plant spacings are normally obtained. Equal row spacing has long been advocated, but it takes more time and labour and farmers apparently do not adopt it.

In many cases, broadcasting is used because it is fast and requires less labour. In some cases planting needs to be done quickly, forcing the farmer to go for a quick method. In other cases labour may be a constraint, or the expected output may be too low and too variable for the more intensive management to be worthwhile in the farmers' view. Weeding is also done by hand. Thus, there is no benefit of row planting over broadcasting in terms of weeding efficiency. With broadcasting, plant population is difficult to control.

It appears that while researchers are more interested in optimum plant population, farmers are more concerned with time and labour. In developing improved management practices, it is necessary to take all of these into account.

Examples given previously indicate that optimum plant population varies in the different moisture regimes and plant types. Fertility levels also affect optimum plant population. Generally, in a given condition, there is a range of optimum plant populations for which crop yield is not much affected. There is a need to establish these ranges for the individual food legumes in different conditions. Although a lot of research has been done on plant population of food legumes, for a given crop, generally only one population (spacing) is still recommended for all conditions. More research is needed. In fact, there is a need to establish the yield–population responses for the different conditions, as it may be necessary to go beyond the optimum range for practical reasons. To do this, some kinds of environmental classification are also needed.

Once the optimum population ranges are established, it is a matter of determining how these could be best achieved within the available resources and time constraints of the farmers in a given area. On-farm trials of potential practices are also required to test their suitability to the farmers' conditions. Clearly, low-cost items such as a seeder or even a row marker would play an important role in improving the management. Additional research in these areas is also needed.

Fertiliser Input and Chemical Control of Pests and Diseases

Application of fertiliser, insecticide, and fungicide involves cash inputs. Among the three, insecticide is probably the one used by most farmers. Some farmers may apply fertiliser to their legume crops, but fungicide is rarely used.

Having limited resources, cash input is of great concern to the farmers, particularly when there is a risk involved. Under rainfed conditions, in which crop responses to fertilisers are quite variable due to environmental factors, farmers are generally reluctant to use fertiliser. Other management limits are the unavailability of the recommended fertiliser formulae in the local market and the lack of knowledge of the differences among different fertilisers. The consequence is a misuse of fertilisers and the potential responses are not realised.

Insecticide is normally used because insect damage is clearly visible, and damage from certain insects, for example pod borers, can cause a substantial yield loss. On the other hand, yield losses from most diseases are not apparent, therefore fungicide is considered unnecessary. Sometimes, farmers do not know the difference between insecticide and fungicide, or cannot differentiate between insect and disease damage. In such cases, insecticide is often sprayed on diseased crops. Also insecticide is sometimes applied too late when insect damage has already occurred. This is because the farmers wish to avoid cash outlays and thus generally prefer cure to prevention. Other activities may also prevent them from applying the insecticide on time.

Future research in these areas is discussed in other papers in this workshop. The point to make here is that the risk involved should be taken into account in developing improved practices. Unless the benefit is clear, it is unlikely that the farmers will adopt the recommended practices.

Weeds

Effective control of weeds can be achieved by mechanical means, crop rotation, and chemical control, but hand weeding is by far the most common in rainfed farming. However, increasing labour cost and greater availability of chemicals will favour the use of herbicides. Crop yield is most sensitive to early competition from weeds, but beyond a certain period crop growth is sufficient to suppress weed competition. In soybean, yield losses from weed competition continue until 60 days after planting (Sajjapongse and Wu 1985). A similar response to weed competition has been reported for pigeonpea by Shetty (1981).

Farmers normally weed once or twice, depending on the weed population and the availability of labour. Mechanical weeding is, at present, beyond the reach of most farmers, since there is no low-cost machine available. Herbicide is also costly, and most farmers cannot afford to use herbicide, although some do. High plant population is another means normally used to reduce weed population.

It is often claimed that traditional intercropping systems give better control of weeds. Where total intercrop population is higher than in sole crop (which is often the case), then greater weed suppression can be achieved (Rao and Shetty 1976). However, where the total population is similar to that of the sole crop, weed suppression is likely to be intermediate between the two sole crops, depending on their respective proportions. Slow-growing crops like pigeonpea are less competitive than other legumes, and suppression of weeds may be even poorer in intercropping situations.

Farmers are well aware how weeds can affect crop yield, but unavailability of labour at weeding time is normally a constraint, and cash is required in using herbicide. It appears that combination of the two would be a good compromise. Future research should emphasise the use of herbicide in combination with manual weeding to reduce the herbicide cost and also reduce labour requirement for manual weeding. Again, low-cost tillage implements would be of great benefit.

Postharvest Management

Postharvest management is another aspect affecting the yield and quality of food legumes. In double cropping systems, the first crop may mature during the rainy period when damage from fungal attack could be serious and drying is difficult. In some cases, the marketing system has an influence on the postharvest management of the farmers. An example is the case of groundnut in Kalasin province in northeast Thailand. Farmers in this area, and probably in other areas, normally sell their groundnuts soon after harvesting because of cash need. Local merchants come to the village to buy groundnuts, but not every day. If the crop is harvested several days before the merchant comes, drying will be done for several days. But, if the crop is harvested a few days before the merchant comes, it is insufficiently dried. Groundnut is sold by volume, thus, moisture content has no effect on the measurement. No grading system is used, and the farmers get the same price whether their groundnuts are sufficiently dried or not. Therefore, there is no incentive for the farmers to carry out proper drying.

The principles of postharvest handling are well established, but practical applications are rather difficult. Unless there are incentives for good quality seeds, it will be difficult to change the farmers' practices. Improvement thus lies in the changes in marketing system and price structure so that there is an incentive for good quality seeds, and quality grading can be employed.

Labour requirements for harvesting, depodding (in groundnut), and threshing are also high. Obviously, low-cost machinery for doing some of these would be of great benefit. Varieties with synchronous maturity and resistance to weathering and fungal damage on seeds would also reduce the labour requirement for harvesting and improve seed quality.

Limits Imposed by Management of Cropping Systems

The cropping systems involving food legumes in rainfed areas in Asia are numerous, depending on the environmental conditions, marketing opportunities, and farmers' preference and perceptions of the immediate return for their efforts. In terms of productivity and stability, each has its own advantage in certain environments. For example, intercropping has high advantage under low soil fertility conditions (Reddy and Willey 1982) and under moisture stress conditions (Natarajan and Willey 1986). In the long-term stability evaluation of several productive cropping systems conducted at ICRISAT Centre, intercropping of pigeonpea with cereals or low canopy legumes was found to be the most profitable and stable cropping system on deep and medium-deep Vertisols. An extra early pigeonpea or soybean in the rainy season was also found to be remunerative for these soils. The legume/pigeonpea intercrop was the most profitable option with or without fertilisers in both deep Vertisols and medium Alfisols, and the groundnut/pigeonpea intercrop was the best. In the wetter regions of Madhya Pradesh, India, rainy season soybean gave an excellent first crop to be followed by a postrainy season wheat. These options have very high yield potential on deep black Vertisols, compared to the traditional system of growing only a single crop in the postrainy season (Reddy and Willey 1982).

The productivity of existing cropping systems could also be further improved. For example, a decade of research at ICRISAT on both basic and agronomic aspects of intercropping has shown that better agronomic management (e.g. high population and fertiliser input) and the use of improved varieties of both component crops can result in substantial yield increases (Willey and Rao 1981; Reddy and Willey 1982). Improvement of the components of cropping systems discussed previously should also lead to an increase in cropping system productivity.

There is also great potential for incorporating food legumes into new cropping systems and for introduction of food legumes into new areas. In several Asian countries, a number of food legumes have been evaluated in rice-based cropping systems to utilise the residual soil moisture, and several of these cropping systems are now under production (Carangal et al., these proceedings). The promise of several new cropping systems involving food legumes is also reported in some of the contributed papers in these proceedings (Chatterjee and Battacharyya; Pillai et al.; Yadavendra et al.; Sangakkara; Laosuwan et al.). Jain and Farris (these proceedings) provided evidence to show the potential of medium-duration pigeonpea in several new areas. The potential of pigeonpea for small-holder livestock production systems may also lead to new cropping systems (Wallis et al. 1986).

Opportunities also exist for mechanised farming of food legumes. The potential of large-scale mechanised production of early pigeonpea in rainfed systems has been demonstrated in Queensland, Australia (Wallis et al. 1981). Extension of mechanised production of pigeonpea or other legumes elsewhere will depend on the cost of production and the market acceptance of the legumes. Certainly, this type of production is not applicable to small farmers. There is, however, a great scope for small-scale low-cost mechanisation as mentioned several times in the foregoing discussions.

Improvement of existing cropping systems and introduction of food legumes into new cropping systems or new areas requires changes in both management practices and crop variety. Apart from those mentioned earlier, the recent development in Queensland in pigeonpea production is an excellent illustration of the important role of phenological research and the need for new management systems to accompany the introduction of new genotypes (Wallis et al. 1981). From the initial work on a photosensitive genotype, it was found that the most important factors affecting production are choice of sowing date (mainly an interaction with photoperiod) and plant density which has to be increased to compensate for reduced vegetative growth, as sowing is delayed. The introduction of photoinsensitive varieties has helped to simplify these management practices, and yields exceeding 5000 kg/ha have been recorded. The same principle is applied in India where pigeonpea could be grown during the cool, postrainy season when photoperiod is short and the reduced growth of the plants enables them to be grown at high density and to be managed like annual crops (Sheldrake 1984). This evidence suggests that major and stable increases in food legume production will depend on the development of management strategies incorporating many of the genetic improvements.

It should be emphasised that, in management of cropping systems, not only the management of the legumes but also the management of other component crops has to be taken into account, since they interact with each other. Interactions could be positive or negative. The role of legumes in providing nitrogen to the system benefiting other crops is a clear example of a positive interaction. In turn, the legumes could also benefit from the residual effects of fertilisers applied to other crops. To change the management of the legume may require a change in management of other crops, and this could have a negative effect on other crops. Competition for time, labour, and other resources always occurs. It is important that these interactions be understood and, where possible, quantified, so that positive interactions could be capitalised and negative interactions be avoided. This is another area in which a lot more research is needed, and an interdisciplinary team approach is required.

A prerequisite to that is, perhaps, a change in perspective of the researchers. As a farming system consists of several components, each interacting with the other, a change in one component will affect the others. Socioeconomic factors are also involved. It is particularly important that researchers should have a farming systems perspective.

Another area which should be considered in cropping systems management is the long-term productivity of the land. The enlargement of cleared areas, the shortening of fallow period, the cultivation of steep slopes, etc. have led to a large scale degradation of soils and sites in many parts of the tropics. The implementation of more intensive systems to increase the productivity of agricultural lands must therefore include soil conservation and soil improvement. Crop residue management is important in maintaining soil productivity. Both land management and crop management play an important role in determining the extent of soil erosion by water. For instance, in large areas of the deep Vertisols of the rainfed semi-arid tropics of India where the rainy season fallow is practiced, vegetative cover is absent leading to frequent occurrence of substantial amounts of runoff (25% of rainfall) and soil erosion (2.5-5.0 t/ha). Only 25-30% of the rainfall is actually utilised for evapotranspiration of the postrainy season crop (Kampen 1982). Improvement in the productivity of the deep Vertisols through facilitating rainy season cropping using improved land management and soil tillage (dry land preparation, dry seeding, minimum tillage with intercropping) could result in a 3-5-fold increase in land productivity.

The dominant role of woody perennials for soil improvement and conservation is not confined to shifting cultivation but has a great potential throughout the humid and semi-arid tropics. A considerable amount of agroforestry research at IITA based on the alley cropping concept has stimulated studies in the drier parts of the tropics where potential benefits include improvement in organic content of the soils, nutrient enrichment, and reduction in soil erosion and runoff (Kang et al. 1985). The key to the success of agroforestry systems depends on the progress in identifying woody perennial species and crop management practices which do not have an adverse effect on the associated crops of resource-poor farmers.

Summary and Conclusions

The foregoing discussion has attempted to provide an overview of the constraints to food legume production in rainfed farming systems in Asia and the difficulties facing the farmers in managing the crops. Under rainfed conditions where moisture cannot be controlled, drought and excessive moisture are the key constraints which have several consequences in terms of management. Being secondary crops grown on marginal land and coupled with limited resources of the farmers, the crops are placed in unfavourable situations in terms of both natural environments and management inputs. This means much more research is required to develop appropriate management practices than for irrigated conditions where the environments are more favourable.

Examples have also been cited which indicate that possibilities exist in improving the management practices which will lead to higher crop yield. There is also a great scope in incorporation of food legumes into new cropping systems and expansion of the crops into new areas, and this is probably where an increase in food legume production has the greatest potential. In most cases, the improvements have come about by the changes in both management practices and crop variety. This suggests that further improvement will lie in the development of appropriate management strategies that incorporate many of the genetic improvements. It also highlights a need to reorient the direction of breeding programs towards the development of varieties suitable for the various cropping systems.

In terms of management, the major constraints appear to be in the area of crop establishment and plant population which involve several management practices previously discussed. This is the area in which it is felt a lot more research is needed. To facilitate the management operations, different types of farm equipment are required. Thus, more efforts should be given to the development of low-cost farm implements which are within the reach of small farmers.

Under the high risk situations of rainfed conditions and limited resources of the farmers, it is unlikely that the farmers will adopt high input technologies. Adopting management strategies which require cash inputs, e.g. fertilisation, will rely on the capitalisation of positive interactions of the legumes with other crops in the cropping systems. This is a complex situation in which a lot more research is needed, and an interdisciplinary team approach is required. It is also important that researchers have a farming systems perspective.

There are, however, possibilities for farmers to use higher inputs in some legumes which are grown as cash crops, e.g. soybean and groundnut. The adoption will depend on the economic return of the inputs, which is a function of yield response, cost of input, and crop price. The possibilities are more under irrigated conditions where less risk is involved.

As management practices are location-specific, and different locations differ not only in the natural environments but also in the socioeconomic conditions, difficulties arise on how research should be conducted to serve these various needs. The complex situations of rainfed farming point out that much more research is required both in basic understanding and in adaptive research. A prerequisite to these is a need to derive some kinds of environmental classifications to guide the direction and determine the priority of research, and to facilitate the transfer of research findings. Environmental classification needs not be one, in fact, there is a need for different types of classification to serve the different purposes, and these are not necessarily mutually exclusive. For example, a classification based on soil type and moisture regime at seeding period may be sufficient for crop establishment, but classifications for other managements may require different sets of parameters. There are also hierarchies of classifications depending on how broad the objectives are.

The need for basic research appears to lie in the more basic understanding of crop responses to environments and genotype x environment interactions complex. Phenological research mentioned previously is a good example of how this basic understanding could help the development of management practices. Crop modelling also appears to be a useful approach in understanding the interactions of various factors and in determining the critical constraints in a given situation.

The second level of research would be to transfer those basic understandings into management practices. At this level, research may concentrate on the individual components of cropping systems, and here comes the need for different classifications of environments to serve the different purposes. For a component, there is also a need to develop management alternatives for an environmental class so that farmers in a given area can have a choice.

The third level would be on-farm testing of those management alternatives to evaluate their appropriateness and scope of applicability, and to identify the suitable alternatives for the individual locations. It will not be possible nor desirable to conduct the tests in all locations, thus, some kinds of location classification or 'zoning' are also required.

These different levels of research fit different research groups. While basic research is more appropriate to international research institutes, universities, or well established national research centres, third level research is more fitted to regional research stations or regional research and development programs in the different countries. The second level could be taken up by both international organisations and national research programs, the extent of which depends on the mandate and scope of work of the individual research institutes.

The basic understanding of the food legume production systems in the different locations in

Asian countries also appears to be inadequate. There are several food legume species, each involved in different types of cropping systems. Certainly, management practices will be different. For a crop in a given area, there are usually only a few key constraints which, if overcome, will result in a substantial improvement. There is thus a need for more understanding of the production systems of the individual legumes in the different countries.

Two types of analysis appear to be useful in this regard — the individual crop analysis and the area analysis. In a country, it should not be very difficult to gather information on where the individual legumes are grown, what cropping systems are involved and their extent, what are the farmers' goals in growing the crops and what are the key environmental characteristics in the different production areas. Much more understanding could be obtained by analyses of available secondary data and interviewing local researchers and extension workers in the areas. Identifying key constraints and farmers' practices in the different areas will take more time and effort, but would be worthwhile. Some could readily be obtained from local personnel in the areas.

The type of area analysis like the agroecosystem analysis (KKU-Ford Cropping Systems Project 1982a, 1982b) or the rapid site description used in many farming systems research sites will not only provide a good background of the physical environments and production problems but also give an insight into the socioeconomic conditions in the area. This type of analysis could be employed at the macro, meso, or micro level, and at different depths, depending on the objective. These two types of analysis would provide useful information for deriving the different types of environmental classifications and for determining research priorities. It will also be useful in determining what management alternatives should be tested in a given area.

Lastly, there are several farmers' management practices which have given good results. These practices have survived through a long period of testing and are appropriate for such circumstances. They can readily be transferred to similar conditions. Scientific examination of these practices to understand why they are successful and in what conditions will not only help the transfer of these technologies but also should provide useful information for future research. A lot could be learned from the farmers.

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Limits Imposed by Climatological Factors

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CLIMATE is the major component of the environment conditioning the regional and seasonal adaptation and yield of crop plants. While climate is not homogeneous in either space or time, generally similar patterns prevail over quite wide geographic areas, and the cyclic changes in these patterns provide the seasons. It is within the context of these broader effects that the other components of the environment (i.e. the edaphic and biotic) affect plant performance — both directly and in interaction with climate and each other — to condition adaptation to specific environments. Improving climate adaptation is therefore fundamental to the process of crop improvement, which in this paper is considered in its broadest sense, viz. the manipulation of both genotype and environment to respectively maximise genetic potential and minimise environmental constraints to expression of that potential.

Leaving aside questions of desertification, nuclear winters and glasshouse effects, there is little man can do to influence climate on a geographic scale, and nothing he can do to manipulate it in a directed sense. Thus attempts to minimise climatic limits are constrained to the localised scale of the individual field and the crop microenvironment, or to trying to avoid the problem altogether by restricting the climate that the crop experiences. The opportunities for improving crop performance through breeding are somewhat less constrained, plants having been exposed to the vagaries of climate for sufficiently long and over a wide enough geographic range, that a reservoir of genetic variation in plant response exists for most climatic factors. The problem thus becomes one of first defining appropriate climatic adaptation and then combining it with other desirable (e.g. agronomic) traits.

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In this paper, the limits imposed by climatic factors to the yield of the tropical food legumes are discussed in relation to improving their productivity in Asian farming systems. It is not a comprehensive review of the influence of various climatic factors on plant performance per se. The key climatic factors influencing the tropical food legumes — radiation, temperature, daylength and water — are each examined in turn, and discussed in the context of adaptation and the opportunities for crop improvement.

Radiation

Photosynthesis provides the basis of dry matter (DM) accumulation and plant growth, and thus the amount of solar radiation entering the plant's environment establishes, in the absence of other climatic constraints, the upper limit of productivity. Over the past several decades, substantial progress has been made in developing a conceptual and analytical framework for describing the conversion of radiant energy to crop yield and the impact of other factors such as temperature and water (e.g. Charles-Edwards 1982; Warren-Wilson 1971; Monteith 1972, 1981). In the simplest approach, economic yield can be expressed as the product:

$$Y_e = \{Q\} \times \{i\} \times \{E_c\} \times \{p\} \qquad (1)$$

where:

- Y_e = economic yield
- Q = cumulative radiation incident on the crop
- i = proportion intercepted by the crop
- E_c = conversion efficiency to TDM
- p = partitioning efficiency to economic yield

An examination of the four components of the above relationship helps to illustrate the potential role of various physiological and environmental factors in contributing to variations in crop performance, and thus to identify where opportunities exist for improvement. It also serves as a framework for subsequent discussion of the other climatic factors, since the constraints imposed by them operate through one or more of these four processes.

Cumulative Incident Radiation

One of the main determinants of the cumulative energy falling on the crop is simply the duration of crop growth. In this context, the effect of those climatic factors which determine crop phenology is to establish the time limit for energy input for that crop i.e. to establish its 'phenological potential'. The second main determinant of cumulative incident radiation is level of insolation. Near the equator, year-round variation in average daily irradiance is small (ca10%) because seasonal variation in both daylength and maximum sun elevation is relatively small (Nieuwolt 1972). Moving progressively to higher latitudes however, seasonal variation in both daylength and maximum sun elevation increases, and so does year-round variation in total daily irradiance. For example, at latitudes 20–30°, in what may be loosely termed the subtropics, the combination of high sun elevation and longer days around the summer solstice can provide daily irradiance 15% higher than at the equator. Conversely, the combination of low sun elevation and shorter days around the winter solstice in the subtropics provide daily irradiances of only a third to half the average at the equator.

In practice, these generalised patterns are substantially confounded by variations in cloudiness. Most pronounced are the differences in irradiance induced by cloudiness between rainy and dry seasons, which it is suggested could result in up to 50% higher yield potential for the latter (Versteeg and van Keulen 1986). Levels of irradiance can present a severe constraint to growth of the legume component in various mixed cropping systems e.g. inter-, alley, relay and companion cropping. Research on inter- and mixed cropping systems has identified the need for the legume to complement the other component(s) in terms of phenology and leaf area development to maximise interception and minimise intercomponent competition (Willey et al. 1981). There are no known systematic attempts to improve adaptation of food legume species to low light environments, such as under young rubber and oilpalm where crops can be grown for several seasons until irradiance levels become too low (Laosuwan et al. 1985).

There is evidence that such an approach may be profitable. Recent studies with leguminous ground covers under sorghum and sunflower have shown that *Vigna trilobata* compensates for low irradiance levels with higher specific leaf areas and increased partitioning of DM into leaf area development (Leach et al. 1986). In the Philippines, evaluation of food legumes under full sun and 50% shade indicated shading reduced yields of soybeans only 30% (Catedral and Lantican 1986) compared with 68% for mungbean (Lantican and Catedral 1986), although in part, the mungbean response related to increased incidence of leaf disease. There was differential genotypic response to shade in both species.

Radiation Interception

Numerous empirical studies have shown that within a closed crop canopy, irradiance is attenuated downwards with cumulative leaf area index (LAI) in approximate accordance with Beer's Law, with an extinction coefficient (k) characteristic of the canopy. The main influences on k are the orientation, angle, size and dispersion of leaves, and prior to canopy closure, spatial arrangement of plants. However, k can be influenced by the proportion of diffuse to direct radiation. Thus the LAI necessary to effect $>$95% interception of incident radiation ('critical' LAI) depends partly on the level and nature of irradiance, and the extinction coefficient for that crop. Critical LAI values for the large-leaved food legumes fall in the range of 3–3.5 depending on genotype and spatial arrangement (e.g. Muchow and Charles-Edwards 1982a; Shibles and Weber 1966), but can exceed 5 for small-leaved pigeonpeas (Rowden et al. 1981).

Clearly, radiation falling on bare ground is wasted energy, and the sooner a closed canopy is formed, the greater will be the total energy intercepted. Thus spatial arrangements e.g. isometric sowings and higher densities, which enhance early LAI development will, in the absence of stress, also enhance total DM production. However, vegetative growth in excess of that necessary to form a closed canopy represents DM that might more efficiently be used for seed DM. This need to optimise LAI provides the basis of genotype × sowing date × density interactions in phenologically unstable crops such as the tropical food legumes (see later).

Radiation falling on non-photosynthetic tissue such as woody stems, senescent leaf, flowers or ripe pods is also wasted energy. Thus the photosynthetic efficiency of pods relative to leaf in top-podding crops such as some cowpea, pigeonpea and mungbean genotypes remains to be clarified, since a significant proportion of the total incident energy during podfilling can be intercepted by the flowers and pods (e.g. Rowden et al. 1981). Actively growing soybean (Spaeth and Sinclair 1983) and cowpea (Littleton et al. 1981) pods can recycle much of the CO_2 evolved by respiring seed, but are not capable of net CO_2 uptake even in full sunlight.

A detailed analysis of the growth of two (top-podding) mungbean lines showed that for closed canopies, photosynthetic conversion efficiencies declined following the start of pod growth (Muchow and Charles-Edwards 1982a). Further, above-ground growth rates during the reproductive phase (Muchow and Charles-Edwards 1982b) were only around 80% that of a black gram line, in which pods were located within the canopy. It is tempting to speculate these differences may have been due to the significant interception of radiation by the mungbean pods, but with a lower E_c, perhaps because of the proportion of interception by already ripe pods.

Efficiency of Conversion

Growth rate in the absence of stress is a linear function of the amount of radiation intercepted (e.g. Muchow and Charles-Edwards 1982a; Shibles and Weber 1966), with the slope of the relationship providing an estimate of E_c. Physiological factors which might conceivably contribute to differences in E_c include the inherent photosynthetic capacity of leaves, the balance between photosynthesis and respiration, and canopy extinction coefficients.

In the tropical food legumes, genotypic variation within species in photosynthetic efficiencies has been found (e.g. Dornhoff and Shibles 1970) although its contribution to differences in DM accumulation is small relative to variation in leaf area and light interception (e.g. Duncan et al. 1978). Thus the productivity in terms of DM accumulation of differing genotypes is remarkably similar once a closed canopy has been formed. Likewise, much of the large variation in initial crop growth rate among food legume species can be ascribed to differences in leaf area expansion rate. In pigeonpea for example, relative higher partitioning of DM into roots appears to slow initial crop growth rate through slower leaf area development (Sheldrake and Narayanan 1979).

Enhanced leaf photosynthetic capacities are often related to compensatory mechanisms, such as thicker leaves but with slower leaf expansion rates (Charles-Edwards 1982). Thus the potential contribution of selection for improved photosynthetic capacity appears small. Various attempts have been made to manipulate canopy architecture to reduce k and increase E_c by distributing the incident radiation over as much leaf area as possible. The experience with leaf size and shape (Mandl and Buss 1981; Wien 1982) has not been encouraging.

Partitioning

Harvest index (HI) depends on the relative durations of the vegetative and reproductive phases, the proportion of DM (or more appropriately, energy) assimilated during the reproductive phase and partitioned into reproductive growth, and the amount of assimilate remobilised from vegetative to reproductive organs. Much of the advance in cereal yields has been from improvement in HI, rather than in total crop DM (Donald and Hamblin 1976), and as is discussed later, the trend is similar with the tropical food legumes. In effect, the direction is toward a shorter vegetative period combined with more determinate or synchronised growth, so that following the onset of flowering a higher proportion of assimilate is partitioned into reproductive growth. At the same time, the relative contribution to yield of stored assimilate is declining.

For example, in some of the more recent improved groundnut genotypes (ICRISAT 1983), partitioning of DM into the pods after the onset of flowering exceeds 90%, establishing potential growth rates of 100–125 kg/ha/d and a yield potential in the absence of stress of 7 t/ha of nuts-in-shell. Similar advances are being made with short-duration pigeonpea (Byth et al. 1981).

Temperature

Effects on Growth and Development

Temperature affects the rates of the metabolic processes involved in growth and development. Usually, temperature responses take the form of a skewed, optimum-response curve characterised by three cardinal temperatures, the optimum, minimum and maximum. In general, developmental processes (such as germination, ontogenetic change, leaf initiation, meiotic division) are more sensitive to temperature than growth or photosynthesis per se, and have more sharply-defined optima, although there is substantial differential sensitivity among processes. At extremes of temperature, cellular ultrastructure, most particularly membrane structure and function, can be irreversibly damaged.

Temperature effects in the suboptimal range can often be approximated by a simple linear function (Monteith 1981), and where the diurnal range of temperatures does not encompass high or low extremes, a linear function of daily mean temperature can be used to approximate temperature responses in the field (Angus et al. 1981). This implies in effect that the 'cumulative' temperature (accumulated daily above a 'base' temperature at which the process rate approaches zero, and expressed as day-degrees) needed to complete the process is constant. This thermal constant has been termed the 'thermal time' for that process (Monteith 1981).

Experimental estimates for base temperatures and thermal time for germination of a range of tropical food legumes (Angus et al. 1981), and estimates of the time needed for germination at 16 and 25°C are shown in Table 1, along with those of several

TABLE 1. Emergence times at mean temperatures of 16 and 26°C, based on experimental estimates of base temperature and thermal time (Angus et al. 1981), for a range of tropical grain legumes and several temperate species.

Species	Base temperature °C	Thermal time (Day degrees)	Days to emergence 16	25
Glycine max	9.9	70.5	11.6	4.7
Arachis hypogaea	13.3	76.3	28.3	6.5
Vigna unguiculata	11.0	43.0	8.6	3.1
Phaseolus vulgaris	10.6	52.1	9.6	3.6
Vigna radiata & V. mungo	10.8	49.6	9.5	3.5
Vigna angularis	9.9	69.9	11.5	4.6
Cajanus cajan	12.8	58.2	18.2	4.8
Lablab purpureus	9.6	56.2	8.8	3.6
Cyamopsis tetragonoloba	14.7	32.4	24.9	3.1
Triticum aestivum	2.6	77.9	5.8	3.5
Avena sativa	2.2	91.1	6.6	4.0
Brassica napus & B. campestris	2.6	79.0	5.9	3.5

temperate crops for comparison. The main difference between the two groups is in base temperature, and thus in the time taken for emergence at the cooler temperature.

Similar relationships have been shown between rates of development during other phases in the absence of photoperiodic response. Thus temperature is a major determinant of the duration of developmental phases.

In photoperiod-sensitive genotypes, the effect of temperature on various phases of development in the tropical food legumes is somewhat more complex, although generally the effect is for warmer temperatures to hasten development. One of the main effects of temperature in several species is for temperatures to modulate the critical photoperiod of a genotype (Hadley et al. 1983). More recent analysis suggests that in an analogous manner daylength may influence base temperature in relation to preflowering development (Roberts and Summerfield 1987).

Increase in temperature above the optimum reduces rates of growth and development, often very sharply, as increasing temperatures progressively disrupt metabolic activity. However, the optimum temperatures for various processes may differ substantially. Thus for example, optimum temperature for rates of development prior to floral initiation in a range of pigeonpea genotypes is around 20–24°C, but rates for leaf emergence are fastest in the range 28 – >32°C (McPherson et al. 1985). Symbiotic N fixation (Layzell et al. 1983) and meiotic division during gametogenesis are very sensitive to temperature extremes. Pollen formation is particularly sensitive, both to high (Warrag and Hall 1983) and low (Lawn and Hume 1985) temperature stress.

Thus, temperature can influence economic yield through each of the components of the model in Equation 1, although the relative magnitude of the effect on each varies greatly. In most situations, the main effects are likely to be on Q_i, through crop duration (i.e. phenological potential) and rate of leaf area development. Temperature can influence E_c through effects on rates of both photosynthesis and respiration. While photosynthesis has a very broad optimal range and is therefore only marginally responsive to temperature, short-term measurements suggest respiration rate increases with temperature (Wardlaw 1979). Thus, at higher temperatures E_c might be expected to decline, although Monteith (1981) argues that over time respiration represents a fixed proportion of assimilate and is thus fairly independent of temperature. There is relatively little information available for the tropical food legumes about the effect of temperature on HI, although there is evidence in soybeans (Seddigh and Jolliff 1984) and *Vigna* spp. (Lawn 1979b) that cool night temperatures can depress HI. Clearly, extremes of temperature which reduce the reproductive sink through effects on gametogenesis can substantially reduce HI.

Implications for Adaptation and Improvement

The tropics are characterised by generally warmer temperatures, with thermal uniformity both diurnally and over seasons. Temperature per se is unlikely to be a significant factor limiting yield of the tropical food legumes in the coastal lowlands. However, in continental areas, at higher elevations, and in the subtropics, temperature is likely to pose a significant seasonal constraint.

In the main, cooler temperatures, particularly at night, cause the most serious constraints for later summer sowings in the subtropics (e.g. Akinola and Whiteman 1975; Lawn 1979b), 'winter' sowings in continental areas (e.g. Lawn et al. 1984) or at higher altitude (Williams et al. 1975). Problems with high temperature stress are most likely in continental areas (e.g. Warrag and Hall 1983).

Opportunities to limit temperature constraints to yield of the tropical food legumes through agronomic approaches are in practical terms few, and limited mainly to decisions on where and when to sow. Not surprisingly, the generalised patterns described above have substantially determined traditional patterns of seasonal production and, because species differ in temperature response, the geographic patterns of distribution of their production. For example, temperatures in the northern areas around Chiang Mai in Thailand are too cold for mungbean during the dry season but not for soybean (Na Lampang 1985). There have been some limited attempts (e.g. with soybean — Bharati et al. 1983) to extend the range of production through seed acclimatisation treatments, but with little success.

There are large opportunities for genetic improvement however, both in terms of expanding the seasonal and regional range over which individual crops might be grown, and in improving yield within existing production areas. In those crops for which information is available, there are numerous examples of differential genotypic sensitivity to suboptimal temperatures, and to high and low temperature extremes. In many cases, these differences relate directly to the latitude of origin of the genotypes, implying differentiation has occurred as a direct consequence of past selection pressures. In addition to this intra-cultigen variation, there exist for most food legumes related wild subspecies (Smartt and Hymowitz 1985), which are likely to be a rich source of adaptive traits such as differential temperature response (cf. Lawn et al., these proceedings).

To date, most effort has been directed at improving adaptation to cooler temperatures, with some success (Voldeng et al. 1982; Holmberg 1973). However, opportunities for genetic improvement in relation to temperature responses remain largely unexploited. In most cases, little is known about the complexity of genetic control of differential responses, and the consequent difficulties in making progress. Genetic advance may be further hindered by lack of correlation between sensitivities at different stages (Hume and Jackson 1981) and between different processes (McPherson et al. 1985).

Research is needed at this stage to identify effective selection criteria and efficient screening techniques, to allow identification of temperature response types within segregating populations. In this context, physiological criteria may assist. For example, a heat tolerance test for soybean and other crops has been developed, based on leakage of electrolytes from heat damaged leaf tissue (Bouslama and Schapaugh 1984). Chlorophyll fluorescence has been used to identify tolerance to temperature extremes in potato (Smillie et al. 1983), and the potential exists for assays based on metabolic processes in seedlings or perhaps even in tissue culture where problems with plantlet regeneration can be overcome.

Daylength

Photoperiodism

Daylength is the other major climatic factor influencing the rate of ontogenetic development in plants. It is the most predictable of the climatic variables, which is presumably why photoperiodism has assumed major adaptive significance. Photoperiodism provides a mechanism whereby the plant's life cycle can be matched to seasonal change and thus to variation in other, growth-limiting climatic factors such as temperature and water. Its most dramatic effect is on the progress of plants from a vegetative to reproductive state, and it has been most extensively studied in this context.

All of the tropical food legumes exhibit photoperiodism, and all are short-day plants (Roberts and Summerfield 1987). In those species which have been extensively studied, most lines show quantitative short-day flowering response, although qualitative response types occur (Aggarwal and Poehlman 1977; Hadley et al. 1983; Lush and Evans 1980; McPherson et al. 1985; Turnbull et al. 1981). In most species, there also exist either day neutral or relatively daylength insensitive genotypes, at least in the context of rate of development to flowering (Aggarwal and Poehlman 1977; Ariyanayagam and Spence 1978; ICRISAT 1983; Inouye and Shanmugasundaram 1984; Turnbull et al. 1981). Usually, but not always, insensitivity is associated with earliness of flowering.

Rate of development after induction in the tropical food legumes is also commonly sensitive to daylength, although the relative sensitivity during later phases of growth remains to be clarified. However, it seems likely that their evolution as summer-growing plants would have favoured the development of a post-inductive requirement for daylengths at least as short, if not shorter, than those required for rapid induction. The limited available evidence tends to support this supposition. In soybean, for example, exposure to non-inductive long days following initiation can cause reversion to the vegetative state (Lawn and Byth 1973) and in some genotypes at least, continued exposure to short days beyond induction is necessary to ensure the formation of viable pollen (Fisher 1963). In cowpea (Lush and Evans 1980), the asiatic *Vigna* species (Lawn 1979a), pigeonpea (Wallis et al. 1985) and soybean (Lawn and Byth 1973; Board and Hall 1984), exposure to long days after floral induction/

initiation can variously extend the duration of the flowering period, reduce the synchrony of flowering, podset and pod maturation, and extend the post-flowering period by delaying pod ripening and/or inhibiting leaf senescence and abscission.

Groundnut is somewhat unusual in that it is relatively insensitive to photoperiod prior to flowering, but some genotypes are quite sensitive in post-flowering development (J.H. Williams unpubl.).

In soybean, growth of plants in relatively long days following induction has been shown to enhance vegetative growth (Guiamet and Nakayama 1984) and reduce the partitioning of DM and N (Cure et al. 1982) to pods and seeds. Long days also delayed the transition of stem apical buds to a reproductive state, altering apical dominance and consequently branching habit and stem growth (Thomas and Raper 1983). Conversely, exposure to relatively shorter days during reproductive growth can enhance HI and, except for short duration lines where vegetative growth is already limiting, result in at least similar yields in shorter time (Schweitzer and Harper 1985). In essence, the effect of daylength post-induction is one of altering the balance between reproductive and vegetative growth, with longer days enhancing the tendency to continued vegetative growth and expression of indeterminateness, and reproductive growth enhanced by shorter days.

Thus, the main effect of daylength is to determine, in concert with temperature, crop phenology (i.e. the timing of particular ontogenetic events in the crop cycle, and the durations of the phases between those events). As such, daylength directly influences the potential productivity through its influence on crop duration (i.e. the 'phenological potential'). It also influences productivity indirectly, through the matching of various phases of growth with changes in other growth-limiting environmental factors, which in turn influence the efficiencies of interception and use of energy. The other important effect in the tropical food legumes is on the synchrony of flowering, podset and maturity, and the relative partitioning of DM between vegetative and reproductive growth, which contributes to differences in HI.

Photoperiodism and Adaptation

Daylength varies systematically across latitude and season, with the longest day in midsummer and the shortest in midwinter. With annual crops such as the tropical food legumes, therefore, the daylength experienced by the crop depends on both the latitude and date of sowing.

Several aspects of the role of daylength in conditioning adaptation with respect to latitude and sowing date warrant elaboration. Firstly, in most of the tropical food legumes, there exists a wide range of differential genotypic response, and most usually, differential response can be directly related to latitude of origin (e.g. Byth 1968; Lawn 1979a). Generally, lines which are later flowering in relatively short days originate in the tropics, and those which require longer days to delay flowering originate at progressively higher latitudes. Because they are short day plants, sensitive genotypes will be earlier flowering the closer they are grown to the equator (Hartwig 1970; Lawn et al. 1984). Likewise, they will flower earlier when sown after the summer solstice than before it, and, in the absence of confounding temperature effects, when grown as dry season crops (Pookpakdi 1984).

Secondly, for summer crops, the seasonal variation in daylength is greater and therefore occurs more rapidly in the subtropics than the tropics, so that relatively small changes from any particular sowing date will ensure crops experience progressively larger changes in daylength as they are moved further into the subtropics. Consequently, the potential magnitude of effects of sowing date within the season becomes more pronounced moving away from the low latitude tropics.

Thirdly, in the tropics per se, although seasonal variation is smaller, the range of potential sowing dates is extended because temperatures are generally sufficiently warm for year-round cropping, and the differences in daylengths experienced between wet and dry season crops become comparable with those due to varying sowing dates for summer grown crops in the subtropics. At very low latitudes ($<10°$), the maximum range in daylength is 1 hr, and the differences in average daylengths experienced by wet and dry season crops are small.

Where the tropical food legumes are grown as summer season crops, the effects of long days on development after floral induction are not usually of practical concern. These crops are sown either prior to, or around, the summer solstice, and in most daylength sensitive genotypes, induction occurs some time after the solstice. Thus flowering and subsequent phases occur during progressively shortening days, and any requirement for short days post-induction is automatically satisfied. However, for very early sowings, induction may occur during the shorter days preceding the summer solstice (Board and Hall 1984; Lawn 1979a). Likewise, very early flowering genotypes may also flower prior to the solstice, so that subsequent development phases are exposed to comparatively long days, leading to problems in synchrony of development.

Undoubtedly post-induction effects emerge as the potentially most significant problem with dry season or 'winter' crops in the tropics, which experience reverse profiles of daylength (and often temperature) to those for wet season crops. Sown sometime after the autumnal equinox, these crops flower during the shortest days around or after the winter solstice. Thus, they complete their growth in lengthening days, sometimes maturing after the spring equinox, where irrigation is available. The latter crops experience longer days during late reproductive growth than do summer grown crops at any latitude maturing after the autumnal equinox. The consequence can be disastrous, with prolonged and asynchronous flowering and podset, and delayed leaf senescence and/or pod ripening (Lawn et al. 1984).

Photoperiodism and Crop Improvement

Photoperiodism has undoubtedly been the climatic response most successfully accommodated, and indeed exploited, in improving the tropical food legumes, and photoperiodic effects can and have been used to improve breeding methodologies, e.g. by facilitating hybridisation, synchronising flowering among diverse parents (Hadley et al. 1983) and enabling rapid generation turnover (McPherson et al. 1985).

The widest use of photoperiodic response has been made in the context of matching crop growth cycle to the environment, usually to maximise exploitation of the period when other climatic factors such as water or temperature are favourable, but occasionally to avoid the occurrence of critical growth phases during periods of high likelihood of particular stresses. For example, Putland and Imrie (these proceedings) describe the use of photoperiodic response to delay maturity of mungbean beyond the end of the rainy season and thus minimise the risk of weather damage to ripening seed.

In several species, the generally high correlation between time to flowering and crop duration has been exploited to develop an index whereby different daylength responses among cultivars can be classified and their likely region of adaptation indicated. This has resulted in various 'maturity group' classifications to discriminate between genotypes (Aggarwal and Poehlman 1977; Sharma et al. 1981; Shibles 1980). The differentiation among genotypes is largely due to differences in critical daylength, although clearly, variation in other parameters (e.g. relative sensitivity, length of juvenile phase, differential sensitivity post-induction), as well as differential temperature effects on all these, will contribute to maturity differences.

The most sophisticated example of a maturity group system is that employed for soybeans in North America (see Shibles 1980), whereby cultivars are classified into at least twelve groups, so that each group is 'adapted' over a latitudinal range of only about 4°. 'Appropriate' adaptation or crop ideotype in this system is effectively defined so as to match crop duration to the duration of favourable temperatures. Movement of a cultivar to a zone of higher group number than its adaptation would result in it becoming too early, and in a zone of lower group number it would not mature before the onset of frost.

The North American maturity group system for soybeans has been of limited value in the subtropics and tropics (Shanmugasundaram 1976), one reason being that water rather than temperature is the main climatic constraint to growth. This introduces the need for greater flexibility in the crop ideotypes which need to be considered (cf. Byth et al. 1981), in part because the year-round favourable temperatures of the tropics increase the range of cropping opportunities and in part because of the inherently greater variability of rainfall as a climatic factor. The former is exemplified in Thailand where soybean and other food legumes are grown in the early or late rainy season as well as the dry season (Na Lampang 1985). The crops thus sample a wide range of photothermal regimes, and necessitate greater flexibility in agronomic approach (Pookpakdi 1984).

The latter is exemplified in subtropical and tropical Australia, where the advent of adequate sowing rains is the main determinant of sowing date for raingrown summer crops (Lawn et al. 1984). In that situation, the existence of cultivar x sowing date x density interactions is turned to advantage to increase flexibility of the crop ideotype (Lawn et al. 1977; Lawn 1983a), by extending both the range of potential sowing dates and geographic range over which given varieties can be effectively grown. This greater flexibility also assists scheduling of crop rotations in double-cropping areas.

One of the most interesting developments has been to directly exploit the photoperiodic effects on both phenology and morphology which contribute to genotype x latitude/sowing date x density interactions and thus manipulate crop ideotype (e.g. Byth et al. 1981; Schweitzer and Harper 1985; Sheldrake and Narayanan 1979; Spence and Williams 1972; Wallis et al. 1985). The approach relies on the fact that when short-day plants are grown in daylengths which are short relative to their range of quantitative sensitivity, crop duration is shortened and the less vegetative, shorter plants are therefore less prone to lodging and leaf diseases. Moreover, flowering, podset and pod maturity became more synchronous, particularly in the physiologically indeterminate species such as cowpea, mungbean, black gram and pigeonpea. Reduced biomass per plant is compensated for in part by increased plant density and by increases in

HI, a trend which effectively mimics that experienced a decade earlier in the cereals.

A related trend is the development of early-flowering, day-neutral or relatively photoperiod insensitive lines (e.g. Ariyanayagam and Spence 1978; Byth et al. 1981; Sumarno 1984) as an attempt to: (1) broaden the adaptation of lines by reducing the magnitude of potential daylength effects; (2) improve adaptation to water limiting situations e.g. as rainfed crops (Hall and Grantz 1981) or post-rice crops (Sumarno 1985); or (3) improve suitability for use as short season relay crops in intensive cropping systems (Benjasil and Na Lampang 1984).

The use of photoperiod insensitivity has not been universally successful, however, partly because of its frequent association with extreme earliness. In soybean for example, complete insensitivity has usually been accompanied by a preflowering period of <28 days and, except where associated with indeterminateness or an extended flowering period (Inouye and Shanmugasundaram 1984), by short stature, lowset pods and limited yield potential. The discovery of a source of reduced sensitivity which may be related to an extended juvenile phase (Hartwig and Kiihl 1979) offers the hope of breaking this apparent nexus, so that yield potential need not be sacrificed. Thus far, insensitivity as an approach has been most effective in pigeonpea (Byth et al. 1981; Wallis et al. 1985) which has an extended juvenile phase, and, in the context of mechanised agriculture, those pulses such as cowpea and mungbean which bear their pods high in the canopy.

Water

Tropical monsoon Asia can be broadly divided into three basic climatic zones (cf. Nieuwolt 1972) viz. the equatorial monsoon climates, where both 'summer' and 'winter' monsoons bring rainfall, the wet/dry monsoon climates, where rainfall comes during the summer monsoon while the winter monsoon is dry, and the dry tropics where neither monsoon brings much rainfall. Within the wet/dry monsoon pattern, the trend is for the duration of the rainy season to shorten with increasing latitude and distance from the sea. These broad patterns are, however, very much disturbed, by local orography and geography, and rainfall is very unpredictable, varying in intensity and duration with time and place.

In terms of water supply to the plant, the picture is further complicated by local topographic and edaphic factors which influence runoff, infiltration, storage, and subsequent availability. Thus, depending on time of year, a given field might be arid or flooded, and in the rainy season, plants within a crop might alternately experience water supply deficits and excesses. It is even possible for different plants within a crop to be simultaneously droughted or waterlogged depending on topography. Both conditions substantially limit yield of mesophytic plants such as the food legumes.

Water Deficit and Productivity

A number of comprehensive reviews on the effects of stress induced by water deficit are available (Mussell and Staples 1979; Paleg and Aspinall 1981; Turner and Kramer 1980). In terms of the model outlined earlier in Equation 1, the main effects of water deficits can be summarised as follows:

1. A decrease in cumulative radiation interception through reduced rates of leaf initiation and/or expansion, reduced leaf area duration through faster senescence rates and/or phenological adjustment and paraheliotropic leaf movements and leaf rolling (Hughes and Keatinge 1983; Lawn 1982a; Muchow 1985). Soil water deficits during establishment can also reduce plant stand.
2. A reduction in the efficiency of utilisation of intercepted radiation, largely through a reduction in carbon exchange rates (Cortes and Sinclair 1986) associated with reduced stomatal conductance; and
3. A reduction in partitioning efficiency, either because of a shortening of the duration of reproductive growth or because of the abscission of pod and seed sinks (Korte et al. 1983b).

The relative effect of water deficit on each of the above depends in large part on timing relative to crop ontogeny, and duration and intensity. For example, Muchow (1985) reported that where water deficits developed gradually from sowing, the reduction in light interception due to reduced leaf area development was initially greater than that in conversion efficiency for a range of food legumes. Only after a prolonged drought, when the intensity of the deficit was strongest, were the effects on conversion efficiency comparable with those on interception. However, when an intense deficit developed rapidly following the establishment of a closed canopy, the reductions in E_c were relatively large. Likewise, water deficits during reproductive growth reduced leaf carbon exchange rates for soybean by 25% (Cortes and Sinclair 1986), although deficits occurring late in reproductive growth also promoted leaf senescence.

The effect of water deficit on sink development also depends largely on timing relative to crop ontogeny. Usually, water deficits during reproductive development prior to rapid seed growth reduce pod numbers through abscission of, variously, flower buds, flowers and small pods (e.g. Korte et al. 1983b). Water deficit progressively later in ontogeny results mainly in abortion of seeds within pods and, ultimately, in smaller seed. Seed size is most likely to be reduced when water deficits late in crop growth promote leaf senescence and advance crop maturity.

In addition to constraints to the carbon economy of food legumes, N fixation is extremely sensitive to water deficits (Pankhurst and Sprent 1975; Weisz et al. 1985). In large part, the effects appear to be due to rapid and direct effects of stress on the permeability of the nodule cortex to oxygen although it is likely there are also longer-term, indirect effects of carbon supply on nodule development and activity. The consequence is a substantial reduction in N accumulation under drought conditions (e.g. Chapman and Muchow 1985).

The extent to which effects of water deficit during growth translate into reductions in seed yield in turn depend on their severity and timing, and subsequent pattern of water supply (e.g. Korte et al. 1983a; Nageswara Rao and Williams, in press). In general, the earlier in crop growth the deficit occurs, the greater the opportunities for subsequent compensation, provided subsequent water supplies are adequate. The effects of a water deficit during vegetative growth can be fully compensated for in situations where water supply during subsequent growth is adequate. This is achieved by either subsequent vegetative growth, as with indeterminate varieties (e.g. Villalobos-Rodriguez and Shibles 1985), or by increased HI, as with 'full-season' varieties where vegetative growth tends to be in excess of that required to ensure full light interception during reproductive growth (e.g. Nageswara Rao et al. 1985; Ashley and Ethridge 1978). In this sense, short duration, determinate lines are more susceptible to water deficits during vegetative growth.

Food legumes are generally most sensitive to water deficit during reproductive growth, particularly during the time when pod numbers are being determined (e.g. Korte et al. 1983a; Nageswara Rao and Williams, in press). Beyond that time the opportunities for compensation are much reduced, although in most food legumes some yield homeostatic potential exists through compensatory change in seeds per pod and/or seed size (cf. Korte et al. 1983b). In many species, e.g. groundnut (Williams et al. 1986), cowpea, mungbean and black gram (Lawn 1982a), less determinate genotypes produce new flushes of flowers and pods when water deficit during reproductive growth is relieved. In groundnut, some genotypes respond to the relief of water deficit with a rapid increase in pod initiation without the development of new flowers, implying an ability to sustain a number of viable but non-developing embryos during the period of deficit (Williams et al. 1986).

Increasing the 'determinateness', or degree of synchrony of flowering and podset, may increase the vulnerability of food legumes to intermittent water deficit during reproductive growth by shortening the period over which pods are set. For example, Villalobos-Rodriguez and Shibles (1985) reported that the relative effects of water deficit during reproductive growth were greater in determinate compared with indeterminate tropical soybeans. Likewise, the groundnut cultivar JL 24, which has a highly synchronous podding habit, has proven very susceptible to intermittent water deficit in studies at ICRISAT (Nageswara Rao and Williams pers. comm.). However, synchronous podding may be of benefit in the case of terminal water deficit (see below).

Strategies for Improvement

Numerous studies show that like most crops, the food legumes respond positively to irrigation. In practice, however, opportunities for irrigation are very limited, with farmers usually preferring to use scarce water resources for the production of more profitable crops. At best, sufficient water may only be available for supplementary irrigation, and in this case the most efficient use will be made of water applied during the pod-formation/seed-filling phases (cf. Nageswara Rao et al. 1985).

In the absence of irrigation, attempts to overcome limits imposed by water deficit must focus heavily on: (1) agronomic approaches to improving the conservation and storage of soil water; and (2) agronomic and genetic approaches to improving the effectiveness of water use and water use efficiency (WUE) by minimising the impact of water deficits. The latter approaches are of main interest here. Most important is the effectiveness of water use, since biomass is a linear function of water use (e.g. Lawn 1982b), and water left in the soil is unexploited potential.

A comparison of the performance of four groundnut genotypes to intermittent water deficit at ICRISAT (Table 2) suggests improvements in WUE are possible. Although all four lines used the same amount of water, there was large variation in both WUE and HI, presumably because of differential tolerance to/recovery in the pattern of water deficit imposed in that study (Williams et al. 1986).

Likewise, isotopic discrimination has identified genotypic variation in WUE (Farquhar and Hubick 1985). Genotypic differences have also been observed in groundnut in terms of the ability to continue to initiate pods after the onset of drought.

Both agronomic and genetic strategies for improving yield in drought environments can be broadly grouped into those of drought 'escape' or 'resistance'. In turn, the latter can be further

TABLE 2. Total water use, water use efficiency and harvest index of groundnut genotypes relative to EC 76446(292). (From Williams et al. 1986).

Genotype	Total water use (%)	Water use efficiency (%)	Harvest Index (%)
TMV 2	98	111	181
Robut 33-1	101	125	156
NC Ac17090	101	118	125
EC 76446(292)	100	100	100

subdivided into strategies to reduce the rate of water use, sustain the rate of water uptake, or to tolerate tissue water deficits. Resistance can also potentially contribute to plant survival and potential for recovery if and when the water deficit is relieved.

Targeting the Environment

The most appropriate strategies for crop improvement in drought environments depend on the likely pattern of water availability and of the likelihood of variations about that pattern (Lawn 1982b; Williams et al. 1986). In Southeast Asian cropping systems, the two situations most commonly confronted are: (1) terminal droughts, where the quantity/duration of water supply is relatively fixed by soil storage so that the plant is exposed to water deficit only toward the end of growth; (2) intermittent droughts, where the crop may be exposed to droughts of variable intensity and duration at any stage of growth. Examples where terminal droughts can be expected include post-rainy season crops following rice and areas of seasonally-defined, but reasonably reliable rainfall. Intermittent drought confronts most upland crops, except in the most reliable rainfall areas.

In the case of terminal drought, the aim is to ensure full use of available water with the maximum possible being used over the reproductive phase. The most appropriate improvement strategy is drought escape, although a level of tolerance of tissue water deficits late in growth may facilitate maximum water extraction. Choice of sowing date and sowing arrangement/density can be respectively used to match crop phenology to environment and influence rate and effectiveness of water use. For example, equidistant spatial arrangements can enhance early LAI development and water use but favour more effective exploitation of soil water at depth in interplant spaces (Lawn 1983b).

The importance of matching crop to environment is illustrated by the situation with groundnut at ICRISAT, where in the absence of drought the yield potential of genotypes maturing in 110 and 140 days is respectively 4.5 and 6.0 t/ha, whereas if a terminal drought commences after 100 days, the respective yields are 3.0 and 0.7 t/ha for these same lines (Nageswara Rao and Williams, pers. comm.).

Where the duration or amount of water supply is very reliable, the most efficient mechanism to achieve escape is likely to be rapid phenological development such that the crop matures before water supply ceases. A synchronised reproductive growth habit would enable maximum partitioning into seed and also facilitate matching crop duration to water supply. However, where the year to year duration of water supply is variable, the most productive mechanism is likely to be rapid phenological development combined with plasticity in the duration of the reproductive phase. Thus, in those years where water is available for longer, reproductive growth can be extended to take advantage of it.

With intermittent droughts, the most successful strategies will be those based on resistance — particularly those which favour recovery following stress — combined with a limited array of management options. Such options include choices of sowing date/phenology to minimise the coincidence of critical growth stages with periods of high likelihood of drought.

Breeding for Tolerance/Escape in Food Legumes

Various physiological mechanisms that contribute to resistance or escape of drought have been identified in food legumes (Table 3). The most important escape mechanism is rapid development, which is being widely exploited in soybean, mungbean and cowpea with the development of short duration lines for post-rice crops. A related escape mechanism, often associated with indeterminate growth, is phenological plasticity, whereby the duration of reproductive growth depends on the continued availability of water. This mechanism has been observed in some mungbean and black gram (Lawn 1982a) and chickpea lines (Sheldrake and Saxena 1979).

Mechanisms contributing to resistance through reduced water loss include differences in stomatal sensitivity, cuticular conductance, paraheliotropic leaf movement, and in the rates of change in leaf area either through reduced leaf expansion or advanced abscission (Lawn 1982a; Sinclair and Ludlow 1986; Muchow 1985). Each of these

TABLE 3. Physiological mechanisms contributing to drought escape or tolerance identified in various of the tropical food legumes.

Strategy & mechanism	Example of occurrence
A. Escape	
* Rapid progress to flowering	Short duration genotypes e.g. of cowpea, soybean & mungbean (cf Hall & Grantz 1981; Sumarno 1985)
* Plasticity in reproductive phase	In several *Vigna* spp. (Lawn 1982a) and chickpea (Sheldrake and Saxena 1979)
B. Resistance	
I. Reduced water use	
* Stomatal closure	Variation among spp. (Lawn 1982a; Muchow 1985)
* Reduced cuticular conductance	Variation among spp. (Sinclair & Ludlow 1986) & within soybean (Paje et al. pers. comm.)
* Slower leaf area development	Variation among spp. (Lawn 1982a; Muchow 1985)
* Shorter leaf area duration	Variation among spp. (Lawn 1982a; Muchow 1985)
* Paraheliotropic leaf movements	Variation among spp. (Lawn 1982a; Muchow 1985)
II. Improved water uptake	
* Improved root function e.g. density & depth	Variation in groundnut (Williams et al. 1986) & among spp. (Angus et al. 1983; Lawn 1982a)
III. Desiccation tolerance	
* Osmotic adjustment	Variation among spp. (Ludlow pers. comm.) & some within pigeonpea (Flower & Ludlow 1987)
* Lower critical relative water contents	Variation among spp. (Sinclair & Ludlow 1986)

mechanisms results to some degree in reduced productivity although mechanisms such as stomatal sensitivity, cuticular conductance and leaf movements appear more conducive to rapid recovery following the relief of drought. Increased rooting density and rooting depth contribute to sustaining water uptake and species differences have been observed (Angus et al. 1983; Lawn 1982b). Mechanisms which contribute to enhanced tolerance of tissue water deficits include osmotic adjustment and desiccation tolerance (Flower and Ludlow 1986; Sinclair and Ludlow 1986).

Comparative studies suggest that there is strong interrelationship between various mechanisms, and that several may operate in concert, perhaps causally, to give rise to overall strategies of response. Thus, it appears to be the various combinations of these which make some species better adapted to certain patterns of drought stress than others (Angus et al. 1983; Lawn 1982b; Sinclair and Ludlow 1986; Muchow 1985). Substantial research remains to clarify these interrelationships and their consequences for crop water use and yield. It also remains to be seen to what extent the various mechanisms can be exploited within any particular species.

Investigations with pigeonpea have revealed that while osmotic adjustment was high relative to other food legumes, only moderate variation was found among genotypes (Flower and Ludlow 1986). On the other hand, a twofold range in cuticular conductance has been found in soybean (M. Paje et al., pers. comm.) offering the prospect of improving the survival time of plants during severe water deficits with that species. Wide variation in rooting habit has been found in groundnut, and studies at ICRISAT have shown that this can contribute to differential sensitivity to water deficits (Williams et al. 1986). The genotype NC Ac 17090 is shallow rooted, and much better able to exploit water from light showers, but less so for soil water at depth.

Given the complexity of the interrelationships between the mechanisms in Table 3, it seems unlikely that approaches focusing solely on any one will result in significant advance. Further, the importance of particular mechanisms will most certainly vary among species. Nonetheless, investigations into these mechanisms offer one of the most promising areas for improving drought performance in the food legumes. Certainly, the complexity of the interactions between genotype and timing, intensity and duration of water deficit (e.g. Nageswara Rao and Williams, in press) suggests that alternative approaches based on empirical screening will have to be very specific indeed to the patterns of stress being targeted.

Limits Imposed by Excess Water

Excessive water can limit yield of the food legumes in several ways. The most common is a reduction in N fixation caused by reduced oxygen supply to the nodules in temporarily waterlogged soils, an effect often exacerbated by soil denitrification. If the duration of waterlogging is short, the main effect observed is a transient chlorosis and reduction in crop growth rate. However, where waterlogging is prolonged, it can induce the death of roots and nodules, in which case the setback to growth can be serious. In some species, wet soil conditions and the death of roots facilitate the entry of pathogenic organisms (e.g. *Phytophthora* stem rot in cowpea, chickpea and soybean), leading to the death of waterlogged plants from disease.

There is variation among food legume species in tolerance to temporary waterlogging. For example, mungbean, pigeonpea, guar, and moth bean are particularly sensitive while others, most notably soybean, are tolerant. Indeed, studies in Australia have shown that soybean seedlings readily acclimate to growth on saturated soils, providing a shallow zone of aerobic soil is maintained at the soil surface (Troedson et al. 1984). The growth of acclimated soybeans in saturated soil exceeds that of well-watered, conventionally-grown crops, so that provided sufficient time is available following acclimation, yields can ultimately exceed those of well-watered crops.

Apart from agronomic approaches to avoid waterlogging, e.g. through drainage or matching crop to environment, the most promising approach appears to be to select for tolerance among and within species. Tolerance to intermittent waterlogging appears to involve two related components: (1) tolerance of roots and nodules to temporary anaerobiosis; (2) ability of roots and nodules to rapidly recover following soil drainage. Field screening for tolerance to waterlogging has been successful in identifying genotypic differences in several food legumes (ICRISAT 1982, Alvino et al. 1983). In the case of soybeans, it appears it may be possible to select for genotypes which will respond even more positively to saturated soils (Hartley, Lawn and Byth pers. comm.).

Another important constraint imposed by excessive water in some species e.g. mungbean and cowpea, is damage caused to ripening pods by exposure to humid, wet conditions. As discussed elsewhere in these proceedings, opportunities exist either for escape (Putland and Imrie) or tolerance (Imrie et al.). Finally, exposure to humid, wet conditions can favour rank growth, predisposing plants to lodging, or to a host of foliar and pod diseases. If the crops are to be grown in such environments, breeding for disease resistance is the only appropriate solution.

Overview

Earlier in this paper, it was suggested that opportunities to manipulate the crop environment to minimise climatic constraints are limited to the localised scale of the individual field and the crop microenvironment. It is apparent from this brief review that despite this restriction, the opportunities for improving performance of the tropical food legumes through various aspects of management are substantial. The main requirement is a critical analysis of the contribution of the various climatic factors affecting performance in order to identify the major constraints in particular environments. Flexibility in management can often broaden the range of environments over which particular lines can be grown.

It was also suggested that opportunities for genetic improvement were less limited. Nonetheless, it is apparent that the situation is complex, particularly in a relatively underdeveloped group of plants such as the tropical food legumes, where the concept of 'appropriate' climatic adaptation has often been recognised only in its absence i.e. when genotypes have been moved away from the area that most suits them. Only in recent years has breeding for climatic adaptation emerged as a more purposeful, directed concept.

There are several (usually interacting) climatic factors affecting the physiological processes of growth and development, with potentially different levels of complexity of genetic control and different levels of importance to seed yield. In breeding for climatic adaptation the problem is firstly to clarify breeding objectives by identifying the climatic factor(s) of major adaptive significance in the target environment, the process(es) they influence, and the range of different response types. Secondly, effective selection criteria must be defined, and efficient screening techniques designed, to achieve these objectives.

Implicit in this analysis is recognition of a need to try to exploit specific climatic adaptation if yield potentials are to be maximised in the shorter term. The alternative, and longer term approach, is to attempt to breed genotypes which are less sensitive to climatic factors such as daylength, temperature and water. The advantages of the latter approach, if successful, are obvious: the broader adaptation of cultivars would reduce the resources needed for investment in breeding and seed production and distribution, and facilitate the more rapid geographic dissemination of breeding advances made in any one area.

The disadvantage however, is that there is a very real cost in terms of reduced yield potential in particular environments because 'insensitive' cultivars are not completely so. The best broadly adapted cultivar will have the highest yield over a range of climatic environments but, to the extent that insensitivity is not achieved, will be lower yielding than the best specifically adapted line in each environment. The complexity of the interaction between climatic factors and the growth and development of the food legumes is such that the simultaneous achievement of high yield potential and 'broad climatic adaptation' will be difficult and time-consuming to achieve, particularly in relation to constraints imposed by water and temperature. Thus, the cumulative cost of ignoring specific genotype x climate interactions could be large.

Apart from these biological considerations, the most appropriate balance between emphasis on specific and broad climatic adaptation will depend on the resources available for improvement relative to the diversity of climatic regimes being targeted, and the potential economic significance of each to production of the crop as a whole. Whatever that balance, there is little doubt that directed research, based on an understanding of genotype x climate interaction, will be preferable to a continuation of the empirical research approaches which have characterised much improvement effort to date.

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Mineral Constraints to Food Legume Crop Production in Asia

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FOOD legumes are considered secondary crops in Asian farming systems but they play a vital role in providing proteins, fat and vitamins in the diet of the 2.5 billion inhabitants of the region (Moomaw et al. 1977). However, in sharp contrast to the yield gains made with rice and wheat in the past two decades, average yields of food legume crops in most Asian countries are low and do not show a comparable increasing trend. Country reports at the Review and Planning Meeting for Asian Regional Research on Grain Legumes (ICRISAT 1985) show that, whereas average crop yields in farmers' fields are 0.5–1.2 t/ha, yields from varietal trials of a range of food legumes are generally 2.0 t/ha or more and range as high as 5.6 t/ha. The yield gap between trial yields obtained with good management and high inputs on the research station and yields on farms therefore varies from approximately 1–5 t/ha. This yield gap, the primary focus of the conference, may be caused by a number of interacting constraints such as drought, pests, diseases, soil physical problems, poor nodulation, mineral disorders, etc. This paper is concerned with the role of mineral constraints.

The requirement of food legumes for nutrients does not differ greatly from that of non-leguminous crops (Robson and Loneragan 1977; Munns 1977). However, for effective symbiotic nitrogen fixation, legumes require Co and Mo in larger quantities and, under some circumstances, have a specific need for adequate levels of Cu, Ca and perhaps P (Robson 1978). Furthermore, the symbiosis is particularly sensitive to the Al and Mn toxicities and the Ca deficiency associated with soil acidity (Munns and Franco 1982). Munns (1977) considers that alkalinity is a more severe constraint to legumes than salinity, for which tolerance varies considerably between species. A detailed discussion of the effects of these mineral constraints on food legume growth and nitrogen fixation is given in the excellent reviews referred to above.

This paper focuses on the food legume producing areas in Asia, with particular attention to South and Southeast Asia. The production systems and soils of these areas are discussed and the current fertiliser use on food legume crops is considered. Published experimental data are then reviewed in order to explore the potential role of mineral constraints in limiting food legume production. The diagnosis of nutritional deficiencies through the use of plant and soil analyses is then discussed in detail, using the example of ACIAR's cooperative research on micronutrients in Thailand, and leading to a consideration of research needs to define and overcome mineral constraints to food legume production in the region.

Production Systems, Soils and Fertiliser Use

Food legumes are grown in a wide range of agricultural production systems in humid and semi-arid Asia (Dent 1980; Yaacob et al. 1980; Kampen and Burford 1980). The following major systems have been defined:

1. Production Systems Based on Wetland Rice

The main crop is irrigated, rainfed or deep-water rice; the food legume crop is sometimes irrigated, but in many areas the food legumes are grown without irrigation on residual water in soils which have been puddled for the previous rice crop (see So and Woodhead, these proceedings).

2. Dryland (Upland) Production Systems

These may be further subdivided into:

a. Rainfed systems based on annual crops Large areas of the Indian semi-arid tropics would fall into this category (Kampen and Burford 1980). In these areas, food legumes are frequently grown in various types of multiple cropping systems in order to minimise the risk of crop failure. Food legumes are

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also grown as intercrops in upland rice areas in Southeast Asia (IRRI 1984).

b. Plantation crop systems Although cover crop legumes or natural covers have traditionally been used in the interrow spaces of rubber and oil palm plantations, Pushparajah (1985) has recently emphasised the suitability of these areas for food legume production by smallholders who require a cash income during the early unproductive establishment years.

c. Rainfed shifting cultivation systems These traditional systems, which are based on long periods of bush fallow to rehabilitate the soil between cropping periods, are declining in importance, due to increasing population pressure in the region.

Data on the extent of food legume production in these different systems are not available; nor are data on the areal extent of different soil types used to produce these crops. However, the classification and distribution of soils used for wetland rice systems have been discussed in detail by Moormann (1978) and Gong (1981), while Kyuma (1981) has described the fertility of these soils. Dent (1980) and Kampen and Burford (1980) detail the soils and associated constraints to crop production in Southeast Asia and India respectively. In general, most important wetland soils fall within the Alfisol, Entisol, Inceptisol and Ultisol orders of the USDA Soil Taxonomy. Ultisols occupy 56% of the total land area in Southeast Asia and are also used for rainfed annual cropping and plantation systems. Alfisols cover 38% and Vertisols 25% of the area in the semi-arid tropics of Asia used mainly for rainfed annual cropping.

Associated with each of the major soil types is a suite of potential mineral stresses, including salinity, acidity, and deficiency or toxicity of various elements (Dent 1980). According to Dent, mineral stress is the major soils limitation to crop production on 59% of the area of Southeast Asia, 9% of North and Central Asia and only 5% of South Asia; in South Asia drought is the major limitation on 43% of the area. The expression of these potential mineral stresses in terms of the yield of food legume crops will depend upon the crop species and cultivars, soil type, the use of fertilisers and soil amendments, cropping history, climate and a whole host of factors influencing crop growth. Thus, while a general knowledge of the production systems and soil types indicates that mineral stresses are a widespread constraint to food legume production in Asia, the magnitude and the extent of the problem can be defined more accurately only through a closer examination of the experimental data from the region. Before pursuing this in subsequent sections of the paper, data on current fertiliser use with food legumes in Asia will be reviewed.

Although agricultural intensification in Asia has led to a trebling in fertiliser use between 1972 and 1983 (FADINAP 1985), much of this increase is due to a rapid expansion in the production and the use of nitrogen, which is largely applied to rice and other cereals or plantation crops. Data on the use of fertilisers on food legume crops are scarce; Table 1 shows the only such data given in a report by Martinez and Diamond (1982) who conducted a survey of 300 fertiliser experts and agencies around the world and reviewed the available statistical sources. Table 1 shows that on average the countries of South and Southeast Asia use very low rates of fertiliser on food legumes compared with the amounts applied in south Korea and Japan. Data for India were not given, presumably because fertiliser use on food legumes is so rare that statistics are not collected.

TABLE 1. Use of fertilisers on food legumes in selected Asian countries (from Martinez and Diamond 1982).

Country	Crop	Rate — Total Harvested Area		
		N	P_2O_5 kg/ha	K_2O
Burma	groundnuts	3	4	0
Bangladesh	pulses	3	1	0
Indonesia	groundnuts	3	4	0
	soybeans	2	6	0
Japan	edible beans	37	105	101
South Korea	pulses	40	25	16

It is possible that, although the direct use of fertilisers on food legumes is small, these crops may benefit to some extent from nutrients applied to associated crops, in particular wetland rice and plantation crops. It is difficult to judge how important such residual or associated effects may be, especially since sequential waterlogging and drying affect the availability of soil nutrients. In the case of phosphorus, fertiliser applied to wetland rice may be immobilised and made unavailable to upland crops when the waterlogged soil is dried after rice harvest (Willett 1982). In intensive rice-based cropping systems such as those in China, the combination of unbalanced fertilisation and the removal of large amounts of nutrients in high-yielding rice crops may in fact be leading to a depletion of soil reserves of sulfur and some micronutrients (Blair 1983). Thus, while nitrogen fixation by food legumes contributes to the nitrogen economy of other crops, it appears that in most developing Asian countries food legume crops must rely largely on natural soil fertility, which declines as cropping intensity is increased. The consequences of this to yields of these crops are discussed below.

TABLE 2. Nutritional constraints to yields of food legumes in some Asian countries — selected experimental data.

Location	Soil type	Crop	Maximum yield (MY) t/ha	Nutrient(s) or amendment omitted	Yield reduction t/ha	Yield reduction Percentage of MY	Comments	Reference
India								
	Alfisol	Groundnut	5.76	K	0.71	12		Badiger et al. (1982)
				Ca	0.63	11		
				S	1.12	20		
Jabalpur	Vertisol	Soybean	3.06	P	1.11	36	MY — 90 kg P_2O_5/ha	Mahajan et al. (1982)
Bhavanisager	Red Loam	Soybean	1.66	P	0.34	21	MY — 120 kg P_2O_5/ha	Krishnamoorthy et al. (1983)
Hyderabad	Alfisol	Groundnut	3.01	Ca, S	0.70	23	My — 100 kg $CaSO_4$ + 25 kg $ZnSO_4$/ha	De et al. (1982)
				Zn, S	0.30	3		
				Ca, Zn, S	1.06	25		
Indonesia								
Muara	Latosol	Mungbean	1.44	Mg	0.18	13	MY — no added lime or S	Ismunadji et al. (1982)
				Mo	0.48	33		
Lampung	Ultisol	Soybean	1.78	Lime	0.83	47		Ismunadji et al. (1982)
				Mo	0.50	28		
				P	1.10	62		
Bogor	Latosol	Groundnut	2.97	Ca	0.22	7	MY — 50 kg Mg/ha 50 kg Ca/ha	Soepardi and Idris (1977)
				Mg	0.21	7		
				Ca, Mg	0.94	32		
Malaysia								
Jln. Kebun	Histosol	Groundnut	1.48	P	0.24	16		Foster et al. (1980)
				K	0.33	22		
				Lime	0.48	32		
				N	0.35	23		
L. Pergau	Entisol	Groundnut	2.49	P	0.29	12		Foster et al. (1980)
				K	0.39	16		
				Lime	0.55	22		
				N	0.50	20		
Temerloh	Inceptisol	Mungbean	2.30	P	0.41	18		Foster et al. (1980)
				K	0.19	8		
				Lime	0.70	30		
				N	0.34	14		
Serdang	Ultisol	Soybean	1.73	P	1.15	66		Foster et al. (1980)
				K	0.44	26		
				Lime	0.73	42		
				N	0.21	12		
Serdang	Ultisol	Mungbean	1.01	P	0.33	32		Foster et al. (1980)
				K	0.23	22		
				Lime	0.55	54		
				N	0.17	16		
Thailand								
Nakon Sawan	Mollisol	Groundnut	0.98	Fe	0.72	73	MY — Fe applied 9 times as a spray	Ratanarat et al., these proceedings
San Sai	Alfisol	Black gram	1.45	B	0.67	48	MY — 10 kg borax/ha	Rerkasem et al., these proceedings

Constraints to Yield

In order to assess the magnitude of the yield limitation caused by nutritional disorders, the authors undertook a computer search of the literature. The search was restricted to research papers reporting data on the yield response of food legumes to fertilisers or amendments in experiments from the field in Asia. Many of the papers located in the search came from India, and only a selection of these is presented in Table 2, together with papers from other Asian countries. It should be noted that the material in the table is probably only the tip of the iceberg of data that are published in local languages, reported in unpublished departmental documents or otherwise inaccessible. In Table 2, the data are presented as yield reductions (in relation to maximum yield), due to the omission of the particular nutrient(s). Only statistically significant differences are included.

The results from India cover some of the major crops and soils in the subcontinent; as mentioned above, the Alfisols and Vertisols cover more than 60% of the semi-arid areas. The limitation to yield due to the omission of the various nutrients ranged from 0.3 to 1.12 t/ha, representing 3-36% of the maximum yield. The high maximum yields in three of the experiments (3.01-5.76) suggest that the crop varieties used were responsive to fertiliser and that soil water, pests and diseases were not major constraints under the conditions of the experiment. Although the experimental treatments were not designed to determine systematically which nutrients limited growth, the results indicate that the deficiency of a wide range of nutrients could be responsible for low yields in the fields by the many farmers who do not apply fertilisers to legume crops growing on these soil types.

In Indonesia and Malaysia, the maximum yields are generally low. Nevertheless in Indonesia, the 0.83 t/ha limitation to soybean yield due to soil acidity and the 1.10 t/ha due to P omission are equivalent to 47 and 62% of the maximum yield respectively. These are important results, because the soil at the experiment site concerned was an Ultisol, the most widespread soil order in the region. At the Malaysian Ultisol sites, large yield reductions were recorded when P and lime were not added. Soil acidity was also a problem on the Histosol, an important problem soil in the region. Foster et al. (1980) consider that the soil factor limiting legume yields in Malaysia most severely is high acidity. Also worth noting is the relatively large yield reduction when nitrogen was omitted, even in the case of soybean which was inoculated in these experiments.

The results from Thailand show that the micronutrients B and Fe are severe constraints to food legume yields in some areas. In the case of Fe, groundnut is particularly susceptible. The planting of alternative crops presents one solution to the problem, although groundnut varieties more tolerant to Fe deficiency are being sought.

The data in Table 2 suggest that nutritional constraints severely limit the yields of food legumes in many important soil types in South and Southeast Asia. The large yield reductions measured when the various nutrients were omitted indicate that farmers, who currently use little or no fertiliser on these crops, could increase yields substantially by the application of the missing nutrients. The key to the efficient, economical use of fertilisers is to add a balanced dose of the correct elements. Ways to achieve this through better diagnosis of crops requirements are now considered.

Diagnosis and Prediction of Nutrient Deficiencies

As discussed above, the response of seed production to fertiliser treatment of field crops provides the most direct method for assessing nutritional limitations in soils for production of food legumes. But field trials carried through to crop maturity are expensive in technical expertise and land. Moreover, they provide no information of value to the current season's crop. There is, therefore, considerable interest in less demanding procedures which can provide information in time to prevent the development of nutrient deficiencies in legume crops or, at least, to correct them early in crop life.

This section of the paper is concerned with the various soil and plant tests which have been developed for diagnosing and predicting the development of nutrient deficiencies which might limit grain production in legume crops. But, while they might provide information more easily and quickly than fertiliser field trials, such procedures are only worthwhile when calibrated against the response of grain production of specific legume crops under field conditions to fertiliser applications.

In considering procedures for assessing fertiliser requirements of crops, it is essential to distinguish between diagnostic and prognostic tests. Diagnostic tests define the nutritional status of crops at the time of sampling; prognostic tests predict the nutritional status of crops in the future. Diagnostic tests are restricted to plant tests and are used to define nutrient deficiencies or toxicities in standing crops. Because the ability of plants to respond to any one nutrient is limited by any other factor which limits their growth, plant tests can only diagnose a single nutrient limitation at any one sampling. Hence, if nitrogen is limiting, it is not possible to diagnose other potentially limiting nutrients. For legumes, it is thus essential to check that the plants are well nodulated and that plant nitrogen levels are high before considering other nutrients; a low nitrogen level in legumes indicates an ineffective symbiotic system and this must be corrected before proceeding with diagnosis of other deficiencies. The same principle applies to other nutrient deficiencies — with removal of each nutrient limitation to crop production, another nutrient limitation may be revealed. Where soils are low in several nutrients, plant analysis may be slow to diagnose all nutrient limitations to optimal crop production unless combined with some other diagnostic procedure such as a subtractive or a factorial fertiliser trial.

Prognostic tests would ideally provide information about all nutrients from a single sampling. All soil tests are prognostic and theoretically can be used prior to sowing to recommend the fertilisers needed for maximum crop production. Plant tests may also sometimes be used in a prognostic way as, for example, when plant analysis during early vegetative growth of soybean is used to predict the adequacy of soil nutrients for maximum grain production (Small and Ohlrogge 1973).

Diagnosis of Plant Nutrient Status

Plant tests are based upon some plant characteristics responding to the changing status of a specific nutrient in a way which is unique to it and reproducible under a variety of environmental conditions.

A great variety of diagnostic procedures have been devised, including ones based upon observation of symptoms, measurement of nutrient concentrations, metabolites, or enzyme activities in tissues, and physiological, biochemical or growth responses to addition of nutrients (Bouma 1983; Moraghan 1985).

Symptoms

Plant symptoms provide the simplest indicators of nutrient deficiencies and toxicities (Bergmann 1983). They are frequently useful as guides to identifying specific nutrient deficiencies. However, crop production may be seriously depressed before symptoms appear. Moreover, symptoms may vary with plant species and environmental conditions and are generally not sufficiently specific to identify deficiencies of individual nutrients without support from other evidence.

The symptoms of boron deficiency in peanuts are an exceptional case. The condition of peanut kernels known as 'hollow heart', in which the adaxial surfaces of cotyledons become discoloured and depressed leaving a small hollow in the centre of the seed, appears to be a symptom which is specific to boron deficiency (Cox and Reid 1964). This specific symptom has recently been used in identifying soils which are low in boron for peanut production in the north (Rerkasem et al., these proceedings; Netsangtip et al., these proceedings) and northeast (Keerati-Kasikorn, these proceedings) regions of Thailand. In each region, application of borax fertiliser alleviated or eliminated the symptoms; no other fertiliser had any effect.

Iron deficiency may also be somewhat exceptional in that the symptoms of deficiency in peanuts are very striking and unlikely to be confused with other nutrient deficiencies, except possibly manganese in some species. The symptoms are sufficiently clear-cut to be usable as a criterion for selection of cultivars for their ability to obtain iron from soils (Ratanarat et al., these proceedings).

Nutrient Concentrations in Plants

Diagnosis of nutrient deficiencies based upon the concentration of nutrients in plants is the most widely used of all plant tests. It will therefore be treated in somewhat more detail than other procedures. More thorough reviews will be found elsewhere (Ulrich and Hills 1967; Bouma 1983; Moraghan 1985; Reuter and Robinson 1986).

GENERAL CONSIDERATIONS

The use of nutrient concentrations in plant tissues for diagnosis of nutrient status of plants is based upon the relationship of nutrient concentration to yield depicted in Fig. 1. This relationship assumes that for each nutrient a minimum concentration is necessary for plant growth, that lower concentrations are deficient and depress growth, that higher concentrations up to a limit are adequate

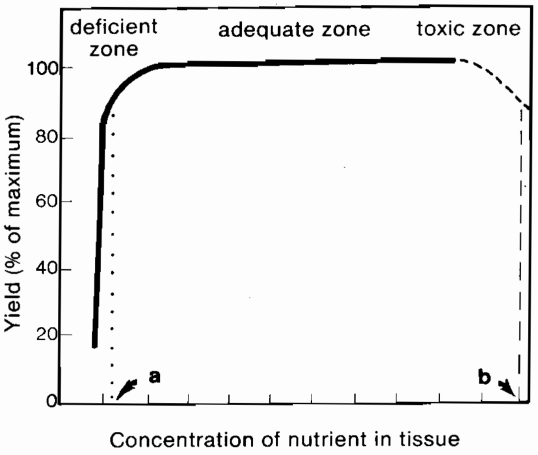

Fig. 1. Relationship of plant yield to nutrient concentration in plant tissue. The letters a and b indicate the critical concentrations for deficiency and toxicity respectively at 90% maximum yield. After Ulrich and Hills 1967.

or luxurious and sustain growth, and that above that limit they are toxic and depress growth.

Diagnosis of nutrient status from nutrient concentration further assumes that the minimum concentrations for deficiency and toxicity are uniquely defined for each plant species. These unique concentrations are known as the 'critical values' or 'critical concentrations' for deficiency and toxicity, respectively.

While some researchers have defined critical values as the lower and upper limits of nutrient concentrations for optimal growth, others prefer to define them as those concentrations associated with a 10% reduction in yield (Ulrich and Hills 1967). Yet others (Dow and Roberts 1982) prefer to define a range of concentrations as critical rather than a specific value. Any one of these definitions provides workable values.

When first developed, the concept of critical values was applied to nutrient concentrations in whole plant shoots. While satisfactory for some nutrients and some plant species sampled at well defined growth stages, critical concentrations of whole plant shoots have generally proved less satisfactory than those of specific plant organs for three reasons. Firstly, critical values for whole plant shoots generally decline progressively with time. This decline has been attributed to differences in the nutrient concentrations among plant parts and to changes with time in the proportion of plant parts in shoots. Secondly, for some nutrients, critical levels in whole shoots may vary widely with the conditions of nutrient supply under which the deficiency develops. This behaviour has been attributed to the low mobility from old leaves of the relevant nutrients; nutrients such as calcium (Loneragan 1968) and manganese (Nable and Loneragan 1984) have been shown to accumulate to high levels in old leaves and to remain there even after young leaves have become deficient. As a result, the critical value of these phloem-immobile nutrients may vary markedly in whole plant shoots according to the supply of nutrient prior to the onset of deficiency.

Finally, the concentration of a deficient nutrient in severely deficient plant shoots sometimes rises above the lowest value for optimal growth, making it impossible to distinguish from a plant with adequate nutrient supply. The resulting curve relating nutrient concentration to yield is C-shaped and the aberrant bottom portion is referred to as a 'Steenbjerg' or a 'Piper-Steenbjerg' curve after the researchers who first drew attention to it (Piper 1942; Steenbjerg 1951). The phenomenon has been attributed to effects of nutrient deficiency in either changing the proportions of various plant parts or of senescent tissues (Bates 1971; Loneragan et al. 1980).

For diagnostic purposes, far better relationships to the nutrient status of plants are obtained with nutrient concentrations in specific plant parts of similar physiological age. For example, with increasing age of subterranean clover plants from 26 to 98 days, critical values for diagnosis of copper deficiency progressively decreased from 4 to 1 μg Cu/g dry matter (DM) in whole shoots, but remained relatively constant at 3 μg Cu/g DM in the youngest open leaf (Reuter et al. 1981).

CHOOSING A SUITABLE PLANT SAMPLE

For use in deficiency diagnosis, the nutrient concentration in any plant part sampled should show a simple relationship to the nutrient status of the plant. Ideally, critical values should be clearly delineated, free of Piper-Steenbjerg anomalies, and remain constant with changing environmental conditions and plant age. In addition, the plant part chosen must be easily identified and sampled. Furthermore, plants sampled should be actively growing — i.e. free of disease and moisture stress.

For many nutrients in many species, the YFEL (youngest fully expanded leaf (Ulrich and Hills 1967)) meets these criteria. For some nutrients and some species, younger or older leaves may be preferred.

Whatever the final choice, the selection of an appropriate plant part is crucial to the development of a satisfactory diagnostic test. For successful application of such a test in the diagnosis of nutrient deficiencies in farmers' crops, great care must also be taken in the collection of plant samples from crops in the field. Samples should be free from contamination and dried soon after sampling. Some examples of variation in critical values encountered in an ACIAR project (concerned with diagnosing nutrient deficiencies in soybeans and peanuts grown on Thai soils) will serve to illustrate some of the problems which may be encountered if adequate care is not taken in sampling.

Specific plant part In individual plants, nutrient concentrations vary widely among plant parts. Specific plant parts may also respond differently to varying nutrient supply. As a result, both the precision with which they can be used and the actual value of critical concentrations vary with the plant part sampled.

For example, critical values for potassium concentration were around 1.3 and 0.5% in the blade and petiole respectively of the YFEL of soybean plants at a single harvest; values were around 0.3% in the bark of the first stem internode in the same plants (Bell et al. 1986). In this case, it would be wise not to use the complete YFEL for leaf analysis since its petiole and blade have such different critical values. But whatever part is chosen, it is absolutely essential to specify and sample the specific part or parts to which the critical values apply.

Leaf age Data presented by Bell et al. elsewhere in these proceedings suggest that the YFEL blade is satisfactory for diagnosing many nutrient deficiencies in soybean and peanuts. However, for zinc, great care must be taken in selecting the YFEL, since critical values increase sharply with progressively younger leaves; in soybean, critical values for the next youngest leaf were sometimes double those of the YFEL (Bell et al. 1986, and these proceedings).

For some elements, the YFEL is less satisfactory than other parts. For diagnosing boron deficiency in soybean and peanut, the youngest open leaf and the young folded leaf respectively have been recommended as more sensitive (Kirk and Loneragan, these proceedings). In contrast to zinc, critical concentrations for boron in leaves near the shoot apex were lower in the younger than in the more mature leaves. For copper in peanuts, the YFEL was also less satisfactory than the young folded leaf with its shoot tip which gave excellent relationships to vegetative and fruit yields with a range of critical values from 1.2 to 1.7 $\mu g/g$ (Nualsri 1977; Robson et al. 1977).

Although not ideal for diagnosis of boron and copper deficiency, the YFEL can be used to obtain a preliminary diagnosis; confirmation of deficiencies of these two elements requires sampling of younger leaves (Nualsri 1977; Robson et al. 1977; Kirk and Loneragan, these proceedings).

Plant age and development stage Critical values could be expected to vary with the stage of plant development. Indeed, critical concentrations for potassium in YFEL blades of soybean fell progressively from 2.1% in early vegetative growth to 0.35% at pod fill (Bell et al. 1986, and these proceedings). But for many nutrients, critical values in some plant parts are stable through a number of growth stages. For example, critical concentrations for phosphorus in soybean YFEL blades remained constant at 0.35% from early vegetative growth to pod set and only fell at pod-fill (Bell et al., these proceedings). Critical values for copper in young folded leaves of peanut also remained constant from early vegetative growth through flowering to early pod maturity (Nualsri 1977; Robson et al. 1977).

In the case of potassium, the decline in critical values observed with plant development has also been observed with ageing of plants which were prevented from flowering (Bell et al. 1986, and these proceedings). To what extent this phenomenon can be related to declining supply of potassium from the soil rather than to plant age per se is not clear. Certainly, declining potassium supply during the onset of deficiency has been shown to give lower critical values for potassium than those in leaves of plants grown at constant but suboptimal potassium supply: apparently, under conditions of declining nutrient supply, the concentration of an element in plant parts may drop below their functional nutrient requirement before dry matter is depressed (Spear et al. 1979). Where declining nutrient supply rather than plant age is the cause of declining critical values, the problem could be overcome by using some criterion of nutrient deficiency other than dry matter production closer to the onset of deficiency. For critical values of manganese in clover, photosynthetic oxygen evolution, which responds much more rapidly than does dry matter, has been suggested as a more suitable criterion of manganese deficiency (Nable et al. 1984).

The extent to which plant age or declining nutrient supply is responsible for declining critical values in plant parts under some conditions needs further resolution. In the meantime, where this phenomenon occurs, critical values can only be used when related to specific growth stages for which precise critical values have been established; schemes for describing specific growth stages at sampling such as those devised for peanuts (Boote 1982) and soybean (Fehr et al. 1971) then become very useful.

Nutrient interactions For a few nutrients, critical values vary with the level of other chemical elements in the plant. The effect of nitrogen in replacing the requirement of legumes for molybdenum in nitrogen fixation is the best known example (Anderson and Thomas 1946). In the case of molybdenum, legumes still require some molybdenum for growth but the critical value may be much lower when soil nitrogen is high than when it is low. In the case of cobalt, high soil nitrogen completely replaces the legume's cobalt requirement (Ahmed and Evans 1960). For both cobalt and molybdenum, it may be best to set critical values at levels which would be required if no soil nitrogen were present. Such values would guarantee adequate levels of these elements.

Additional problems occur with plant diagnosis of soil deficiencies of both cobalt and molybdenum for legumes with large seeds, owing to the ability of such seeds to store sufficient of these elements to supply one crop (Meagher et al. 1952; Gladstones et al. 1977; Robson and Mead 1980). Experimental seed brought in from areas of high nutrient supply can give misleading results in experiments on soils low in available cobalt or molybdenum.

In some species, diagnosis of potassium deficiency may also be complicated by the ability of sodium to partially replace potassium in some of its functions. For these species, critical values for potassium need to be related to sodium levels in plant tissues (Smith 1974).

In the case of soybeans (Bell et al. pers. comm.) and peanuts (Brady pers. comm.) this does not appear to be a problem because sodium appears unable to alleviate potassium deficiency to any degree.

Biochemical and Physiological Tests

With some nutrient deficiencies, specific metabolites may be unusually low or high, providing the basis for diagnostic tests. For example, in copper deficiency, lignin synthesis slows; failure of xylem tissues to stain with lignin reagents in freshly cut stems of plants has been used to diagnose copper deficiency (Bussler 1981). Accumulation of putrescine in plant tissues has also been suggested as a test for potassium deficiency; unfortunately, putrescine may also accumulate in magnesium-deficient tissues (Smith 1984).

Enzymic activities in plant tissues have been used as diagnostic tests. For example, ascorbic acid oxidase activity has been used to diagnose copper deficiency in citrus (Bar-Akiva et al. 1969) and subterranean clover (Delhaize et al. 1982) and is currently being examined as a possible test for soybean and peanut (Mahmood et al., these proceedings).

The measurement of metabolite concentrations and enzymic activities for diagnosing a nutrient deficiency requires that no other nutrient or environmental factor produces similar effects. This problem can sometimes be overcome by observing the response of metabolite concentrations or enzymic activities to the addition of nutrients to test tissues; a powerful diagnostic test may be devised if the test tissues respond to a deficient nutrient but to no other. Examples include the response of nitrate reductase activity in leaves to addition of molybdenum in wheat (Randall 1969). The response of photosynthetic oxygen evolution to incubation with manganese has also been shown to give a good test for manganese deficiency in soybeans (Ohki 1982) and subterranean clover (Nable et al. 1984).

Physiological response to the addition of nutrients has also long been used to diagnose nutrient deficiencies. In its simplest form, it involves observing the effects of spraying nutrients onto portions of a crop with symptoms of nutrient disorders; only the deficient nutrient will bring about recovery as, for example, in the greening of chlorotic leaves.

The response of the area of individual leaves removed from plants and placed in nutrient solutions has also been suggested as the basis for specific tests for diagnosing a number of nutrient deficiencies (Bouma 1983). A variant of these tests promises to be useful for diagnosing boron deficiency in soybean and other legumes: in soybean it involves painting one of the lateral trifoliate leaflets of a young leaf and comparing its subsequent growth with that of its paired leaflet (Kirk and Loneragan pers. comm.).

Prediction of Nutrient Response from Plant Tests

Most diagnostic tests suffer from the fact that the production of standing crops will have been affected by the deficiency by the time it is identified. It is preferable to use tests which can predict the likely development of specific nutrient deficiencies and allow preventative action to be taken.

As already mentioned, nutrient concentrations in plants can be used in this predictive way. Nutrient concentrations recommended as critical values for predicting nutrient deficiency are generally higher than those for diagnosing the same nutrient deficiency. For example, a range of 3-5 μg boron/g DM in young leaves has been suggested as critical for diagnosis of boron deficiency in the standing peanut crop (Kirk and Loneragan, these proceedings) whereas a value of 30 μg/g in leaves during vegetative growth is recommended as a critical value for predicting the development of hollow heart in peanut kernels at maturity (Morrill et al. 1977).

Prognostic critical values are also inherently more variable for two reasons. Firstly, the predicted expression of a nutrient deficiency assumes that growth subsequent to sampling will proceed in a particular way; unexpected variations in climate, infestations by pests, or outbreaks of diseases may limit crop production and hence its capacity to respond to nutrients in low supply. To some extent this problem may be overcome by relating the critical values for nutrient deficiencies in predictive tests to the potential yield of the crop or to target yields.

Secondly, soils vary in their capacity to supply nutrients to crops following sampling for plant analysis. The critical values for predictive plant tests therefore only apply to soils with properties of nutrient supply similar to those on which the tests were calibrated. Alternatively, predictive plant tests may need to be supplemented by information on soils.

To some extent predictive plant tests may themselves give a measure of the ability of soils to supply nutrients. Indeed, for those nutrients which are not mobile in the plant phloem (Ca, Mn, B), this is likely to be the only value of a predictive test since, as already mentioned, these nutrients will become deficient in young leaves as soon as the external supply becomes insufficient, regardless of the prior level of the nutrient within plant tissues.

Within these limitations, leaf analysis during vegetative growth can be sometimes used to predict seed production in crops, as already mentioned for soybeans (Small and Ohlrogge 1973). However, storage of nutrients in organs other than leaves may also need to be considered. Indeed, for prognosis of manganese deficiency affecting seed production in lupins, manganese concentrations in leaves at flowering were not helpful, whereas manganese concentrations in stems were (Hannam et al. 1985).

Prediction of Nutrient Response from Soil Tests

As already mentioned, soil tests are predictive: they cannot be diagnostic. Soil tests therefore suffer some of the same problems of predictive plant tests. For example, environmental factors which change the expected yield potential of crops will cause the relationship between soil test and plant yield to vary. As for prognostic plant tests, problems of this nature may be overcome by relating soil tests to potential rather than actual yields. A test set up in this way allows the farmer to examine the cost of a range of fertiliser applications against a range of potential yield increases. He may then choose that fertiliser application which suits his particular situation.

Soil tests have an advantage over prognostic plant tests, in that they can measure both the immediately available level of nutrients in the soil (nutrient intensity) and the ability to continue to supply nutrients throughout crop growth (nutrient capacity). In some soil tests these intensity and capacity factors are measured by separate procedures; in other tests a single soil extraction procedure appears to give an estimate of both factors. However, most soil tests are empirical, do not measure discrete forms in the soil and are useful primarily because they correlate with plant response to added nutrients.

Whatever the procedure used, soil tests for each nutrient must be calibrated against the response of crops growing in the field on the tested soil to applications of fertiliser. From such calibrations, values obtained in soil tests may be related to the potential crop yield without fertilisation and also the potential response in crop yield with addition of fertiliser.

For macronutrients such as phosphorus, potassium, and nitrogen, it may sometimes be important to know the potential yield increase which might be obtained by nutrient applications over a range of fertiliser levels. Where these or other nutrients are severely deficient, it may be sufficient to define a single critical value for a soil test at which a nutrient deficiency would be expected to develop in soils under normal conditions of crop growth. However, it must always be remembered that any such value should be related to the potential crop yield under those conditions; if the actual yields achieved are higher or lower than those predicted, the critical value will appear to vary. Perhaps differences in yield may partly explain some of the apparent anomalies in the literature. For example, in a field trial by Ho and Sittibusaya (1984), the critical level of soil P for soybean grown in Thai Gray podzolic soil was 17 ppm (Bray II) whereas in a glasshouse trial by Suwannarit et al. (1978) on the same plant and soil type, soybean did not respond to P when the soil contained 11.3 ppm P.

Other difficulties may be encountered in the interpretation of soil test values, due to differences in plant behaviour. For example, soil temperature is an important factor in the absorption of phosphate and boron by some plants. Species and cultivars may also vary widely in their ability to obtain nutrients from soils: for example, on the same type of Thai soils, the critical level of K for soybean was 55 ppm whereas that for cotton was 120 ppm (Ho and Sittibusaya 1984).

The advantages of soil tests are that they are rapid, reproducible and can be carried out in large numbers in well equipped laboratories. If the critical value of a soil nutrient can be defined from a good research program, it is a very useful parameter for knowing the nutrient status of the soil as well as for predicting the fertiliser need before crops are planted. Even though critical levels for a number of soil nutrients were compiled by Katyal and Vlek (1985) and Walsh and Beaton (1973), they are not readily available and applicable in many Asian countries. This is because the soils and conditions for crop growth vary from place to place and country to country, and soil test methods also vary from laboratory to laboratory. Melsted and Peck (1973) have pointed out that the soil critical value for a particular area should come from a local field research program in order to ensure that the value is reliable in determining the nutrient status of the soil. Relatively little work has been published on setting up critical values of soil nutrients in South and Southeast Asian countries. Apart from variations in soil types, there is a diversity in both plant species and cropping systems in upland areas; these would make the definition of critical values of soil nutrients most difficult. The exception is India where a great deal of research on soil testing has been done (Khanna and Pathek 1982; Sekhon and Ghosh 1982).

Soil testing based on the analysis of samples from the fields of individual farmers is not an economic, practical consideration in most Asian countries, because the cost of these tests is too high relative to the size of the farm enterprise. Soil analysis for levels of 'available nutrients', using soil test methods in general surveys, does however provide valuable information about the need for a particular fertiliser or soil amendment in a region or country. For example, Keerati-Kasikorn (1985) reviewed soils data from northeast Thailand which shows that low levels of P and S are common in that region. Working on a broader scale, Katyal and Vlek (1985) have reviewed data on micronutrient availability in soils in Asia, including the results of Sillanpaa (1982), who undertook a survey of the micronutrient status of soils and crops on a global scale. Low levels of B, Zn and Cu in soils are a potential problem in many areas, and the occurrence of these low values is related to the distribution of some parent materials. For example, B levels are low in the gneiss, granite, shale and basalt of the Indian shield. In the case of potassium, soil tests have been used on a national scale to develop maps of the available nutrient status in India and China (Kemmler 1980). Widespread potassium deficiency is indicated in humid tropical areas, paralleling the low available phosphorus levels common in highly weathered Southeast Asian soils (Friesen and Blair 1981). However, as discussed above, surveys using soil tests alone do not provide a very sound basis for fertiliser recommendation. As Greenland (1985) has pointed out in the case of defining crop requirements for K, an integrated experimental approach utilising soil and plant analyses and field trials on a number of representative, well characterised sites is needed. In regional surveys, nutrient screening of representative soils in the greenhouse can also be used (Andrews and Fergus 1976). The choice of techniques used will depend on the logistics and the amount of information already available.

Conclusions

There is evidence that mineral constraints are a major cause of the low yields of food legume crops in the fields of many Asian farmers. This conclusion is based on experimental evidence showing that, on the major types of soils used for food legume production, yields were reduced by up to 1.1 t/ha (i.e. up to 73% of the maximum yield at the particular site), if some key nutrients were omitted or, in the case of acid soils, lime was not applied. Available statistical data suggest that, in most areas, farmers do not apply fertilisers or amendments to food legume crops. The exact reasons for the low or non-use of inputs are difficult to gauge, but both biological and economic factors are probably influencing the farmers' decisions.

Major biological factors affecting the farmers' use of fertilisers are the fertiliser-responsiveness of the varieties available to them and the extent to which drought, disease and pests etc. interact to limit the yields of fertiliser crops. The role of fertilisers in increases in expanded cereal production provides an interesting parallel for consideration — nitrogen fertilisers played a key role in the 'green revolution', in large part because the high-yielding varieties were shorter than traditional varieties and did not lodge when fertilisers were applied. In many rainfed areas where the use of fertilisers is too risky or, as in Thailand, the profit margin from increased cereal production is low due to high input costs and low rice prices, high-yielding cereal varieties have not been adopted and many farmers do not use fertilisers. The food legume crops do not require short or stiff straw or, if well nodulated, nitrogen fertilisers. It is therefore important to consider whether or not improvement of these crops through breeding and selection for fertiliser-responsiveness specifically should be a major focus of plant improvement work with food legumes. On the contrary, the breeding of food legumes might better be aimed at selecting varieties that are tolerant to mineral constraints such as aluminium toxicity and salinity and to the low levels of available nutrients that seem to occur commonly in the farmers' fields where they are grown. Such a strategy has recently been advocated in the CGIAR Impact Study (Anderson 1985) which has pointed out that poor people's crops are often grown unfertilised on fragile soils. The role of vesicular arbuscular mycorrhiza, particularly in relation to plant cultivar differences and micronutrient availability, should be considered. It is also worth noting that the focus of IRRI's plant breeding program has moved recently towards developing rice varieties for marginal conditions such as rainfed, upland, deepwater and problem soils.

The economic factors influencing farmers' decisions about the use of inputs on food legume crops are considered in more detail in other papers in these proceedings. However, it is appropriate to discuss briefly the economics of fertiliser use. Rajendran et al. (1982) have, for example, analysed data from a large number of field trials in India which show that net returns per rupee spent on phosphate were commonly less than 2 for rainfed chickpea, whereas the use of 30 kg N/ha was quite profitable. Neither N nor P were profitable for irrigated chickpea crops. It is ironical that N fertilisers were shown to be profitable on a nitrogen-fixing crop. Although the results of Rajendran et al. (1982) are limited to one region, it may be that the low usage of fertilisers on food legumes by farmers in many areas largely reflects the low returns from increased production relative to the high costs of these inputs, as indicated in their study.

The other major conclusion from this review is that, except in some countries with a strong research base, there is relatively little known about the extent and magnitude of mineral constraints to food legume production. The soil and plant diagnostic methods that could be used to redress this gap in knowledge have been described, with particular emphasis on methods for plant analysis to diagnose micronutrient deficiencies. This emphasis is based on the fact that micronutrient deficiencies, properly diagnosed, can usually be corrected with low rates of application and therefore at low cost to the farmer. In order to contain further the costs to farmers, the macronutrient requirements would best be met through the use of cheap sources, such as rock phosphate in the case of P, or through an effective symbiosis in the case of N. However, whatever the nutrient source, it is essential that the accuracy of fertiliser recommendations made to farmers be improved considerably beyond the common practice in many countries of making blanket recommendations. Specific recommendations should be developed for each crop, season, soil type and region. The research needed to achieve this goal will be a somewhat daunting task in some countries. Nevertheless, the experience gained with plant and soil diagnostic methods described above should be a valuable aid. Furthermore, the use of modern computer-based techniques for the simulation of crop growth and response to fertiliser could be used to take account of seasonal climatic variation, and thence risk. At the same time, this technique reduces the number of multisite fertiliser trials needed to establish the criteria for fertiliser recommendations.

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Alleviation of Soil Physical Limits to Productivity of Legumes in Asia

H.B. So * and T. Woodhead **

Soil physical characteristics may impose limitations on plant growth and yield through their effect on root growth. There is a close coordination between the growth of roots and shoots. In a constant environment, a linear relationship between the logarithm of shoot and root weights characterises such coordination, at least during the vegetative growth of a plant (Russell 1977).

Some of the soil physical characteristics that are important in controlling root growth are the soil moisture regime, soil bulk density, aeration, soil strength and soil temperature. The effect of soil water deficit on plant growth is well recognised, however, the effect of compaction or naturally occurring strong horizons on plant growth is not as well understood despite the large yield reductions (28-66%) reported as a result of compaction from tillage operations (Batey and Davies 1972). Artificially induced compaction is a universal problem. It is associated with most tillage operations, and the cost of yield losses associated with compaction can be very high.

Legumes are major food crops in Asia, both for human consumption as well as animal feed. A number of rice-producing countries are spending large sums of foreign exchange on imports of grain legumes. Therefore, expansion of local production of these crops to reduce or eliminate imports is a high priority for many nations. In the tropical Asian farming systems, yields from food legume crops are generally low due to a combination of factors such as poor soil physical conditions, low use of fertiliser and other management inputs, poor seed quality and lack of suitable cultivars, at least for soybeans (Heydecker 1985). Poor soil physical conditions could be a major factor causing low yields. With legumes grown after rice, the prolonged puddled soil conditions result in a massive structureless soil. It is separated by a plough pan from the structured soil underneath, a condition which cannot be considered as conducive to growth of upland crops. However, generally the subsoil has sufficient water stored to grow a dryland crop (Greenland 1985). In the upland cropping system, the use of low energy methods will confine cultivation to a constant shallow depth, giving rise to a smeared and compacted layer which may reduce the growth of crops.

This paper discusses the limitations that soil physical properties may impose on plant growth in general, followed by a more specific discussion of soil conditions under Asian farming systems. Possible means of overcoming the associated limitations and the research required to raise yields of upland crops are discussed, with particular reference to legume crops.

Limitations to Crop Growth and Yield

The three main functions of the soil for plant growth are: (a) to provide anchor to the plant; (b) to act as storage for water and nutrients; (c) to provide suitable conditions for germination and establishment of seedlings and the growth and proliferation of roots.

It is convenient to discuss the soil physical limitations to productivity in relation to the processes that are likely to be affected and that are likely to affect yield, such as limitations to the process of (1) germination and seedling emergence; (2) root growth and development; (3) the supply of water and air to the root. This classification is concerned only with the soil-root environment. Although there are strong interactions between the growth of the shoot and root, for the purpose of this discussion it is assumed that limitations imposed in root growth will proportionately affect the growth of the shoot. This is generally correct, at least during the vegetative growth of annual crops. Thus, a delay in root development due to environmentally-induced stress will show up as a delayed shoot growth, and may never be compensated during its growth cycle (Russell 1977).

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Germination and Seedling Emergence

Germinating seeds must absorb water at a sufficiently rapid rate to reach their critical water content for germination before the effect of other environmental stresses, e.g. drying of the soil or fungal attack, prevent germination. The rate of water absorption is dependent on the water potential of the soil, the seed soil contact area and the hydraulic conductivities of the soil and seed. If germination is successful, the seedling must emerge and start photosynthesis before the seed reserves are depleted. Thus, limitations may occur to any of these processes which will affect the rate and number of seedlings emerging through the soil surface.

Poor emergence alone may not necessarily result in reduced yield. Long season crops often have sufficient time available for compensation. Yields of soybean cultivars adapted to the mid-west regions of the USA are generally not affected by plant population density between 15-50 plants/m^2, provided they are uniformly distributed (Hume et al. 1985). However, in the tropics yields of soybeans after lowland rice are linearly related to plant population density in the range of 40-70 plants/m^2, as shown in Fig. 1 (Carangal 1985).

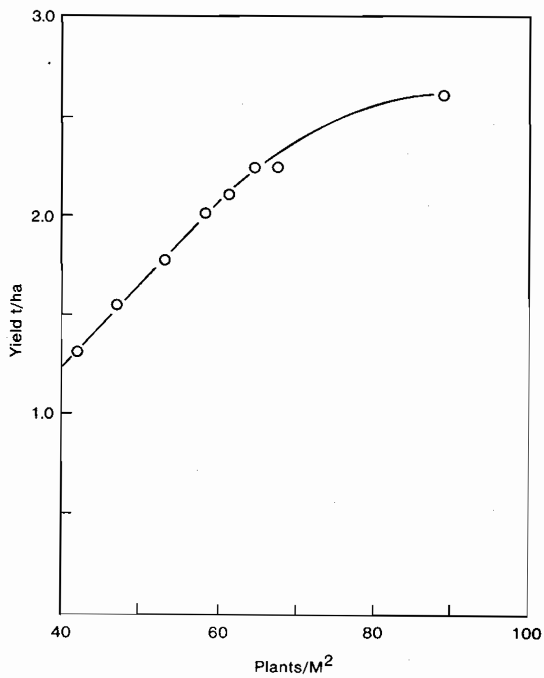

Fig. 1. Yield of soybeans relay planted into puddled lowland rice soil, as a function of plant population at 2 days before harvest. Data include soaked and unsoaked seeds, either broadcast or drilled. (Adapted from Carangal 1985).

The rate of drying of the surface soil is an important factor in the success of the germination process, particularly in arid or semi-arid regions with high evaporation. The rate is particularly high when the surface soil is excessively cloddy, such as after cultivation of a wet clay soil. In addition, cloddy seedbeds result in low contact area between seed and soil. Together these two aspects will significantly reduce the rate of water absorption by the seed, and hence the success of germination. Work at IRRI (Fig. 2) has shown that decreasing soil matric potential strongly reduced the percentage germination of mungbeans, providing aeration is not limiting, whereas Fig. 3 shows that the effect of

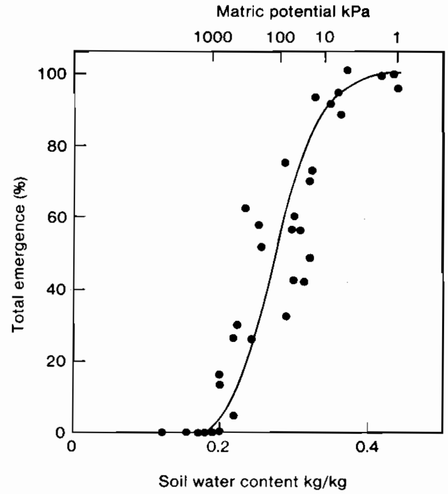

Fig. 2. Effect of soil-water content and potential on percentage emergence of dry seeded CES 1d-21 mungbean from beds of 2 mm soils. Growth chamber at 30°C, 50% R.H.

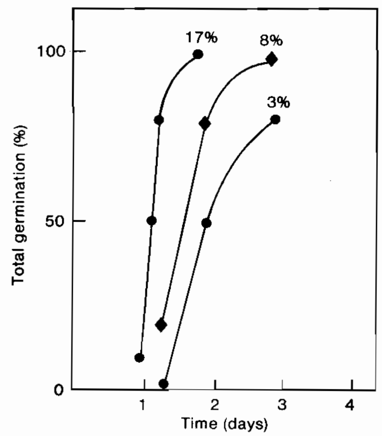

Fig. 3. Total germination of chickpea seeds as functions of relative wetted area (%). Soil hydraulic conductivity range is 5-10 × 10^{-10} ms^{-1} (After Hadas 1975).

the relative contact area between seed and soil on the germination of chickpeas (Hadas 1975). In reality, these factors strongly interact in such a way that the relative contact area decreases rapidly with increasing soil aggregate size and decreasing soil matric potentials.

Excessive amounts of water can be detrimental to germination if aeration is limiting, a condition generally referred to as waterlogging of the seed. Also there can be detrimental interactions between high soil temperature and water contents that together promote fungal attacks on the seed.

The emergence of the seedling may be prevented by either of two soil conditions, i.e. hard-setting and crusting surfaces. 'Hard-setting' is a condition associated with soils high in silt and fine sand and low in organic matter content. The aggregates are weak and they slake and disperse upon wetting. These fine particles are small enough to fit into the pores between the coarse sand particles and aggregates or they form a dense matrix which dries into a massive and hard soil. 'Crusting' is associated with soils of low silt and fine sand content which slake and disperse upon wetting. It usually requires an additional input of energy, such as the impact of raindrops. Breakdown is confined to the immediate surface of the soil, which dries into a thin hard crust on the surface. Both conditions will prevent emergence if they occur prior to germination of the seeds.

When crusting or hard-setting occurs after emergence, it forms a collar around the seedling and may give rise to heat damage. In the semi-arid tropics, the dry surface tends to become hot after exposure to sunlight (Ross et al. 1985) and it softens the stem tissues in contact with it. The seedling is then susceptible to wind damage. This phenomenon is referred to as heat cincturing. Temperatures of the surface soil will affect seed germination, particularly when too low or too high, but field data on the effects on legume germination are very scarce.

Root Growth and Development

Providing soil temperatures are suitable, root growth requires adequate supplies of water, nutrient and oxygen as well as low mechanical resistance and freedom from toxic substances. Besides temperature, the single most important factor controlling root growth is the mechanical resistance of the soil. The effect of the soil's mechanical resistance to penetration, expressed as the point pressure on a small blunt penetrometer, on the rate of elongation of several legume species is shown in Fig. 4. Root growth ceases when point pressures reach values greater than 3.0 MPa.

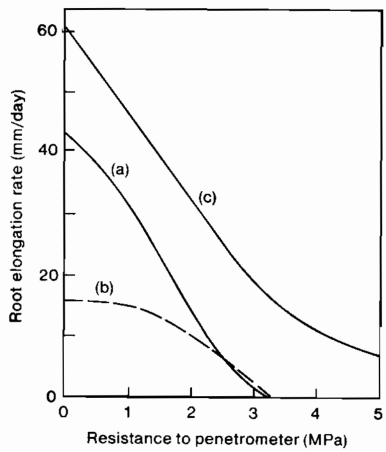

Fig. 4. Root elongation rates of legume seedlings as a function of soil mechanical impedance.
(a) Pigeonpea (Kirkegaard, Univ. of Queensland).
(b) Peas (Gerard et al. 1972).
(c) Peanuts (Taylor and Ratcliff 1969).

By comparison, the effect of soil water potential on root growth within the range of available water is relatively small. Elongation of peanut radicles are not affected until soil matric potential falls below −0.7 MPa (Taylor and Ratcliff 1969) and −0.66 MPa for soybeans (Hunter and Erickson 1952). Generally, the reduction in growth rates of radicles at −1.5 MPa are relatively small (So 1981) and roots have been reported to grow into soil at −4.0 to −5.0 MPa (Portas and Taylor 1976). However, soil water potentials strongly affect soil strength, particularly at high bulk densities (Fig. 5).

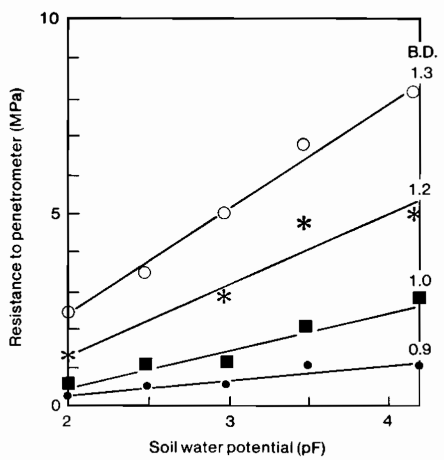

Fig. 5. Resistance to penetrometer (MPa) of an oxisol as a function of soil matric potential and soil bulk density (g/cm^3).

and hence, soil water potential indirectly affects root elongation rates through its effect on soil strength. On the other hand, water can have a significant effect in root development e.g. shallow and persistent water tables will prevent deep rooting.

Most data on root elongation rates are derived from observations on radicles of non-transpiring seedings. It is assumed that roots of transpiring seedlings or mature plants have a similar response to soil strength or soil water potentials. This may be correct for plants with low transpiration rates, however, high transpiration rates may reduce the rates of root elongation by reducing the turgor pressure of root cells and therefore the root pressures required to penetrate the soil (Greacen and Oh 1972). It follows then that plants capable of osmoregulation against water stress should be able to maintain higher root pressures, but data to confirm this are not available.

Compaction layers or naturally occurring strong horizons (e.g. B horizon of a duplex soil profile) have a significant influence on the productivity of the soil. They affect the distribution of the roots through increased proliferation above the strong horizon and less growth within and below that horizon, thus affecting the ability of the roots to extract water. Furthermore, strong horizons are generally associated with low hydraulic conductivities, resulting in temporary waterlogging in the surface soil after a rainstorm and low water contents within and below such horizons. The net result is generally a reduced crop water use efficiency.

The effect of temporary waterlogging on the growth and yield of non-adapted legume crops can be severe, depending on its frequency and duration. Carangal (1985) has shown that a single flooding of the whole root system of 7 days duration can reduce yields of soybean by 23–67%, peanut by 30–55% and mungbean by 28–67%, depending on the stage of development. Damage was most severe when it occurred at 15 days after sowing and damage was more severe with two periods of waterlogging compared to a single one. Working with soybeans and sorghum, Dunlop and So (1979) have shown that most of the damage occurred in the first three days of waterlogging, with little difference between 3 and 7 days of flooding. Death of root tips of beans will occur after 5 hours of complete anoxia (Huck 1970). Legumes do, however, possess an ability to adapt to long-term waterlogging, as shown by the process of the wet-soil culture method with soybeans (Troedson et al. 1985), where the crop is grown in near-saturated soil throughout its entire life cycle. In cases where the probability of waterlogging is high, or where watertables are shallow and persistent, such methods should be considered as an alternative.

The damage to the surface roots from lack of oxygen during periods of waterlogging may result in reduced water uptake from the surface soil. Coupled with the lower availability of water within and below the strong horizon, this may result in greater stress and lower water use efficiency. Furthermore, evaporative losses from a waterlogged surface soil will be high.

TABLE 1. Seed yields of mungbean (cv. CQ 1608) and pigeonpea (cv. QPL126) grown under deep cultivation to 25 cm (C_1), control (C_2) and compaction at 5–7 cm depth (C_3) on a vertisol, under both irrigated and dryland conditions. (J. Kirkegaard, University of Queensland, summer 1984–1985.)

		Seed yield (t/ha) for treatments			
		C_1	C_2	C_3	!sd 0.05
Mungbean	dryland	0.12	0.06	0.03	0.33
	irrigated	0.89	0.67	0.69	0.33
Pigeonpea	dryland	0.64	0.27	0.21	0.33
	irrigated	1.70	1.80	1.30	0.33

The magnitude of yield reductions may be dependent on the degree of compaction and on the depth to the compacted layer. Work at the University of Queensland has shown that the growth and yield of mungbean and pigeonpea grown in vertisols is dependent on the bulk density of the soil (Table 1). The bulk density (standardised to water content 0.35 g/g) and the cone index profiles for the top 30 cm measured at emergence are shown in Fig. 6.

Yield reductions were associated with delay in taproot penetration into the compacted soil, reduced root growth in the subsoil as well as reduced water storage. The season was very dry, and crop growth under dryland conditions was dependent entirely on stored subsoil water. Hence, the very low yields generally. Although yield differences in mungbeans were statistically not significant, the trends were consistent with that of pigeonpea. The greater the depth to the strong horizon, the greater will be the ability of the surface soil to store water and to avoid waterlogging. Work at IRRI by San Agustin and Woodhead (1985) shows clearly the influence of the depth to the strong horizon on the yield of mungbeans grown after upland rice (Fig. 7).

Reduced root growth and development associated with high soil mechanical resistance will reduce the rate of uptake of non-mobile nutrients such as P and possibly K and Zn. This will be an important determinant of early seedling growth, particularly under a minimum tillage situation such as legumes after rice. Since P is taken up by diffusion from the

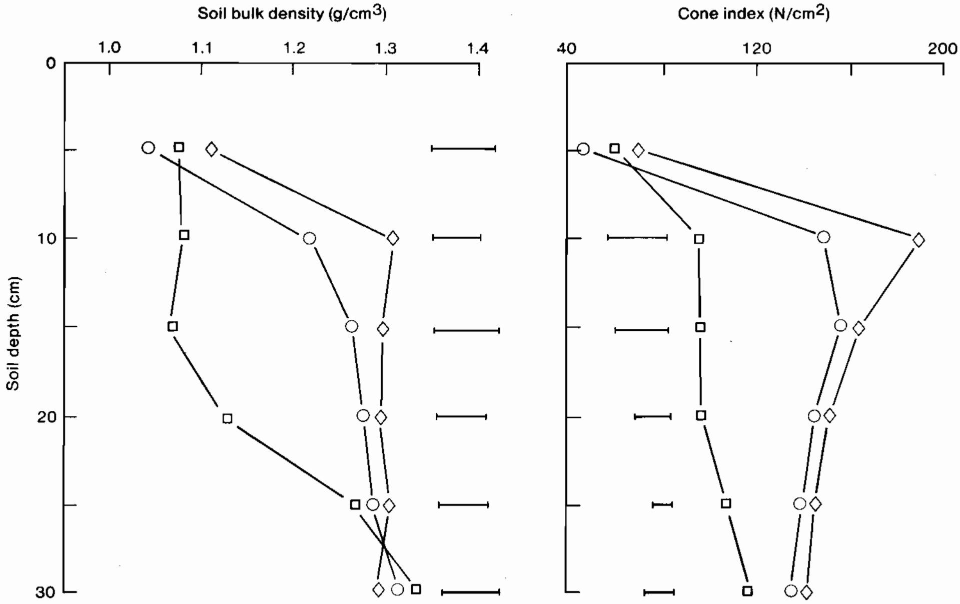

Fig. 6. Bulk density and cone index profiles of a vertisol subjected to tillage and compaction treatments of control (o), deep cultivation to 25 cm (□) and rolled at a depth of 5–7 cm (◇). Bars indicated LSD at 5%. (Kirkegaard and So, Uni. of Queensland, 1984–1985 (unpubl.)).

root hair zone (Lewis and Quirk 1967), total P uptake (P_{upt}) under constant water content can be described by the following equation (Cornish et al. 1984).

$$P_{upt} = P_a \cdot \pi R^2 L . \rho_B \qquad (1)$$

where

P_a = available bicarbonate P per unit mass of soil (g/g)

R = effective root radius (cm), equivalent to radius of root cylinder + root hair length + average distance of P diffusion (cm)

L = length of root system (cm)

ρ_B = soil bulk density (g/cm^3).

Cornish et al. have shown that P_{upt} by ryegrass, which is linearly related to plant dry weight, predicted using equation (1), is significantly correlated with measured P_{upt} under conditions of non-limiting water (Fig. 8). For lower levels of available P (non-luxury), a linear relationship fitted through the origin has a slope of 0.9 (significant at P = 0.01). Hence equation (1) is an acceptable model. At luxury levels above 36 $\mu g/g$, measured P uptake tends to lag behind the calculated values.

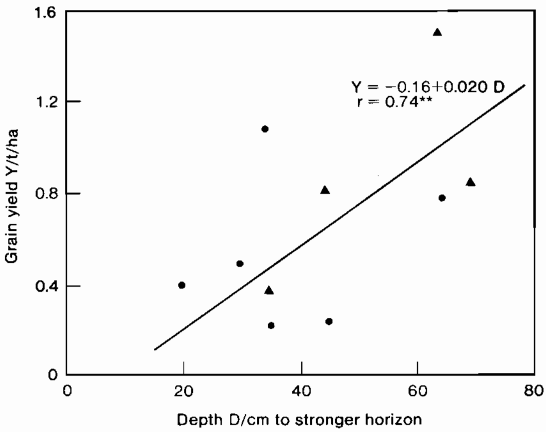

Fig. 7. Yield of dry season mungbean in relation to the depth to the stronger soil horizon. (Field UO1, IRRI farm: 1985 dry season.)

Availability of Soil Water

The amount of soil water available to the plant is dependent on the soil storage capacity, uptake from shallow groundwater if present and the net effect of the processes of infiltration, internal drainage or redistribution and evaporation. These processes are affected by the soil texture, structural stability, surface soil conditions (cloddiness and surface cover) and the soil profile characteristics such as hard pans, compaction layers and other types of strong horizons. Hardsetting and structurally unstable soils tend to have low rates of infiltration and drainage, resulting in temporary waterlogging of the surface soil and high initial rates of evaporation (McKenzie 1982). The associated rates of increase in water storage will be low.

Improving the structural stability of the surface soil will increase the rates of infiltration and drainage and reduce the losses through initial evaporation resulting in greater water storage in the subsoil. (So and McKenzie 1985). McKenzie (1982) has shown that stabilisation of sodic grey clay soils using gypsum can increase the efficiency of use of rainfall from less than 10% to 80%. Associated with this improved efficiency, wheat yields were increased from 0.6 to 1.82 t/ha.

It is clear from the preceding three sections that structural stability is a major soil property that determines the degree of soil physical limitation to plant growth. Structural instability of the surface soil is generally manifested as slaking and dispersion. The finely dispersed material tends to fill the space between the larger particles and aggregates, resulting in a surface seal. Infiltration rates are drastically reduced as well as the drainage rates, and the surface becomes waterlogged. Initial evaporation rates are high and drying is rapid because of the low unsaturated hydraulic conductivity. A crust or a hard-setting surface is formed, and emergence of seedlings may be reduced. The low hydraulic conductivity may reduce subsequent evaporative losses from subsurface layers, which remain wetter and more subject to compaction. Cultivation of this soil tends to produce a cloddy surface.

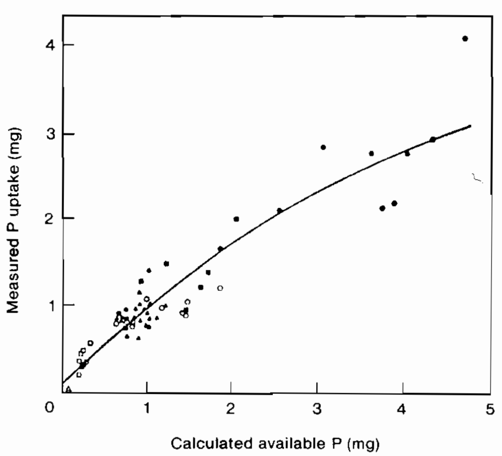

Fig. 8. The relationship between measured total P uptake from soil contained at −0.2 MPa and the potentially available P calculated from Equation 1. Available P concentration in the soil ranged from 4 to 50 μg/g. (After Cornish et al. 1984.) P Levels used were 4 (△), 10 (□), 20 (0), 29 (▲), 36 (■) and 50 (●) ppm. Solid line = $y = 0.08 + 0.92x - 006x^2$ with $r^2 = -.94$ (P = 0.01).

Soil Structure of the Two Major Asian Cropping Systems

Rice-based cropping systems predominate in many Asian countries. Both upland and lowland rice crops are often followed by upland crops. In the lowland areas, continuous rice is common, and in the upland areas which have insufficient water, a series of upland crops is generally grown. A feature of these systems is that after the main crop of rice, there is plenty of water in the subsoil that will be available to the follow-on crop, providing the crop can be established quickly and that the roots can penetrate into the subsoil. These systems are now considered in terms of soil structure and its relationship to legume crops.

The Upland Cropping System

In this system, the soil is cultivated at the beginning of the rainy season to prepare the seedbed for the main crop, usually rice. The soil is cultivated in a moist friable condition, using animal-drawn implements or small mechanical cultivators. Being limited in depth, due to limitation in sources of energy, cultivation is repeatedly practised at the same depth. Hence the probability of creating a plough pan below the cultivation zone is high. Since legumes follow the main crop, they are often sown into the stubble of the preceding crop without tillage or with a minimum of disturbance. In areas with a long history of cultivation, the soil organic matter would have been reduced and the soil bulk density below the cultivation layer would have been increased, imposing limitations to its productivity. Furthermore, soil degradation due to erosion may have been significant, particularly on the steeply sloping land. Addition of organic residues where possible should be useful.

A major problem affecting the success of the follow-on crop in this system is the rapid rate of drying of the surface soil. The farmer faces the dilemma that if he plants too soon (such as before the end of the wet season) seedlings may be killed by waterlogging from heavy rainfall. Germination may also be poor when high soil water content combined with high temperature promotes fungal attack on seeds. On the other hand, if the farmer delays sowing for too long, the surface soil may dry out. Legume germination and early growth will be retarded, due to insufficient moisture. The survival and performance of the crop in the latter part of the growing season will depend largely on access to subsoil moisture, and that access will depend on the success of the establishment stages. Access may be improved by deep strip-tillage.

The effect of soil surface drying on the growth and yield of legumes is clearly demonstrated by an experiment at IRRI on an upland soil during the

1984-85 dry season. Mungbeans were planted following two successive rice crops. The effect of soil drying was achieved by comparing crops planted early (19 December) after rice harvest on 14 December and after one week delay (26 December). The 1984 monsoon ended abruptly and sowing was made into a soil that had already dried to 0.27 kg/kg water content on 19 December and 0.23 kg/kg one week later. Emergence was correspondingly low — 65% and 4% respectively compared to 83% in water. The associated yields were low at 0.24 and 0.04 t/ha.

The Lowland Cropping System

In this most important system for the production of legumes in the tropical Asian farming systems, rice is grown in an almost structureless soil underlain by a compaction layer, generally below 20 or 30 cm depth, deliberately created to maintain the high water content. Such layers may offer significant resistance to root penetration, particularly as the soil dries out. The cone penetration index can reach and exceed 2 MPa even for fairly moist soils, and as discussed earlier such levels of soil strength will significantly reduce the rate of root extension of legumes or other crops that seek to exploit the plentiful water remaining in the subsoil after the rice harvest. Experiments in the Philippines have shown that when mungbeans are planted in previously puddled lowland rice soil, growth is decreased when planting is delayed beyond 13 days after rice harvest and after 30 days all plants died as their roots were unable to extend into the hard dry soil (Fig. 9).

The structure of the surface soil in this cropping system is destroyed by puddling prior to sowing or transplanting of rice. After draining the surface water near harvest time, the soil will remain wet for some time due to poor drainage. The soil will dry out and crack into clods that will remain saturated for some time (anaerobic) and which will eventually dry out into hard clods. Such a soil does not present a suitable medium for the establishment and growth of legumes, and hence the low yields under such systems.

Legume seeds are broadcast or drilled into the standing stubble, either as a relay or rotation crop, with and without cultivation. The use of cultivation has generally not shown any beneficial effect; on the contrary many reported detrimental effects (Pasaribu and McIntosh 1985; Greenland 1985). Cultivation of wet puddled soils tends to produce an excessively cloddy surface soil with poor seed-soil contact and an increased rate of drying of the surface soil, often resulting in poor establishment.

Many of the research activities of IRRI have been directed towards solving the soil problems associated with the lowland cropping system.

Possible Solutions and Future Research

The previous section has shown that legume production after rice is generally limited by the presence of compaction (in both upland and lowland systems), the presence of puddled surface soils, rapid drying of the surface soil and waterlogging as a result of poor drainage or the presence of shallow and persistent water tables.

In the upland system, the amelioration of compaction layers will be beneficial to both the legume as well as the main rice crops. However, in the lowland system the presence of these compaction layers is somewhat of a dilemma. It is a necessity for the lowland rice crop, but it forms a production constraint to the upland follow-on crop. The degree of such constraint is determined by the interaction between the degree of compaction, the depth to such layers and the prevailing environmental conditions. More work is required to determine the potential limitations of a given set of soil conditions.

Amelioration of these compaction layers in a lowland system would require the farmer to repuddle the soil for the next rice crop. Both activities require considerable energy and cost. Therefore, keeping the disturbance of the compact layers to a minimum would reduce cost and efforts.

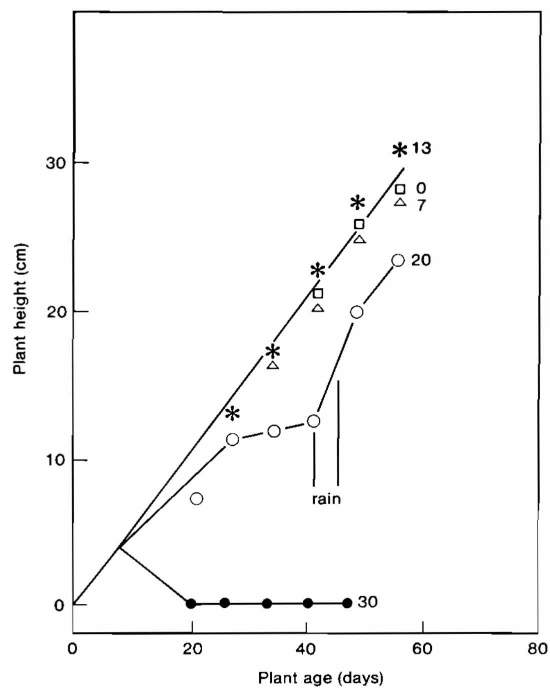

Fig. 9. Effect of subsoil drying (simulated turn around) on mungbean shoot growth. Drying effected by delay in transplanting of potted seedlings (numbers on diagram). Soil is vertic tropaquept clay loam, IRRI, February 1986.

One solution is to practise deep-strip tillage, where only a portion of the land is cultivated to break the strong layers. The crop can then be planted over the strip to encourage deep rooting development and access to the subsoil water. Measurements in the Philippines have shown that a force of 5–7 kN was required for each tyne to shatter the soil strip to 35–40 cm. This force is too high for a buffalo but not for a two-wheel walking tractor. However, in the soil water conditions after rice harvest, traction is usually inadequate and there is a need for research on soil-implement interactions and development of implements with low draught suitable for operation with animals.

A possible agronomic solution is to use legumes that are capable of penetrating strong soil horizons. Some plants do have better ability to overcome mechanical resistance (e.g., lucerne and bahiagress, Elkins et al. 1977). Whether such a characteristic exists amongst the grain legumes is not known. However, this should be taken into consideration in the selection of suitable varieties for the Asian farming system. Suitable techniques need to be developed for the assessment of such a characteristic.

Management of surface soil organic matter should improve the structural stability of the surface soil. This can be achieved through mulching, green manure crops, stubble incorporation and intercropping combined with a zero tillage practice.

The puddled state of the surface soil after lowland rice offers a significant constraint to the germination, emergence and establishment of the seedlings, which would affect the ability of the roots to penetrate the compacted subsoil underneath. Since the water content of this soil is particularly important in determining the strength of this soil, the time of sowing becomes an important controlling factor to the success of the crop. The control of the turn-around time between rice harvest and the sowing of the follow-on legume crop is used to avoid the problem of dry strong soils. In fact, the opportunity to avoid dry soil can be extended if legumes are relay-planted into the wet soil between draining the field and harvesting of rice. The growing root may encounter the compacted layer when it is still wet and soft, providing the legume cultivars can germinate successfully in wet soils. The use of turn-around time as a control, in association with zero tillage as well as strip-tillage, has been of particular interest to the research group at IRRI. Technology has been developed to grow high-yielding mungbeans after lowland rice, yielding around 2 t/ha, without fertiliser or irrigation (Maghari and Woodhead 1984). This involves the use of a single tyne to disrupt the compacted zone and seeds were planted along the tilled strip with a minimum of planting delay. These high yield potentials have been confirmed in recent trials.

The establishment of early root development in these puddled soils may be improved through amelioration, using Ca^{++} from sources such as gypsum ($CaSO_4$) or slaked lime ($Ca(OH)_2$). Experience in Australia has shown that some non-sodic soils puddled through overcultivation under high water contents can be successfully ameliorated by the addition of low concentrations of $CaCl_2$ in the first irrigation water. Wheat yields were increased significantly. The potential of calcium ameliorants for improving the structure of these surface soils requires investigation. If it is a useful method, its effect on the conductivity of the compaction layer needs to be considered in relation to the next rice crop.

The problem of waterlogging of seeds or seedlings can be a serious constraint to the success of legume crops, which are particularly susceptible. Where the probability of excessive water during the early part of the crop is high, several methods may be considered. Firstly, the use of Ca-ameliorants to improve structure and drainage may be useful, particularly on soils dominated by exchangeable Na and/or Mg. Secondly, ridge tillage or sowing on beds would improve the drainage of the soil around the seed. The third possibility is to use legumes that can adapt to waterlogged conditions in a system referred to as the wet soil culture technique developed at the University of Queensland (Troedson et al. 1985). Some legumes can be grown under near-saturated conditions early in the season and later continued as dryland crops.

In summary, this paper discussed the soil physical limitations to crop growth, most of which have their origins in low structural stability. It is difficult to obtain information on the extent and exact nature of the physical limitations, but it appears that the limitations to legumes after lowland or upland rice under Asian farming systems are largely associated with puddled surface soil in combination with compacted subsoils. The problems seem to be exacerbated by either waterlogging or a rapid rate of surface soil drying. Some possible solutions have been discussed and areas requiring further research suggested. These are:

1. the effect of compaction and depth to that layer on crop growth and development;
2. soil implement interactions with a view to developing low draught implements;
3. research into the ability of legume roots to penetrate strong horizons and possible selection of cultivars with such characteristics;
4. potential of Ca-ameliorants and crop residues for improving the surface soil structure for the follow-on crop;

5. the effect of seedbed soil structure on the germination and establishment of legumes;

6. the extent and nature of soil physical limitations under both upland and lowland systems. These need to be defined and documented for the various environments of the Asian continent through well organised surveys. Such documentation would provide a very useful basis for planning regarding specific research requirements.

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Biological Nitrogen Fixation as a Limitation to Food Legume Production in Asia

D.P. Beck * and R.J. Roughley **

THE two aspects of legumes that make them attractive to the world population are their high protein content and their ability to fix atmospheric nitrogen. Biological nitrogen fixation (BNF) should be an advantage rather than a limitation to food legume production. However, the benefits will be realised only if the symbiosis of plant with bacteria can operate effectively. When considering how to maximise BNF in order to increase legume yields, several factors must be appraised. Among these are: the genetic constitution of both the root nodule bacteria and the host plant; the environment in question; technological inputs available; and the effectiveness of extension of current knowledge to farmers.

Symbiotic nitrogen fixation is commonly limited by soil infertility conditions, especially those associated with the acid soil complex of high aluminium, manganese, low calcium and phosphorus, and salinity. Some legumes become especially sensitive to these stresses when they are dependent on symbiotic nitrogen fixation, partly as a consequence of the complexity of establishing an effective symbiosis, which requires more than vigorous plant growth. It requires colonisation and survival in soil by rhizobia as saprophytes in competition with other endogenous microbes; there is evidence that this phase is limited, e.g. by soil infertility (Munns 1977) and temperature (Day et al. 1978). It requires rapid colonisation of the rhizosphere prior to root infection, and this zone becomes acid, saline, or P-depleted even in soils of normal fertility. It requires genetic compatibility between host and root nodule bacteria to establish an effective nodule, and it requires a favourable environment to allow maximum fixation.

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Limitations Associated with the Root Nodule Bacteria

Root nodule bacteria have been assigned to two genera, *Rhizobium* and *Bradyrhizobium*, depending on their rate of growth on laboratory media. In this paper, the term rhizobia is used to embrace strains of both genera.

Agronomically desirable strains of rhizobia should have the ability to nodulate their host promptly and fix nitrogen over a wide range of environmental conditions. If used as inocula they should be able to compete with naturalised rhizobia in the soil. That these are still our criteria for strain selection is indicative of the intrinsic limitations of strains currently in use. Chief among these limitations is the frequent inability of strains to compete with inferior naturalised strains in the soil or to persist as saprophytes in the period between crops. Our expectation from inoculation in competitive situations is beyond our current technology.

The variability and instability within rhizobia exploited by geneticists constitute a limitation. Firstly, it is a problem in maintaining trueness-to-type in strains during culture and in inoculant production, and secondly, because of the likelihood of exchange of genetic material in the rhizosphere (Broughton pers. comm.). It may therefore be argued that the selected inoculant strain should be reintroduced at each year's sowing of food legumes.

Lack of knowledge, both qualitative and quantitative, about rhizobia in tropical soils is itself a limitation. In many situations we must still ask the most basic question, does a particular soil type in a region contain effective rhizobia for a host of interest? Until this is answered, it is not known whether or not rhizobia are a limitation. While absence constitutes a limitation, the condition can easily be rectified. They may be present but ineffective or only partially effective with the host in question, and thus pose what is possibly the legume bacteriologist's most intractable problem —

competition between naturalised rhizobia and the introduced strain.

Soil biotic factors may also be important under some circumstances, e.g. at high population densities, protozoa appear to be significant in killing rhizobia, but the mechanisms causing the decline of small populations are unknown.

It is for these reasons that the ACIAR project 'Ecological Studies of the Root Nodule Bacteria' has seven subprojects in four countries aimed at describing the occurrence and level of effectiveness of rhizobia for target legumes in their local environment.

Knowledge of the population dynamics of rhizobia in soil is limited largely by the difficulty of distinguishing individual strains within a mixed population, and by problems of counting rhizobia in the presence of other organisms. Rhizobia are a minor component of the soil microflora, so that detection of low numbers is particularly difficult. A restriction in the numbers of rhizobia is often a major limitation, and, as the size of the population is a result of the physical, chemical and biological components of the environment, these aspects have received some attention. The effect of these aspects on soybean and cowpea rhizobia has been described by Roughley (1985).

Interaction between Rhizobia and the Environment

Laboratory experiments have demonstrated considerable differences between strains in their response to environmental factors; fewer experiments have established these differences in field soils.

Survival of rhizobia in soil is adversely affected by high soil temperatures. The effect is modified by the soil type; survival is better in heavy or organic soils than in light soils. Survival in light soils may be improved by amendments, including montmorillonite and illite, which probably reduce the amount of water loss from the bacterial cell (Marshall 1964). Rhizobia are generally less tolerant of high temperatures in moist than in dry soils. An exception was the improved survival of cowpea rhizobia at 35°C in moist compared with saturated or dry soil (Boonkerd and Weaver 1982); however, the temperature stress was not severe and the result may express their response to moisture. As would be expected, there are differences between strains in tolerance to high temperatures even when selected from soils of the same region subjected to similar soil temperatures.

Although numbers of rhizobia may be quite small in the surface layers of the soil, numbers may reach high levels down the profile, depending on the ground cover and soil type (Day et al. 1978).

Soil water affects the number of rhizobia in soil, their distribution down the profile and the susceptibility of plant root hairs to infection. Although the importance of soil moisture on rhizobia has been long recognised, there are few reports describing their response. Fewer still have expressed this reponse in terms of water potential rather than percent moisture to allow more general application of the studies.

The effect of waterlogging on rhizobia in soil has been neglected since Vandecaveye (1927) reported that two weeks flooding drastically reduced numbers of *R. leguminosarum*.

The importance of the soil characteristics on the survival of rhizobia undergoing drying was confirmed by Chao and Alexander (1982). Survival of rhizobia was improved when they were established in soil before drying began. Mahler and Wollum (1981) found that numbers in soil fell most rapidly in the first week after inoculation. The stress posed by low moisture could therefore discriminate between the naturalised population and newly introduced rhizobia.

Species of *Rhizobium* respond differently to acidic and alkaline soil conditions. Generally, slow-growing rhizobia which nodulate tropical legumes are less sensitive to acidic conditions than fast growers. These factors may act either directly on rhizobia or indirectly through their effect on the host plant, which commonly is the more sensitive of the symbiotic partners.

The requirement of calcium is definite but low (approximately 10 μM) in simple media. Nevertheless it has been demonstrated that calcium can limit nodulation of *Trifolium subterraneum* by restricting growth of rhizobia in the rhizosphere (Loneragan and Dowling 1958).

The amount of phosphorus in growth media is commonly 500 mM compared with that in soil of 0.1–10 μM and in rhizosphere soil 0.1–0.01 μM. Reports which have used such media to screen rhizobia for growth in soil are unrealistic. Cassman et al. (1981) and Beck and Munns (1984) investigated the P nutrition of soybean rhizobia and found they were unable to store sufficient P to colonise rhizosphere soil. Strain USDA 142 was particularly inefficient at taking up phosphorus and may, therefore, have difficulty colonising soybean rhizospheres in low phosphorus soils. Strains USDA 110 and TAL169 were better able to utilise low concentrations of P. The application of these studies to those using soil and soil plant systems may provide a major ecological advance in the understanding of strain interactions in colonising soil and roots.

The rhizobia so far studied are tolerant of manganese, so that is unlikely to limit their growth and survival in acid soils.

Recent studies have shown rhizobia to be sensitive to levels of aluminium (50 μM) which may be encountered in acid soils. Few authors have attempted to translate the demonstrated tolerance in laboratory media to improved nodulation of plants in the field, but rather have been content to speculate.

Graham et al. (1982) classified 55 strains for *Phaseolus* on media which provided a pH, Mn and Al stress. One strain classified as tolerant survived better than a sensitive one when inoculated into acid soil adjusted to pH 4.15, 4.5 and 4.9. The tolerant strain also improved the yield of beans at pH 4.5, 4.75 and 5.2. By contrast, Bromfield and Jones (1980) reported a clover strain classified as sensitive to low pH persisted better than a tolerant one. Clearly, more comparisons are needed, but it must be recognised that while strains may be selected which are physiologically tolerant of the components of the acid soil complex they may be inferior to some sensitive strains in other features influencing their persistence.

Future Possibilities for Strain Improvement

Improved strains are sought from within a large population of isolates selected from a particular host or environment. It remains a lottery, and is extremely time-consuming and costly. Little is still understood of the basis of a desirable strain, so that selection is based on phenotypic expression in glasshouse and field trials. Until the now well-documented techniques of gene transfer allowed the possibility of genetic strain construction, it was necessary to hope that all desirable attributes would already have combined naturally. In its most attractive form, gene transfer will allow well tested strains to be conserved, while a particular function may be modified to extend the strain's usefulness.

This field is advancing so rapidly that it is easy to be optimistic although the future is hard to predict. It must be remembered that success in establishing a strain depends principally on its ability to compete with rhizobia already established in the soil and on the number of cells introduced. Strains vary in their competitive ability and effectiveness, and these characters are not necessarily linked nor is their genetic base well understood. This limits the ability to capitalise on highly effective strains, whether naturally selected or genetically constructed. Understanding the basis of competition and exploiting this in strain construction will therefore be of major importance.

Limitations Associated with the Host

Many of the limitations to nitrogen fixation, which act through their effect on the host, are dealt with elsewhere in these proceedings. This section, therefore, concentrates only on selected aspects.

The ability of a nodulated legume to fix atmospheric nitrogen may not make it independent of soil N, even when the symbiosis is 'fully effective' (Herridge et al. 1984). Young plants often will experience a period of nitrogen starvation between exhaustion of seed-N and nitrogen fixation. In many cases, this period of deficiency can be avoided by supplying small amounts of nitrogen fertiliser, which will allow rapid early growth until the onset of nitrogen fixation. On the other hand, the presence of combined N, especially nitrate, delays nodule formation. Some hosts such as *Lablab purpureus* are particularly sensitive, while others such as *Vicia faba* are more tolerant. In some soils, mineralisation of organic matter and nitrification may provide levels of nitrate which, at the same time, satisfy the requirements of the young legume plant but inhibit nodulation. When this soil nitrogen is exhausted by plant uptake or soil conditions, the plant may become N-deficient during the period of normally high N-fixing activity because of a lack of adequate nodule mass. This may be partially alleviated by additions of large numbers of rhizobia to the soil at planting (Herridge et al. 1984).

Legumes differ in their ability to maintain fixation into the reproductive phase, e.g. fixation by *Pisum* declines rapidly, while that by *Vicia faba* continues late into pod fill. This characteristic may be altered by the breeder, perhaps unintentionally. For example, the climbing primitive *Phaseolus vulgaris* has a longer vegetative phase and a resultant longer period of fixation than the bush beans 'improved' by plant breeders. The poor fixation by *Phaseolus vulgaris* has also been attributed to selection under high soil nitrogen rather than from symbiotically dependent plants. The number of host genes controlling nodulation in legumes is likely to be quite high (Holl and La Rue 1976). With so many genes involved, it is not really surprising that we continue to identify cultivars defective in some trait limiting nodulation or nitrogen fixation. What is important is that plant breeders and microbiologists cooperate to control this problem, with no lines being distributed before they have been evaluated for symbiotic potential. It is becoming increasingly evident that host-controlled differences can be used in producing agronomically acceptable cultivars active in nitrogen fixation (Graham 1981).

Breeders and microbiologists together may alter a plant selection strategy. Because of the difficulties encountered in distribution of legume inoculants in some areas, and because of the presence of effective nitrogen fixation bacteria in many agricultural soils, some breeding programs have stressed selection of genotypes which nodulate promiscuously with native strains of rhizobia and thereby fix adequate amounts of nitrogen without inoculation (Kueneman et al. 1985).

This practice holds the greatest promise for the most people in terms of exploitation of BNF in the tropics in the very near future, but varieties selected may not fix nitrogen at maximal activity in the majority of situations because of the large variability in native soil strains. This could mean lower yields in the long run.

An alternate approach is to breed and select for an extremely specific symbiosis so that most of the native rhizobia would not nodulate the legume in question, or do so slowly, and would not compete for nodulation. This type of specificity has been reported (Weber et al. 1971; Jones and Hardarson 1979) and appears to be a method of utilising the full genetic potential of the symbiosis (Devine 1984). Unfortunately, the legume bacteriologist is often confronted with a plant that has already been selected and for which he must find a suitable strain, leaving only strain variability to exploit.

When considering methodologies for enhancement of nitrogen fixation through breeding, it is of course necessary to combine enhanced rates of fixation with other needed agronomic and disease-resistance traits. It is of little value producing cultivars which actively fix nitrogen if they all die from disease when grown in the field. The problem here is that both nitrogen fixation and resistance to a number of diseases are likely to have polygenic inheritance. Disease resistance and nitrogen fixation must be combined at an early stage in the breeding program and attempts made to pyramid levels of nitrogen fixation and disease resistance. This again demands active collaboration between microbiologist, plant breeder, and pathologist.

Environmental Effects on the Host

Either an excess or a deficiency of water may affect nitrogen fixation through the respective influences on the growth of the nodulated plant. Recovery of fixation depends both on the duration and severity of either stress and on nodule morphology. Nodules with apical meristems (e.g. *Trifolium* and *Vicia* spp.) can resume growth after drought and produce more cells capable of infection by rhizobia, whereas some species with spherical nodules (e.g. soybean) must form a new population of nodules.

Sub-optimum supplies of water may reduce photosynthesis, restrict transport of fixed nitrogen from the nodule (Minchin and Pate 1973), and reduce fixation by inhibition of oxygen diffusion through the nodule cortex (Pankhurst and Sprent 1975a).

Most grain legumes respond adversely to waterlogged substrates: e.g. *Glycine max* (Sprent 1969), and *Vigna unguiculata* (Minchin and Summerfield 1976). However, cowpea nodules can adapt morphologically to prolonged anoxia and can recover fixation activity rapidly after drainage (Hong et al. 1977). Soybean nodules also respond to excess moisture by the formation of enlarged lenticels (Pankhurst and Sprent 1975b), whereas *Vicia faba* forms large intercellular spaces within the nodule cortex. *Vicia faba* also formed more nodules and fixed more nitrogen under very wet, but not completely waterlogged, conditions than in drier soil (Gallacher and Sprent 1978).

Despite the obvious implications of these studies for agricultural practice there is little information on the consequences of such conditions in the field. Ephemeral waterlogging is not uncommon in the tropics where traditionally grain legumes are planted soon after the onset of rains. Even short periods of stress can be important: when vegetative cowpea plants were waterlogged three times each day for only four days, seed yields were only about 50% of the unstressed controls (Hong et al. 1977).

Despite these reports and others on the effect of adverse soil temperatures, there are few recommendations on methods to ameliorate these effects. Surface mulches may conserve soil moisture, cool the topsoil, control weeds, and reduce available nitrogen concentration which otherwise may delay nodulation of crops especially sensitive to soil nitrogen status (e.g. *Macroptilium atropurpureum*).

Limits to Adoption of BNF Technology

Whilst there are still many unknowns in the scientific understanding of BNF, and research into the biochemistry and genetics of the process is particularly intense and competitive few, if any, of these unknowns are really constraining the implementation of legume-based BNF technology. The basic principles of inoculant technology have been known for many years and have already made major contributions to agricultural production, initially in the USA and Australia and recently worldwide, as cultivation of soybeans and other grain legumes has been increasing. The real constraints to fuller implementation of the technology relate to increasing the awareness of both potential inoculant producers and farmers, and their acceptance of the technology.

There have not been adequate demonstrations in the developing countries under realistic farm conditions of the yield increases and/or reduced fertiliser needs that are repeatedly stated to be the benefits of BNF technology. In some cases, inoculation trials have been performed and no response obtained. However, in these trials, mainly imported inoculants have been used, the quality of which, at the time of their use, was not verified. Although some researchers and agronomists may be aware of the benefits of inoculating legume seeds, in many cases strains selected in laboratory or glasshouse programs for effective nitrogen fixation have not been tested to ascertain whether the host concerned responds to inoculation in the field, or whether the strain used contributes to yield or even accounts for any of the nodules formed.

Thus a related constraint is the lack of trained personnel with the essential combination of agronomic and microbiological skills necessary to design and implement production-oriented research on adaption of BNF technology. Such skills would include determining the basic agronomic requirements of the crop, selecting, if necessary, improved strains of rhizobia and improvising acceptable inoculation methods. It must be remembered that current inoculation technology, as used in the USA and Australia, has been developed for use with legumes grown under favourable conditions with relatively high complementary agronomic inputs. Use of this technology in situations where the legumes are grown on marginal soils and under unfavourable climatic conditions with minimum inputs is questionable.

BNF technology is difficult to deliver by normal extension methods. In addition, the concept and practice of inoculation is so foreign to farmers' normal practices that it should not be recommended lightly. A subsistence farmer can be forgiven for not understanding or accepting a technology that involves sticking black powder containing bacteria to his seeds. It might be questioned if inoculant technology in this form will ever be accepted widely among subsistence farmers in tropical Asia.

Local Production of Inoculant

A serious constraint to fuller implementation of biological nitrogen fixation technology is non-availability of locally-produced, high quality inoculants within each of the countries of Asia. In this way, factors which deter government organisations or private enterprise from undertaking inoculant production in a country are also constraining BNF technology. Among these are: high capital cost of the inoculant production plant (of the type used in the USA and mistakenly assumed to be a prerequisite for any production plant); higher operational costs associated with losses due to such factors as contamination; absence in most developing countries of a suitable infrastructure that would allow marketing and distribution of a biological product easily damaged by high temperatures; absence of a comprehensive quality control program; and the insufficient present demand and uncertain future demand for inoculants.

The solution of these problems should not be difficult as the technology for producing inoculants in Australia could readily be adapted. There are two major initiatives attempting to rectify current problems. One, an ACIAR cooperative project between the New South Wales Department of Agriculture and the Rubber Research Institute, Malaysia, aims at identifying suitable carrier materials and developing methods of preparing them for inoculation. Already inoculants containing in excess of 10^9 rhizobia/g have been prepared with local materials. The second undertaken at the BNF Resource Centre, Bangkok (Thailand Department of Agriculture and NifTAL), with some input from the New South Wales Department of Agriculture has resulted in an inexpensive 100-litre fermenter now being manufactured in Bangkok. New facilities in Thailand are already sterilising peat for use as a carrier. In the future a packaged, sterile carrier, which could be infected with appropriate rhizobia, could be exported to countries lacking suitable carriers.

A quality control organisation will need to be developed wherever inoculants are produced. Its role should be to test strains, maintain them true-to-type and regularly supply them to manufacturers. These functions require considerable skills, which would be best gained by training in a laboratory specialising in quality control.

The survival of rhizobia in inoculants may be adversely affected by exposure to high temperatures. Unfortunately, this has been seen in some quarters as making the successful distribution of inoculants in the tropics impossible. This may be due in part to the strong emphasis in Australian literature on cool storage of inoculants. This emphasis was intended to apply to long-term storage rather than for short periods during distribution. More recent evidence (Roughley 1982) indicates that long-term cold storage of some strains for tropical legumes is harmful. Nevertheless, precautions should be taken to minimise the time inoculants are exposed to temperatures above 35°C.

The cost of inoculants is not usually a constraint to use by farmers who outlay capital for seed. Inoculant will seldom exceed 1% of the seed cost. For subsistence farmers who do not ordinarily purchase seed, the cost of inoculant, though small, may be a hindrance to its use. Cost becomes a more important consideration with granular forms of inoculant, in which the rate of application is much greater than with seed-applied inoculant.

Conclusions

In summary it can be said that the principal benefits from BNF through the use of food legumes in farming systems of Asia are derived from the protein of the grain, the many uses which legumes serve for the subsistence farmer, and the greater stability of yield and financial return of intercrops over monocrops. The indirect benefits from the contribution of biologically fixed nitrogen to companion or following crops may be small, but they are likely to be significant considering the low input levels in subsistence farming in parts of Asia.

A primary limitation to increased adoption of biological nitrogen fixation technology is that there are at present insufficient reliable data on the benefit to be gained from increasing, through use of inoculants, the nitrogen fixation in tropical legumes above the level which would be expected from spontaneous nodulation with native strains already present in the soil. It is tempting to recommend rhizobial inoculation of all legume sowings as an insurance measure against the risk of nodulation failure. Because inoculant technology does represent a cost, though small, and does make the planting procedure more complicated, it should only be recommended when there is known to be a need to inoculate and a probable demonstrable benefit.

Much is now known of the response of *Rhizobium* and of some nodulated legumes to adverse conditions. This knowledge has been used to devise and evaluate management practices for seed inoculation with *Rhizobium* cultures and to ameliorate acid soils unfavourable to the survival of the most strains of *Rhizobium*. Fewer studies have evaluated the responses of nodulated legumes in the field, and little is known of the effects of different management practices on nitrogen fixation. Efforts to exploit nitrogen fixation more fully in the field are frustrated by a lack of detailed studies on its interaction with water usage, mulches, and crop mixtures, the associated effects of soil temperature, crop density and spatial arrangement, and improved pest and disease control. Such studies require an integrated approach by specialists from different disciplines.

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Limits Imposed by Biological Factors: Pests

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THE palatability and high protein content of some food legumes make them desirable to a wide variety of insects. Although most have developed resistance by natural selection to many potential pests, as for example the chickpea with its acid exudate (Rembold and Winter 1982), almost all food legumes suffer severe losses. A possible exception to this is *Lathyrus*; however, the plant and seed itself is toxic to man, unless properly cooked.

Pests can damage legumes from the seedling (e.g. cutworms) through the vegetative (e.g. defoliators) and reproductive stages (e.g. pod borers) and in the stored seed (bruchids). Many insects can act as pests (e.g. over 200 insect species have been recorded damaging pigeonpea in India). A comprehensive account of the pest problems will not be presented, but rather the account will be restricted to the major food legumes — peanuts, chickpeas, mungbeans, soybeans, pigeonpeas, and cowpeas — that are widely grown in Southeast Asia. This paper will concentrate upon the general aspects of the pests, and their management.

Losses from Insect Pests

There have been few, if any, realistic assessments of crop losses caused by food legume insect pests. Such assessments should include not only the losses caused to the crops in the farmers' fields, but also the lost opportunity to grow crops in some areas. Flower- and pod-boring insects have nearly stopped the cultivation of pigeonpea in Sri Lanka (Subasinghe and Fellows 1978). Farmers have, through trial and error over generations, found which crops will produce a reasonable return in their fields. They have abandoned crop production of those species which insects destroy in their area. However, with the advent of modern insecticides, it is now possible to protect crops from damaging pests. There are several examples of 'new crop' introductions or high-yielding varieties of established crops, which do well when intensively protected, but yield nothing when left unprotected. We must add the cost of such lost opportunities to the debit account.

Crop loss assessment is difficult. It is more often discussed than practiced. Most data of crop loss are from research station fields, where the ecology and pest complexes are often atypical of those found in farmers' fields. A good example of this is provided by data from pigeonpea on the ICRISAT Centre farm. Here, pigeonpea is severely damaged by a hymenopteran pest, *Tanaostigmodes cajaninae*. More than 80% of the pods of late maturing pigeonpea can be destroyed by this insect. However, in a survey of farmers' fields across India in collaboration with national scientists, the damage to pods caused by this pest averaged less than 2% (Lateef et al. 1985). Clearly, *T. cajaninae* is a research station nuisance rather than a real pest in farmers' fields.

The ICRISAT surveys of pest damage in farmers' pigeonpea and chickpea fields across India provide us with data that are rarely available. Table 1 shows the percentage of pods damaged by the major pests in these surveys. In collecting such data, ICRISAT scientists visited more than 1200 farms, talking to farmers and collecting pod samples that were later analysed. Few national research organisations afford their scientists the opportunity or facilities to conduct such surveys. Most have no transportation, so their research is restricted to the atypical conditions of their research farm.

Even the extensive and expensive ICRISAT surveys did not provide direct data on crop loss. The percentage of damage caused to pods is obviously an important factor in crop loss, but the survey did not reveal the losses of pods caused by insects feeding on vegetation, buds, flowers, and young pods. Perhaps the easiest means of estimating crop

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TABLE 1. The percentages of pigeonpea pods, sampled from farmers' fields just before harvest, that were damaged by pests in India in 1975-81 (after Lateef et al. 1985).

Pests	Northern India (above 23°N)	Central India (20-23°N)	Southern India (below 20°N)
Lepidopterous borers	15.2	24.3	38.6
Melanagromyza obtusa	20.1	22.3	11.7
Callosobruchus spp.	0.2	2.2	6.3
Tanaostigmodes cajaninae	0.4	1.6	2.4
No. of fields sampled	407	446	444

loss is to compare the yields of plots that are left unprotected and those that are adequately protected by appropriate pesticide use. It is impractical to eliminate all damage, so the difference between the yields of the protected and unprotected plots is generally referred to as the 'avoidable loss'. Such data from replicated trials in farmers' fields would be very valuable for research and extension planning. Unfortunately, such data did not appear to exist for the food legume crops of Southeast Asia.

As a result, no realistic estimate of the losses caused by pests to these legumes can be made. However, the economic estimates that do exist, e.g. the ICRISAT estimate that *Heliothis armigera* causes losses of pigeonpea and chickpea to the value of $300 million per year in India, and the frequent reports of these crops being devastated by insect pests are sufficient to convince us that the food legumes in the region do suffer massive losses and that increased research and development of adequate pest management is urgently required.

Major Pests

Pest problems vary from crop to crop, area to area and season to season. More than 500 insects were listed as pests of food legumes in the book edited by Singh et al. (1978). Many predators and parasites prey on these destructive pests and help maintain the balance of nature and reduce pest outbreaks. Hundreds of species of insects and mites were collected in Cambodia from many crops, including the food legumes, during 1961-1963 and identified in an annotated list by Nickel (1979). This review lists only the major widespread pests on each crop. These are shown in Tables 2 and 3. In general, the most damaging pests are those that attack the pods, for most legumes can compensate substantially for damage caused to leaves and flowers. For example, some peanut genotypes can lose up to 50% of their leaves to insects prior to pod formation without a significant loss of yield (Campbell, unpubl.). Pigeonpea can lose all of its first flush of flowers and pods to insects, but still produce a second flush which will give a good yield, if climate and the pests allow.

Some of the major pests are common to most of the food legumes. *Heliothis armigera, Maruca testulalis, Aphis craccivora* and *Nezara viridula* attack almost all of these crops and in most areas. Others, such as the pigeonpea podfly *Melanagromyza obtusa* and the soybean stemfly *M. sojae* are relatively crop specific. Details of the major pests follow.

Heliothis armigera

The larvae of *H. armigera* damage all food legumes. They are particularly damaging to pigeonpea and chickpea in Asia. The female moths can each lay more than 2000 eggs. The moths move from plant to plant laying their eggs separately. The small white eggs hatch after 2-5 days, depending on temperature, and the young larvae initially feed on the surface of green tissues of leaves or buds. The larger larvae, which can be green, yellow, brown, pink or black, usually feed on flowers or pods, but can complete their development on leaves if fruiting bodies are not available. On most hosts, eggs are primarily laid during the flowering period and most damage is confined to the flowers and pods or fruits. However, chickpea is an exception for it attracts ovipositing moths while in the seedling stage (Table 4) and it can lose most of its leaves to this pest. On peanuts, *H. armigera* feeds on leaves and flowers and can cause substantial yield loss, but normally the plants compensate for most of the damage.

Maruca testulalis

This pest, which is variously known as the bean pod borer, spotted borer or mung moth, attacks many legumes across Asia and Africa. The moth can lay more than 100 eggs in small batches (2-16). These are usually found on flower buds, but are also found on shoots, leaves, flowers, and pods. The larva, which is easily recognised by the two pairs of black spots on each segment of its white body, produces silk which is used to stitch plant parts together to form a web within which it feeds on leaf, flower or pod tissue. Alternatively, it can bore into pods or stems. It is particularly common on cowpea, mungbean, pigeonpea and soybean. In Thailand, it

TABLE 2. Damaging pests of food legumes in South and Southeast Asia

Legume	Pest Type	Order	Family	Gen. & sp.	Common Name
Mungbean	Pod borers	Lepidoptera	Pyralidae	*Maruca testulalis*	Legume pod borer
			Noctuidae	*Heliothis armigera*	Bollworm
			Noctuidae	*Spodoptera litura*	Cutworm
			Lycaenidae	*Lampides boeticus*	Long-tailed blue
			Lycaenidae	*Euchrysops cnejus*	Blue butterfly
	Stem borers	Diptera	Agromyzidae	*Ophiomyia phaseoli*	Stem fly
			Agromyzidae	*O. centrosematis*	Stem fly
	Sucking pests	Hemiptera	Pentatomidae	*Nezara viridula*	Green stinkbug
			Cicadellidae	*Empoasca* sp.	Potato leafhopper
	Defoliators	Lepidoptera	Arctiidae	*Amsacta* sp.	Red hairy caterpillar
		Coleoptera	Chrysomelidae	*Madurasia obscurella*	Leaf beetle
	Virus vectors	Homoptera	Aleyrodidae	*Bemisia tabaci*	White fly
			Aphididae	*Aphis craccivora*	Cowpea aphid
Peanut	Pod borers and root feeders	Hymenoptera	Formicidae	*Dorylus orientalis*	Subterranean ant
		Dermaptera			Earwigs
		Diplopoda			Millipedes
		Coleoptera	Scarabaeidae	*Lachnosterna* spp.	White grub
		Isoptera	Termitidae	*Odontotermes* spp.	Termite
			Termitidae	*Microtermes* spp.	Termite
	Defoliators	Lepidoptera	Noctuidae	*Heliothis armigera*	Bollworm
			Noctuidae	*Spodoptera litura*	Cutworm
			Actiidae	*Amsacta* spp.	Red hairy caterpillar
			Lymantriidae	*Orgyia* spp.	Hairy caterpillar
			Gelechiidae	*Aproaerema modicella*	Leaf miner
			Tortricidae	*Archips micacaeana*	Leaf roller
			Pyralidae	*Laprosema* spp.	Leaf roller
	Sap suckers and mycoplasma vectors	Hemiptera	Cicadellidae	*Empoasca* spp.	Potato leafhopper
	Virus vectors	Homoptera	Aphididae	*Aphis craccivora*	Cowpea aphid
		Thysanoptera	Thripidae	*Frankliniella schultzei*	
				Scirtothrips dorsalis	
Pigeonpea	Pod borers	Lepidoptera	Noctuidae	*Heliothis armigera*	Bollworm
			Pyralidae	*Maruca testulalis*	Legume pod borer
			Pyralidae	*Etiella zinckenella*	Lima bean pod borer
			Pterophoridae	*Exelastis atomosa*	Plume moth
			Pterophoridae	*Spenarches anisodactylus*	Plume moth
			Lycaenidae	*Lampides boeticus*	Long-tailed Blue
	Podfly	Diptera	Agromyzidae	*Melanogromyza obtusa*	Podfly
	Pod sucking insect	Hemiptera	Coreidae	*Clavigralla spp.*	
	Leaf binder	Lepidoptera	Tortricidae	*Cydia critica*	
	Sterility mosaic vector	Acarina	Eriophyidae	*Aceria cajani*	Eriophyid mite
Soybean	Pod borers	Lepidoptera	Noctuidae	*Heliothis armigera*	Bollworm
			Pyralidae	*Etiella zinckenella*	Lima bean pod borer
	Stem borers	Diptera	Agromyzidae	*Melanogromyza sojae*	Stem fly
			Agromyzidae	*Ophiomyia phaseoli*	Stem fly
		Coleoptera	Cerambycidae	*Oberia brevis*	Girdle beetle
	Stem feeder	Lepidoptera	Noctuidae	*Agrotis* spp.	Cutworm
	Defoliators	Lepidoptera	Noctuidae	*Spodoptera litura*	Cutworm
			Noctuidae	*S. exigua*	Cutworm
			Arctiidae	*Diacrisia obliqua*	Jute hairy caterpillar
			Gelechiidae	*Aproaerema modicella*	Leaf miner
			Pyralidae	*Laprosema* spp.	Leaf roller
			Tortricidae	*Archips micacaeana*	Leaf roller
		Acarina	Tetranychidae	*Tetranychus urticae*	Twospotted spider mite

Legume	Pest Type	Order	Family	Gen. & sp.	Common Name
Soybean	Sucking pest	Hemiptera	Pentatomidae	*Nezara viridula*	Green stinkbug
	Virus vector	Homoptera	Aleyrodidae	*Bemisia tabaci*	White fly
			Aphididae	*Aphis craccivora*	Cowpea aphid
Chickpea	Pod borer	Lepidoptera	Noctuidae	*Heliothis armigera*	Bollworm
	Stem, pod and foliage	Lepidoptera	Noctuidae	*Agrotis* spp.	Cutworm
	Virus vector	Homoptera	Aphididae	*Aphis craccivora*	Cowpea aphid
	Root and stem	Isoptera	Termitidae	*Odontotermes* spp.	Termites
Cowpea	Pod borers	Lepidoptera	Pyralidae	*Maruca testulalis*	Legume pod borer
			Noctuidae	*Heliothis armigera*	Bollworm
			Lycaenidae	*Lampides boeticus*	Long-tailed blue
	Stem feeder	Diptera	Agromyzidae	*Melanagromyza phaseoli*	Bean fly
	Pod sucking	Hemiptera	Pentatomidae	*Nezara viridula*	Green stinkbug
	Defoliators	Lepidoptera	Noctuidae	*Spodoptera litura*	Cutworm
			Noctuidae	*S. exigua*	Cutworm
	Sap feeder	Hemiptera	Cicadellidae	*Empoasca* sp.	Potato leafhopper
	Virus vector	Homoptera	Aphididae	*Aphis raccivora*	Cowpea aphid

TABLE 3. Postharvest pests of beans, peas and peanuts

Coleoptera
- Adzuki Bean Seed Beetle — *Callosobruchus chinensis* (Bruchidae)
- Cowpea Seed Beetle — *Callosobruchus maculatus* (Bruchidae)
- Ground nut seed beetle — *Caryedon serratus* (Bruchidae)
- Bean Seed Beetle — *Acanthoscelides obtectus* (Bruchidae)
- Khapra Beetle — *Trogoderma granarium* (Dermestidae)
- Lesser Grain Borer — *Rhizopertha dominica* (Bostrichidae)
- Red Flour Beetle — *Tribolium castaneum* (Tenebrionidae)
- Saw-toothed Grain Beetle — *Oryzaephilus surinamensis* (Cucujidae)
- Merchant Grain Beetle — *Orzyaephilus mercator* (Cucujidae)

Lepidoptera
- Rice Moth — *Corcyra cephalonica* (Galleridae)
- Almond Moth — *Ephestia cautella* (Phycitidae)
- Warehouse Moth — *Ephestia elutella* (Phycitidae)
- Indian Meal Moth — *Plodia interpunctella* (Phycitidae)

was found in the stems of groundnuts, but this appears to be unusual. It has not been reported from chickpeas.

Aphis craccivora

Of the many aphids that feed on the food legumes in the region, the cowpea aphis is the most common and widespread. These black aphids can build up to large numbers on the young tissue of all the food legumes and cause wilting and necrosis of the stems and petioles. However, they cause most crop loss as vectors of various viruses that can cripple or kill the hosts.

TABLE 4. Mean numbers of eggs laid on chickpea and pigeonpea plants grown in pots and exposed to *Heliothis armigera* moths in field cages at ICRISAT 1978–79 (after Bhatagar et al. 1982).

Stage	Mean no. of eggs laid/plant	
	Chickpea	Pigeonpea
Seedling	12.5 (120)[a]	2.3 (134)
Flowering	1.2 (113)	18.5 (105)

[a] Figures in parentheses are number of plants examined.

Nezara viridula

The green stink bug is a common pest of most food legumes, but it causes little damage to peanuts and has not been reported from chickpea. The shield-shaped green or green and gold adult female lays several batches of 10–100 green eggs on leaves or pods. The newly hatched black nymphs disperse over the plant, feeding on the shoots and pods. The feeding causes necrosis, and heavy populations can greatly reduce yields. Very young pods are particularly susceptible. When the stink bug pierces young seeds, they shrink, become distorted and wither. Older beans, when pierced, will show a discolored and slightly sunken spot.

Bemisia tabaci

The common whitefly whose immature stages (scales) feed on the underside of several legumes, particularly mungbean, can build up to heavy populations causing wilting and defoliation. However, this pest causes most damage as the vector of yellow mosaic on mungbean and other legumes.

Agromyzids

The agromyzid flies are particularly important on food legumes in the region. Some, such as the pigeonpea pod fly, *Melanagromyza obtusa* and the soybean stem fly, *M. sojae* are host-specific, but others such as the bean flies, *Ophiomyia phaseoli* and *O. centrosematis* attack the stems of a wide range of food legumes across the region. The plants may be killed if the stem feeding larvae attack the seedlings, but older plants can usually compensate for the damage. The pigeonpea pod fly is the most damaging pest of pigeonpea in central and northern India. ICRISAT surveys found 21% of the pods sampled from farmers' fields were damaged by this pest. The losses caused may amount to 250 000 tonnes, worth more than $US60 million per year.

Aproaerema modicella (= Stomopteryx subsecivella)

The peanut leafminer occurs throughout India and Southeast Asia. Peanut and soybean are the major host, but it also feeds on pigeonpea and mung bean (Mohammad 1981). Females lay an average of 186 eggs. Eggs hatch within 3 days and the larvae tunnel into the leaflet near the midrib. After feeding for about one week, the larva emerges from the mine, folds the leaflet or webs together several leaflets. The destructive larval stage lasts 9–17 days. Young larvae are cream colored and as they age, they turn green to brown with a black head. The life cycle from egg to adult lasts from 15 to 28 days. Adults live only 5–20 days. Keerati-Kasikorn and Hiranyasaree (1975) reported 15–65% leafminer damage to peanuts in Thailand. Arunin (1978) reported 85% soybean seedling stand loss in Thailand. Heavy rain and high humidity results in a decrease in the leaf miner population. Multiple cropping of susceptible legumes, especially soybean and peanut in rotation, should be avoided (Feakin 1973).

Bruchids

Callosobruchus spp. occur worldwide. They are particularly destructive to cowpea, but pigeonpea and soybean pods are also attacked. *Callosobruchus* larvae bore through the green pod to attack the developing bean. Although field infestations may only be 1%, the weevils increase rapidly in storage, so that what starts as a minor field problem blooms into a destructive storage problem. Southgate (1978) reported that damage increased to 33% in six months and 87% after nine months storage. Losses in quality as well as weight loss occur in bruchid-damaged legumes. *Callosobruchus* spp. do not attack peanuts, but *Caryedon serratus* can attack the pods after harvesting in the fields or in storage, causing substantial losses.

Pest Management

Insecticides are useful in limiting the losses caused by the insect pests to food legumes, however experience has shown that there are problems and danger in relying solely upon insecticides for insect pest control. There are many examples of prolonged or intensive insecticide use inducing resistance in pests so that the insecticide is no longer effective. There are also examples of insecticides killing the natural control elements and so promoting populations of pests. In the southeastern United States, Bradley and Van Duyn (1979) reported an outbreak of *Heliothis zea* after predators were severely reduced by the incorrect timing of an insecticide application. Spider mite outbreaks occur frequently on peanuts following fungicide and fungicide–insecticide application intended to control lepidopteran pests and prevent plant diseases (Campbell 1978). Some of the food legumes are not high value crops and many farmers in the region have limited capital. Insecticides are expensive and pollute the environment. Hence, there are many good reasons for using alternative means of pest management.

Alternatives to insecticide use are host plant resistance, biocontrol and the use of cultural practices that reduce pests or allow the plant to escape damage.

Host Plant Resistance

The benefits from host plant resistance have been obvious in plant disease control. There have been very successful efforts to breed food legumes that are resistant to the major diseases, and many new cultivars that have been released have resistance to one or more of the locally damaging diseases in Asia. Unfortunately, the entomologists have not made as much progress, partly because screening and breeding for insect resistance is usually more difficult than for disease, and also because there has been less effort until recently. Good progress is now being reported from ICRISAT, where peanuts, pigeonpeas and chickpeas are being bred for resistance to a variety of pests, and from AVRDC and several national research centres. Lateef (Table 5) evaluated 12 000 chickpea germplasm lines and recorded that very many of these had no insect damage, but it was obvious that most were simply

TABLE 5. Screening chickpea germplasm for susceptibility to *Heliothis armigera*. Plots found to be free from damage in harvested samples, ICRISAT Centre during 1976–77 (after Lateef 1985).

	No. of entries harvested	No. without *H. armigera* damage	% without *H. armigera* damage
Germplasm lines	8629	955	11.1**
Check BEG-482	221	43	19.5*
Check C-235	219	61	27.9*

Differences significant at *P<0.05, **P<0.001

escapes. However, subsequent replicated screening of these lines showed that several were less preferred by *Heliothis armigera* for egg laying and larval feeding. Campbell and Wynne (1980) identified peanut plant introductions and breeding lines with low to high resistance to a complex of insects and mites. Resistance to *Spodoptera litura*, thrips, jassids, aphids and pod borers (including termites) has been identified at ICRISAT and is being incorporated into breeding lines for Asia. Wild species of peanut (*Arachis*) exhibited resistance approaching immunity to thrips, potato leafhopper and *Heliothis* (Amin 1985). Rogers (1982) reviewed the literature on screening legumes for resistance to *Heliothis* spp. Singh (1978) evaluated cowpea for insect resistance and reported resistance to pod, stem and flower feeding insects and postharvest pests.

Mungbean accessions were screened for resistance to beanflies in tests conducted in Indonesia, Taiwan and Thailand. Among the nearly 1200 accessions, 24 were selected as moderately resistant (Chiang et al. 1977). Mungbean seeds were exposed to the destructive weevil *Callosobruchus chinensis* in the laboratory in the Philippines and 11 of the 60 accessions were resistant (Epino and Morallo-Rejesus 1982).

Soybean breeding lines were registered as multiple insect-resistant in tests conducted in North Carolina (Burton et al. 1986). These selected soybean lines averaged 40–60% less damage from defoliators than the standard susceptible check.

Litsinger (1982) suggested priorities for breeding for insect-resistant legumes. On mungbean and cowpeas he placed high priority on the pod borers *Maruca* and *Heliothis* and on the preflowering pests, beanfly, thrips and leafhopper. On soybean *Etiella*, stemfly and stink bug were considered to be important. Pigeonpea breeding priorities were for resistance to *Heliothis, Maruca* and the podfly. Peanut pest priorities included the leafminer, leafhopper, *Aphis* and *Heliothis*. For chickpea, only *Heliothis* was rated as a priority.

There is great diversity of pest susceptibility among germplasm lines of the legume crops that have been adequately studied. It is therefore probable that useful levels of pest resistance can be identified and incorporated into the breeding programs for each food legume in South and Southeast Asia.

Biocontrol

Biological control, involving the introduction of exotic parasites and predators and the breeding and release of these and endemic species, has been most successful on islands and in perennial crops. It has not been very successful on long-established annual crops. However, there are many natural enemies of pests on these crops, without which the losses due to pests would be much greater. We must at least protect these natural enemies and if possible, augment their effects. For example, in central India *Heliothis armigera* is known to be attacked by at least 26 parasites and many predators (Bhatnagar et al. 1982). Injudicious insecticide use can destroy parasites and predators and lead to greater pest attacks.

Many scientists are investigating the potential for biological control on crops, including food legumes, in Southeast Asia. However, most of this research has not yet reached the economic evaluation stage and it is doubtful whether the production and dissemination of parasites and predators will be profitable in the near future, with the possible exception of *Trichogramma* spp. Research into the use of insect pathogens appears to be more promising. The production and dissemination of viruses to control some lepidopteran pests including *Spodoptera* spp. and *H. armigera* is already at the pilot stage of testing at some centres in India (Nagarkatti 1982).

Cultural Practices

Changes in the cultural practices, particularly in sowing dates, can have a great effect on the incidence of most insects. By the adroit manipulation of crop proximities and rotations, it is possible to reduce the damage caused by some insects. The traditional systems that have built up over generations, particularly the careful observance of seasons, have evolved partly in response to pest threats. When farmers in an areas sow synchronously, the pests are diluted across crops. If one sows earlier or later or uses a shorter or longer duration cultivar than his neighbors, then he is likely to experience a more or less concentrated pest attack on his crop. Bradley and Van Duyn (1979) reported that early planted soybeans in southeastern United States escaped *Heliothis zea* damage while 79% of the soybeans planted three to four weeks later

TABLE 6. Percentages of pods damaged by *Tanaostigmodes cajaninae* in samples taken from trials of short, medium and long duration genotypes of pigeonpea at ICRISAT (after Lateef et al. 1985).

Genotype duration	Month harvested	1981–82 n	1981–82 Mean % (ranges)	1982–83 n	1982–83 Mean % (ranges)
Short	Nov.-Dec.	9	16.3 (6.2–32.6 ± 4.46)	12	10.3 (0.4–19.3 ± 2.82)
Medium	Jan.-Feb.	25	22.9 (1.9–83.2 ± 3.88)	18	25.9 (5.4–62.9 ± 7.01)
Long	March	24	49.7 (19.0–68.7 ± 5.23)	15	32.6 (11.3–57.2 ± 4.45)

n = number of genotypes tested.

required insecticide treatment for *H. zea* control. At ICRISAT, short-duration pigeonpea suffered less damage from *Tanaostigmodes cajaninae* than medium or long duration genotypes (Table 6). The many advantages of traditional systems are not well understood and will probably be fully elucidated only when changes in such systems result in major problems.

Food legumes are often grown as intercrops or in sequential-multicrop systems. Ruhendi 1979 (MS thesis, Entomology, Univ. of Philippines) found insect pests on cowpea plants, that had been sown after flooded rice, were affected by the height of the rice stubble. The maximum rice stubble effect on insect reduction occurred at 41–54 cm high for beanfly, 54 cm for thrips, and 44–48 cm for leafhopper. Rice straw mulch reduced thrips and leafhopper numbers but not beanfly. In the United States, Campbell (Table 7) found that peanuts planted after wheat in the stubble (no-till) had significantly less thrip damage than peanuts planted in conventionally tilled land. Campbell (Table 8) reported also that leafhopper damage was reduced on peanuts planted in rye stubble (no-till) compared with conventionally planted peanuts. Irrigation or flooding may have positive or negative effects on insects depending on their environmental requirements. It is therefore possible to take advantage of cultural practices to reduce or manage the complex of pests.

TABLE 7. Comparison of thrips damage on two peanut cultivars planted in wheat stubble (no-till) and conventionally tilled land, North Carolina, USA (Campbell, unpubl.)

Peanut cultivar	Avg. % thrips/damage No-till planting	Conventional planting
NC 6	3.3	14.0
Florigiant	16.7	33.3

LSD at 0.05 level is 8.9 for NC 6 vs. Florigiant and 11.5 for no-till vs. conventional.

Insecticide Use

Insecticides are now widely available in this region, and most farmers in the region have made some use of these, if only for their household pests. In most cases, the high costs of pesticides will ensure that farmers do not overuse these chemicals on their crops. As a whole, insecticides are still relatively underutilised in Southeast Asia. There are, of course, striking exceptions to this, particularly on high-value crops such as cotton and vegetables near urban markets. Most farmers are still at the stage of making tentative, experimental use of insecticides. Unfortunately, most apply insecticides far too late. They wait until they see pest damage and then buy insecticides. The recipe for successful insecticide use is simple; apply the correct insecticide in the right amount at the right time. Unfortunately, few people know the ingredients for this recipe!

TABLE 8. Comparison of potato leafhopper damage on two peanut cultivars planted in winter rye stubble (no-till) and cultivated land (conventional). North Carolina, USA. (Campbell, unpubl.)

Peanut Cultivar	Carbaryl kg/ha	% Leaflets with hopperburn[a] No-till	Conventional
NC 6	1.1	2.3	2.3
	Check	8.0	19.0
Florigiant	1.1	3.0	4.7
	Check	17.0	40.7

[a] Based on 200 leaflet random sample.
LSD at 0.05 level is 7.8 for treated vs. check and 8.6 no-till vs. conventional

Insecticides should be applied when the pest population is such that substantial damage will occur unless the insecticide is applied. Most pest species cause little damage when small or when few are present. Thus, the crops should be regularly monitored and the farmer should be ready to spray whenever counts, particularly of eggs or small larvae or nymphs, threaten to exceed the 'economic threshold'. This threshold is the level of population (or damage) at which the application of insecticide will be profitable.

Thresholds

Economic thresholds are more often discussed than calculated. It is not possible to give a simple economic threshold for a pest on a crop that will be valid for all seasons and all regions. Economic thresholds must take into account the following factors: crop potential, pest damage potential, cost of the treatment and market value of the crop. These factors vary greatly across areas and time. Crude thresholds can be constructed that will be generally applicable to at least prevent gross over-use or under-use of pesticides. We may have to rely on crop stage and calendar date for treatment guidelines until realistic crop losses are established for farmers' fields.

TABLE 9. Reproductive stages of peanut for Spanish (Starr) and Runner (Florunner) varieties (after Boote 1982).

	Days after planting (DAP)	
Reproductive stage	Starr	Florunner
R_1 Beginning bloom	31	31
R_2 Beginning peg	39	42
R_3 Beginning pod	46	51
R_4 Full pod	52	60
R_5 Beginning seed	57	62
R_6 Full seed	67	74
R_7 Beginning maturity	80	93
R_8 Harvest maturity	119	129

An important step is a knowledge of the crop phenology in relation to the insect and its damage potential. In the United States, Boote (1982) described phenological stages for the peanut. A comparison of the reproductive stages of the Spanish and Runner peanut is shown in Table 9.

Thresholds for foliage loss that affect peanut yield also vary with the stage of plant development. Yield reduction occurred at 50% defoliation for the R2 stage, 10% for the R3 and R4 stages, 20% for the R5 stage and 50% for the R6 stage (Table 10). Sathorn Sirisingh (unpublished 1984) found 60-day peanuts were more susceptible to defoliation than earlier phenological stages at Ra Young, Thailand. E.P. Cadapan (Univ. of Philippines, unpubl.) also reported that the R3 to R5 phenological stages of the peanut were the most susceptible to defoliation. In spite of differences in plant duration of 120–150 days, the most susceptible stages for leaf loss occurred at the R3 to R5 stage in North Carolina, Thailand and the Philippines. This is apparently a critical period when pods and young seed are developing. Fehr and Caviness (1977) described growth stages of the soybean. The pod fill stage of the soybean is the most sensitive to foliage loss. Thomas et al. (1974) reported the threshold for soybean defoliator was 40% when pods were just visible, but the defoliation threshold was only 6% when the beans were beginning to develop.

While the economics of pesticide treatment will change, the damage–yield loss relationship remains more stable and will serve as a guide to 'on demand' or 'as needed' treatment. However, the threshold will vary greatly across geographical areas, genotypes and agronomic systems, so it will be necessary to determine thresholds for each situation.

A pilot integrated pest management (IPM) project was established in North Carolina to test the ability of the cooperating scientists to monitor and manage the pest complexes on peanuts, using the established sampling methods and thresholds. The results show (Tables 11a, 11b) that insecticide application, based on thresholds applied when needed, resulted in

TABLE 10. Effect of foliage loss and date of foliage loss on the yield of NC 5 peanuts North Carolina, USA (Campbell, unpubl.)

Defoliation date	Plant stage[a]	DAP[b]	Yield kg/20 m row after defoliation					
			0%	10%	20%	30%	50%	75%
July 12	R2	61	5.87	5.90	5.75	5.79	5.45	5.22
Aug 1	R3	82	6.17	5.57	5.16	5.60	3.56	4.32
Aug 15	R4	96	6.30	5.68	5 98	5.30	4.47	2.69
Sept 1	R5	113	5.79	5.79	5 26	5.22	4.96	3.44
Sept 15	R6	127	5.94	5.79	5.94	5.87	5.34	4.54
LSD at 0.05								0.39

[a]Phenological stage according to Boote (1982)
[b]DAP = Days after planting. NC 5 is late maturing (140–150 days).

TABLE 11a. Summary of insect damage in a preventive vs. on-demand control program in a peanut IPM project, North Carolina, USA, 1984. (W.V. Campbell, H.D. Cole and J.E. Bailey, unpubl.).

Cultivar and treatment	% Thrips damaged leaves	% Leafhopper damaged leaves	% Corn earworm damage	% Southern corn rootworm damage	Average yield kg/65m
NC 6					
Preventive	1.0	1.0	2.3	0.8	23.7
On demand	20.0	6.7	5.0	1.3	24.4
Florigiant					
Preventive	1.2	1.5	9.8	2.7	22.6
On demand	33.7	28.7	12.3	6.7	22.5
Florigiant					
Check	—	—	—	—	18.3
LSD 0.05					0.9
LSD 0.01					1.2
Threshold	>25% damage	>25% damage	>10% damage	>3% damage	

TABLE 11b. Comparative cost for each hectare for on-demand (as needed) vs. preventive insect control program, North Carolina, USA, 1984. (Campbell, unpubl.)

Cultivar	Preventive $ US	On demand $ US
NC 6	47	0
Florigiant	96	22

yields equivalent to the preventive program and saved the grower money. The NC 6 cultivar has multiple insect resistance (Campbell and Wynne 1980) and insect damage did not exceed established thresholds on this cultivar in this trial. The thresholds used are currently being refined. It is better to use an approximate threshold or plant development stage as a basis for insecticide treatment, rather than treat at the first sign of insect damage or after the insect has caused economic damage.

Conclusions

Pests of food legumes need to be monitored and their damage potential established with reference to the phenology of the crop. Thresholds should be determined for the most important pests, and the most pest-resistant and acceptable cultivar should be utilised according to the most damaging pests for the particular legume. The identification and development of pest-resistant food legumes offers the most reliable, long-term method of pest management. Cultural practices may be incorporated to reduce the pest potential so long as they fit into the accepted cropping practices for the crop and region. Preservation of natural enemies of our crop pests is possible by the judicious use of well-timed minimum rates of pesticides. Finally, best pest management packages will be put together as interdisciplinary team research expands.

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Improvement and Change of Food Legume Agriculture in Asia in Relation to Disease

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DISEASES are one of the limits to the productivity of food legumes in Asia, but the combined efforts of plant breeders, pathologists, extension workers and farmers should be able to reduce their depredations. The purposes of this paper are: (1) to list the major diseases of a few important food legumes (soybean, groundnut, and pigeonpea); (2) outline current research on soybean and groundnut pathology in Thailand as a case study of current food legume research in Asia; (3) describe the important virus diseases of food legumes in Asia; (4) discuss some general issues related to the control of food legume diseases in Asia.

Diseases of Major Food Legumes in Asia

Peanut (Groundnut)

Peanut (*Arachis hypogaea*) is a plant of South American origin that is affected by many diseases. Some, such as the foliar leaf spot diseases, occur widely throughout the peanut-growing areas of Africa, North and South America, Australia, South and Southeast Asia, China and Japan. Others, such as bacterial wilt caused by *Pseudomonas solanacearum*, are more restricted in distribution. The major diseases of peanut worldwide are discussed comprehensively by Allen (1983). McDonald and Raheja (1980) have also reviewed the subject, with emphasis on Asia.

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FUNGAL DISEASES

The most important fungal diseases are two *Cercospora* leaf spots, and rust. Aflatoxins associated with the fungus *Aspergillus flavus* are also a widespread problem.

Cercospora arachidicola causes an early leaf spot, while *Cercosporidium personatum* causes a late leaf spot. Both are widely distributed in peanut growing areas and cause premature defoliation. The diseases can be controlled by the application of fungicides, but the cost of fungicidal control is often beyond the reach of many Asian farmers. Peanut cultivars differ in their susceptibility to the *Cercospora* leaf spots, and there are some prospects for breeding for resistance (Allen 1983).

Peanut rust (*Puccinia arachidis*) is widespread in tropical areas, and particularly damaging where it occurs in association with the *Cercospora* leaf spots.

VIRUS DISEASES

The most important viruses are rosette, bud necrosis, peanut mottle and peanut stunt. Of these, bud necrosis, mottle and stunt occur in some Asian countries. Rosette, a damaging disease in Africa, has not yet been recorded in Asia.

BACTERIAL DISEASES

The only bacterial disease of importance on peanuts is bacterial wilt, caused by *Pseudomonas solanacearum*. It is of limited distribution, being reported from Indonesia, Malaysia, China, Uganda and USA. It is considered to be particularly damaging in Indonesia, from where it was first reported in the early 1900s (Hayward 1986).

NEMATODES

Nematodes from the genera *Meloidogyne*, *Pratylenchus*, *Belonolaimus* and *Macroposthania* can cause serious disease losses in peanuts, particularly in association with other diseases.

Pigeonpea

Pigeonpea (*Cajanus cajan*) is predominantly grown in India, where it is thought to have originated. However, the crop is also grown elsewhere in Asia, as well as in Africa, the Caribbean, Latin America, and Australia. The crop is usually grown as a long-duration (6–9 months) intercrop with a cereal, but increasingly as a short-duration (4–5 months) monocrop at high plant density. A different disease spectrum is likely to affect monocropped pigeonpeas.

More than fifty pathogens have been reported on pigeonpeas (Nene 1980). However, only a few are considered to be economically important. Surveys by Kannaiyan et al. (1984) showed these to be wilt (*Fusarium udum*), sterility mosaic (virus?) and Phytophthora blight (*Phytophthora drechsleri* f. sp. *cajani*), in India; witches broom (mycoplasma?) and rust (*Uredo cajani* Syd.) in the Americas; and leaf spot (*Mycovellosiella cajani*) in Africa.

FUNGAL DISEASES

The major fungal diseases of pigeonpea are described by Allen (1983). The most important of these are wilt (*Fusarium udum*) and *Phytophthora* blight, both of which can cause serious crop losses.

VIRUS DISEASES

Several virus-like diseases have been reported from pigeonpeas, but no viruses have been satisfactorily characterised. The most important is sterility mosaic, but no virus particle has been directly associated with this disease as yet. The disease is transmitted by mites. Sterility mosaic has been reported from India, Burma and Thailand.

BACTERIAL DISEASES

A bacterial leaf spot and stem canker, caused by *Xanthomonas campestris* pv. *cajani*, has been reported from India and the Sudan. Halo blight (*Pseudomonas syringae* pv. *phaseolicola*) has been recorded on pigeonpeas in Ethiopia and Australia (Allen 1983). A stem disease of unknown etiology in Fiji may also be caused by a bacterium.

NEMATODES

Pigeonpeas are susceptible to a wide range of nematodes, including species from 12 genera (Allen 1983). Only a few cause economic damage. These include the root-knot nematode (*Meloidogyne* spp.), the cyst nematode (*Heterodera cajani*), and *Rotylenchulus reniformis*.

Soybean

Soybean (*Glycine max*) is the most important food legume crop in the world, in terms of both total production and international trade. Most research on soybean diseases has been conducted in North America. Soybean diseases have been comprehensively described by Sinclair (1982). Little is known of the pathology of the crop in the tropics, particularly in the centre of origin of the genus in the Asian tropics and subtropics, where the diversity of the crop and its pathogens may be expected to be greatest (soybeans, however, were domesticated outside the tropics, in northeastern China).

Most research on soybean in the tropics has been conducted by the Asian Vegetable Research and Development Centre (AVRDC), based in Taiwan (Yang 1980).

FUNGAL DISEASES

The most important fungal pathogens to attack soybeans in the tropics are the seedborne fungi causing seed deterioration, and rust caused by (*Phakospora pachyrhizi*). AVRDC has a regional research program on rust in Asia (Yang 1980), however no satisfactory resistance to rust is available.

VIRUS DISEASES

Several viruses affect soybeans, but only a few are economically significant. In Asia, soybean mosaic virus, mungbean yellow mosaic virus and tobacco ring spot virus occur. The virus diseases of soybean in Asia and Oceania have been reviewed by Goodman and Nene (1976).

Soybean mosaic virus has a narrow host range, and persists between seasons mainly in infected seed. Hence control by the production and use of virus-free seed has considerable potential. Sources of resistance to soybean mosaic have also been identified, and breeding for resistance is possible.

BACTERIAL DISEASES

Two important and widely distributed diseases of soybeans are bacterial blight, caused by *Pseudomonas syringae* pv. *glycinea*, and bacterial pustule, caused by *Xanthomonas campestris* pv. *glycines*. Bacterial blight is more prevalent in the cool, high altitude regions of the tropics. Bacterial pustule is more common in the lowland humid tropics, although both may occur together (Allen 1983). Both pathogens are seed-borne. Sources of resistance are available for both pathogens.

Several other bacterial species have been recorded on soybeans, but none cause serious disease (Allen 1983). These are: *Bacillus subtilis* (seed decay); *Corynebacterium* sp. (vascular wilt, in USA); *Pseudomonas syringae* pv. *syringae* (foliar disease, Kenya); *Pseudomonas syringae* pv. *tabaci* (wildfire disease, USA, Brazil); *Pseudomonas solanacearum* (unconfirmed) (wilt).

NEMATODES

Nematodes can cause damage to soybeans, but their importance is generally unrecognised in the tropics. Species reported are the soybean cyst nematode (*Heterodera glycines*) in temperate regions; root knot nematode (*Meloidogyne* spp.); reniform nematode (*Rotylenchulus reniformis*); and dagger nematode (*Xiphenema* spp.) (Allen 1983).

Food Legumes Diseases in Thailand — Case Studies

There are five food legumes of economic importance in Thailand — soybean, peanut, green gram, black gram and rice bean (Na Lumpang 1985). Of these, only the diseases of peanut and soybean have been studied extensively, as part of crop improvement programs for these crops. Little information is available on the diseases of other food legumes in Thailand.

Peanuts

PEANUT DISEASES

In 1966 there were only four peanut diseases reported in the host list of plant diseases in Thailand (Puckdeedindang 1966). Nineteen years later the number reported increased to more than thirty (Wongkaew 1985). Ten are widely distributed and are considered to be of economic significance (Table 1).

TABLE 1. Major diseases of peanuts in Thailand.

Disease	Causal Agent
Foliar diseases	
Black spot	*Phaeosariopsis personata (Cercosporidium personatum)*
Rust	*Puccinia arachidis*
Brown spot	*Cercospora arachidicola*
Virus diseases	
Bud blight	tomato spotted wilt virus
Mottle	peanut mottle virus
Yellow spot	peanut yellow spot virus
Stripe	peanut stripe virus
Soil and seed-borne diseases	
Seedling blight	*Aspergillus niger*
Collar rot	*Sclerotium rolfsii*

FOLIAR DISEASES

There are three major foliar fungal diseases affecting peanuts in all growing areas of Thailand. Black spot (late leaf spot) caused by *Cercosporidium personata* is the most important, followed by rust (*Puccinia arachidicola*) and brown spot (*Cercospora arachidicola*). Combined yield losses due to these diseases vary, depending on planting season and areas. In the wet season the loss can be as high as 87% in the northern region (Schiller and Sampoapol 1981). Losses are commonly estimated at 30-50% (Kitisin et al 1976). The diseases are much less severe in the dry season. Since under the actual farming condition black spot and rust are found in equal abundance on the same plants, the losses measured are the combined effects of the two diseases.

Control Measures Foliar sprays with chemicals such as chlorothalonil, or a mixture of benomyl and mancozeb, have been proved effective in controlling black spot, rust and brown spot (Schiller and Indraphun 1978). However, fungicide application by farmers is limited. Scarcity of the fungicides and their high cost are the main factors that limit fungicide use on soybeans.

Cultural control, based on planting peanut early in the rainy season or growing only a dry season crop, has been adopted in order to avoid the diseases. These strategies can only be applied in areas where irrigation water is available or where the soil has sufficient residual moisture to sustain plant growth.

Research on disease resistance to these foliar diseases is being conducted as one of the major priorities in the Thai National Co-ordinated Groundnut Improvement Program, established in 1981. Promising lines with high level of field resistance to either rust or leaf spots have been identified from thousands of lines tested in disease nurseries. The nature of the resistance of some of these lines has been investigated (Wongkaew and Tangthumniyom 1984; Butranu et al. 1984). Recently, lines with multiple foliar disease resistance have also been detected (Wongkaew, unpubl.). Some of these resistant sources are being used in the peanut breeding programs in Thailand (Pathanothai and Toomsan, unpubl.). However, in spite of the increased emphasis on resistance to these foliar diseases, there are currently no agronomically acceptable cultivars with adequate resistance to eliminate the use of fungicides for management of the major foliar diseases of peanut.

VIRUS DISEASES

Yellow spot (peanut yellow spot virus) and bud blight (tomato spotted wilt virus) are the most widespread viruses on peanuts in Thailand, followed by peanut mottle virus and peanut stripe respectively (Wongkaew, unpubl.). Virus diseases are predominant in the dry season. Yield losses have been assessed only for peanut stripe virus. Losses of up to 50% have been observed if the plants were infected up to 60 days before harvesting (Anderson, unpubl.). The effect on yield was much less if plants became infected close to maturity. However, on cultivar Tainan 9 the effect of peanut stripe virus on yield was insignificant even though the plant had become infected early (Wongkaew and Kuntrong, unpubl.).

Peanut stripe and peanut mottle appear to be a problem only in the areas where foliage insecticides are applied regularly such as research stations. One hundred per cent disease incidence is commonly observed in such areas. This is in contrast to yellow spot and bud blight which are found in most growing areas but with a low incidence. The incidence of bud blight is increasing as more peanuts are planted in the dry season. This disease was noted in low incidence only in 1985. By 1986 it had spread to most planting areas with a considerably higher incidence (Wongkaew, unpubl.). Early infection by bud blight results in zero yield of peanuts. This disease is considered to be one of the most destructive diseases of peanuts in India (Reddy, pers. comm.).

Dry season peanuts thus face considerable problems with virus diseases. Peanut has been selected as one of the food legumes to be grown in the cropping cycle with rice. It is likely that the area of dry season peanuts will increase greatly in the near future, and so too will virus diseases. Little research has been conducted on effective control measures for these diseases. Some peanut lines with low stripe incidence have been selected (Wongkaew et al., unpubl.). Peanut stripe virus can be transmitted through seeds at a high percentage (Demski et al. 1984), and thus has the potential for large scale epidemics. It is possible that by selecting for lines that have low percentages of infected seed, such potential epidemics can be reduced or eliminated.

The research being conducted on virus diseases of peanuts in Thailand is much less than that required to devise effective control measures against them. The ecology and epidemiology of the different viruses under the Thai cropping systems need to be understood in order to devise effective control strategies, including appropriate disease screening techniques.

SEED AND SOIL-BORNE DISEASES

Aspergillus seedling blight or crown rot is the most serious disease affecting peanut seedlings. Losses of up to 50% have been reported. Losses are particularly high when seeds are predisposed to infection by environmental stresses such as high soil temperature, poor storage handling or insect damage. Losses ranging from 10–20% are observed in most farmers' fields. The incidence is higher in both pre- and post-rice crops than in the wet season crop. Dressing seeds with fungicides such as Captan, Captafol and Thiram controls the disease (Kitisin et al. 1979). However, fungicides are only applied by a few farmers. The benefits of seed dressing to control seedling blight should be made more widely known, since the cost of the fungicide to the farmers would be returned in increased yields.

Sclerotium collar rot is seasonal and location-specific. The disease is prevalent only in the wet season and in areas where benomyl fungicide has been applied regularly. This is an example of a dilemma arising from use of certain fungicides. The benomyl reduces the defoliation caused by leaf spot diseases, and as a consequence, makes the canopy denser, resulting in the increased relative humidity around the plant. This combines with the selective suppressive effect of the fungicide on microflora other than *Sclerotium rolfsii*, and results in increased damage from *Sclerotium* collar rot. Since fungicide spray is still indispensable for the control of foliar diseases, its application should be carefully planned to avoid this effect. This requires more research on the interaction of foliar fungicidal sprays and soil-borne fungi.

AFLATOXINS

Contamination of peanut with aflatoxins is an extremely serious problem in Thailand. The ubiquitous *Aspergillus flavus* which produces these toxic and carcinogenic substances can invade peanut seeds at any stage, even before harvest if the seeds are wet. Concentrations of the toxins in samples collected in Thailand range from less than 1 ppb to higher than 18 000 ppb, depending on peanut grade, storage time, storage condition and sampling location (Nutalai 1984). Various recommendations have been given to farmers and traders on how to handle and store the crop to minimise the toxin contamination. These recommendations are rarely adopted. The national peanut program is investigating the possibilities of genetic resistance to *A. flavus*. The aim is to develop cultivars with pods or seeds which *A. flavus* cannot invade, or which, if invaded, do not support aflatoxin production. So far only lines with dry seed resistance have been selected (Waranyuwat and Bhumibhamon, unpubl.). It is unlikely that these lines are also resistant to pod or seed invasion. Since in Thailand and in many other tropical countries it is difficult to ensure that farmers and traders adopt proper handling and storing methods, the dry seed resistance will be of little use. More attention should be directed into finding genotypes that are resistant to pod or seed invasion or those that do not support aflatoxin production.

SOYBEAN DISEASES

Research on soybean diseases in Thailand has been conducted in a systematic fashion since 1973. Approximately 20 diseases have been recorded on soybean in Thailand. A list of major diseases, their causal agents, and estimated losses is given in Table 2. The most important diseases are rust, anthracnose, bacterial pustule, downy mildew, charcoal rot, soybean mosaic and seed rot.

FOLIAR DISEASES

Foliar diseases such as rust and anthracnose are more prevalent in the wet season. Downy mildew is more prevalent in the cool, dry season in post-rice crops. Rust is considered to be the most widespread and damaging disease of soybean (Sangawongse 1973). Research has been conducted on chemical

TABLE 2. Major diseases of soybeans in Thailand.

Diseases	Causal pathogens	Estimated loss	References
Rust	*Phakospora pachyrhizi*	28–60%	Nantapan and Surin 1978
Downy mildew	*Peronospora manchurica*	8–15%	Poolpolkul et al. 1977
Bacterial pustule	*Xanthomonas campestris* pv. *phaseoli* var. *sojense*	35%	Prateungwongsa et al. 1980
Soybean mosaic	Soybean mosaic virus	52%	Prateungwongsa et al. 1980
Anthracnose	*Colletotrichum dematium* var. *truncata*	reduce seedling stand 30–100%	Achawasmith et al. 1979

control of rust (Sangawongse et al. 1973; Pupipat 1980), integrated control (Sangawongse 1973) and screening for resistant cultivars. Chemical control has been the most successful to date. Dithiocarbamates and Bayleton are the recommended fungicides. The presence of many races of *Phakospora pachyrhizi* makes it difficult to obtain cultivars that are sufficiently resistant to be released as a standard cultivar at present. Breeding for resistance to anthracnose and bacterial pustule has been more successful and sources of resistance have been identified for both diseases (Achawasmith et al. 1980, 1982).

VIRUS DISEASES

There are four viruses reported to affect soybean under field conditions in Thailand. All have been partially characterised (Thongmeearkom et al. 1982; Iwaki et al. 1982; Iwaki et al. 1983). Yield losses have been estimated for soybean mosaic virus (SMV) (Thongmeearkom et al. 1981). Attempts have been made to screen for resistance to soybean mosaic virus but the results have been largely inconsistent (Nantapan and Surin 1982). Lines with some resistance on soybean mosaic virus under both field and greenhouse conditions have been identified (Surin, pers. comm.).

CONCLUSION

Although many diseases of food legumes can be controlled effectively by chemicals, their application requires information and money, both of which are lacking for farmers in many tropical countries, including Thailand. The economics of control methods have not been well studied at the practical or farm level.

Better disease control in food legumes in Thailand requires: (1) improved financial incentives and extension advice to encourage the wider use of fungicides on food legumes; (2) the development of varieties resistant to the major diseases; (3) the safe introduction of a range of germplasm for evaluation.

The preferable option for control is to provide farmers with disease-resistant cultivars. In order to achieve this, rapid and reliable screening methods, which take account of pathogen variation, need to be developed. Pathologists and plant breeders will need to collaborate effectively if a successful breeding and selection program is to be accomplished.

Virus Diseases of Food Legumes in Asia

The important legume virus diseases occurring in each of the major crop species are listed in Tables 3–7, together with information on their known distribution, which is, of course, likely to be an underestimate of the real situation. Witches' broom is also listed, although it is not caused by a virus but by a mycoplasma-like organism. For those viruses for which a particular character has not been determined, a question mark has been inserted in the appropriate column of the table.

Important Viruses of Asian Legumes

Most of the 900 or so named plant viruses fall into one of about 35 'groups', and the 120 or so known viruses of legumes provide a representative selection of those groups.

Potyviruses comprise at least a quarter of the known plant viruses and also of Asian legume viruses. Viruses of this group have flexuous, filamentous particles, and cause characteristic 'pinwheel' inclusions to form in infected cells. Potyviruses cause mosaic symptoms in a wide range of plant species, and many give local lesions when mechanically inoculated to *Chenopodium* species. In nature all are aphid transmitted in the nonpersistent manner by probing aphids of many species, hence they are usually spread over short distances, often into the edges of crops. The spread of potyviruses is usually unaffected by insecticides, because they are transmitted, usually by migratory flights of mixed aphids, before insecticides can kill or deter them from probing. Individual potyviruses usually have host ranges restricted to a few plant families. Those with a very restricted natural host range such as bean common mosaic virus, found in only a handful of species, are efficiently seed-borne. Potyviruses cross-protect against one another poorly, and they often co-infect individual plants; mixtures are common.

TABLE 3. Distribution and transmission characteristics of important virus diseases of peanut (*Arachis hypogaea*) in Asia.

	Disease[a]	Distribution in Asia[b]	Causal virus	Seed transmission	Vector[c]
1.	Bud necrosis	India, Thailand, People's Republic of China, Indonesia, Japan	Tomato spotted wilt virus	None	Thrips (*Frankliniella schultzei*)
2.	Peanut mottle	Thailand, Indonesia, People's Republic of China, Malaysia, Philippines, India	Peanut mottle virus	Yes (0.1–4%)	Aphids (*Aphis craccivora, A. glycines, A. gossypii, Myzus persicae*)
3.	Peanut stripe	People's Republic of China, Philippines, Thailand, Malaysia, Indonesia	Peanut stripe virus	Yes (4%–38%)	Aphids (*A. craccivora, M. persicae*)
4.	Peanut clump	India	Peanut clump virus	Yes (up to 10%)	Fungus (*Polymyxa graminis*)
5.	Peanut leaf-roll and peanut crinkle	Philippines, Thailand, India, Malaysia	Cowpea mild mottle virus	None	Whitefly (*Bemisia tabaci*)
6.	Peanut mosaic	Indonesia	(?)	(?)	Leaf hopper (*Orosius argentatus*)
7.	Peanut yellow spot	Thailand, India	Peanut yellow spot virus	None	Thrips (*Scirtothrips dorsalis*)
8.	Peanut crinkle leaf	Indonesia	(?)	(?)	Leaf hoppers (?)
9.	Peanut[d] witches' broom	People's Republic of China, Taiwan, Indonesia, Thailand	Mycoplasma-like organisms	(?)	Leaf hoppers (*Orosius* sp.)

[a] In order of economic importance.
[b] Information lacking from many countries.
[c] Likely to vary, at the species level, from one country to another.
[d] Not a virus disease.

TABLE 4. Distribution and transmission characteristics of important virus diseases of pigeonpea (*Cajanus cajan*) in Asia.

	Disease[a]	Distribution in Asia[b]	Causal virus	Seed transmission	Vector[c]
1.	Sterility mosaic	India, Burma, Sri Lanka, Thailand, Bangladesh	Sterility mosaic virus (Rod-shaped?)	None	Mites (*Aceria cajani*)
2.	Yellow mosaic	India	Mungbean yellow mosaic virus	None	Whitefly (*Bemisia tabaci*)

[a] In order of economic importance.
[b] Information lacking from many countries.
[c] Likely to vary, at the species level, from one country to another.

All potyvirus diseases can be reduced by measures that deter migratory aphids from probing, such as cover crops. They are also controlled by timing crop planting to avoid aphid flights, and by the use of resistant cultivars. Seed-borne potyviruses may be controlled by use of virus-free seed.

The important potyviruses of Asian legumes include (in alphabetical order):

1. *blackeye cowpea mosaic virus*, which has been isolated from asparagus or longbean (*Vigna sesquipedalis*).

2. *bean common mosaic virus*, which has been isolated from mungbean in Thailand, though it is better known as a worldwide seed-borne virus of certain cultivars of French bean;

3. *bean yellow mosaic virus*, a worldwide and common virus of many species including French beans, peas, freesias and gladioli;

4. *cowpea (aphid-borne) mosaic virus*, which is seed-borne in cowpea throughout the world, is closely related, if not identical, to blackeye cowpea mosaic virus, and is closely related though distinct from peanut stripe virus;

5. *peanut mild mottle virus*, which is found in peanuts and soybeans in China;

6. *peanut mottle virus* (synonyms: peanut mild mosaic and severe mosaic), a worldwide common virus of several legume species including peanuts and soybeans;

7. *peanut stripe virus*, which seems to be confined to Southeast Asia, where it often occurs with peanut mottle virus, but from which it cannot be distinguished unequivocally by field symptoms alone;

8. *soybean mosaic virus*, a worldwide seed-borne virus specific to soybean.

TABLE 5. Distribution and transmission characteristics of important virus diseases of soybean (*Glycine max*) in Asia.

Disease[a]	Distribution in Asia[b]	Causal virus	Seed transmission	Vector[c]
1. Soybean mosaic	Japan, Thailand, Indonesia, Nepal, Malaysia, India (?)	Soybean mosaic virus	Yes (up to 52%)	Aphids (*Aphis craccivora, A. glycines*)
2. Soybean stunt	Indonesia, Japan	Cucumber mosaic virus	Yes (up to 100%)	Aphids (*A. craccivora, A. glycines*)
3. Soybean dwarf	Japan, Indonesia	Subterranean clover red leaf virus	None	Aphids (*A. glycines, Cyrthosiphon solani*)
4. Soybean chlorotic mottle	Indonesia, Malaysia, Japan	Bean yellow mosaic virus	(?)	Aphids (*A. craccivora, A. glycines*)
5. Yellow mosaic	Nepal, Indonesia, Malaysia, India	Mungbean yellow mosaic virus	None	Whitefly (*Bemisia tabaci*)
6. Bud blight	Nepal	Tobacco ring spot virus	Yes	Nematodes (*Xiphinema* spp.)
7. (?)	Indonesia, Malaysia, India	Cowpea mild mottle virus	Yes	Whitefly (*B. tabaci*)
8. (?)	Indonesia	Peanut mottle virus	None	Aphids (*A. craccivora, A. glycines*)
9. Crinkle leaf	Thailand	Soybean crinkle leaf virus	None	Whitefly (*B. tabaci*)
10. Soybean yellow vein	Thailand	Soybean yellow vein virus (500–500 × 15–20)	(?)	(?)

[a] In order of economic importance.
[b] Information lacking from many countries.
[c] Likely to vary, at the species level, from one country to another.

TABLE 6. Distribution and transmission characteristics of important virus diseases of mungbean, cowpea and longbean in Asia.

S. No.	Disease[a]	Distribution in Asia[b]	Causal virus	Seed transmission	Vector[c]
	Mungbean (Vigna radiata)				
1.	Yellow mosaic	India, Thailand	Mungbean yellow mosaic virus	None	Whitefly (*B. tabaci*)
2.	Leaf curl	India	Tomato spotted wilt	(?)	Thrips (*F. schultzei*)
3.	Black gram mottle	Indonesia, Thailand, India	(?)	Yes (1.2%)	*Pagria signata*
4.	Mungbean mosaic	Indonesia, Malaysia	Potyvirus (?)	Yes	Aphids (*A. craccivora, A. glycines*)
5.	(?)	Indonesia	Bean yellow mosaic virus	(?)	Aphids
6.	Phyllody	Malaysia	(?)	(?)	(?)
7.	Yellow mottle	Malaysia	(?)	(?)	(?)
8.	(?)	Thailand	Bean common mosaic virus	Yes (up to 7.2%)	Aphids (*A. craccivora, M. persicae*)
9.	Leaf crinkle	India	(?)	Yes (up to 19%)	Beetles, Aphids, Whiteflies
	Cowpea (Vigna unguiculata)				
1.	Cowpea aphid-borne mosaic	Indonesia, Japan	Cowpea aphid-borne mosaic virus	None	Aphids (*A. craccivora*)
2.	Cowpea stunt virus	Indonesia	(?)	(?)	Aphids (*A. craccivora*)
3.	Cowpea mosaic	India	(?)	None	Aphids (*A. craccivora, A. gossypii, M. persicae*)
4.	Yellow mosaic	Indonesia	(?)	(?)	(?)
5.	Vein-banding mosaic	India	Cowpea vein-banding mosaic virus (25–30 nm?)	(?)	Aphids
	Asparagus or Longbean (Vigna sesquipedalis)				
1.	Longbean	Thailand, Malaysia	(?)	Yes (up to 50%)	(?)
2.	(?)	Thailand, Malaysia	Black eye cowpea mosaic virus	Yes	Aphids (*A. craccivora*)
3.	Bunchy stunt	Thailand	(?)	(?)	(*A. craccivora*)

[a] In order of economic importance.
[b] Information lacking from many countries.
[c] Likely to vary at the species level, from one country to another.

Cucumoviruses are perhaps the next largest group of Asian legume viruses. Their taxonomy has not been fully resolved and is complicated by a genome that is divided into three parts, and hence pseudorecombinants probably occur between. For example, genes controlling host range and those encoding the coat protein (the antigenic determinant) may be recombined. Cucumoviruses, like potyviruses, are aphid-borne nonpersistently and are frequently seed-borne. Thus they may be reduced by the same measures as used for potyviruses.

There are three basic types of cucumoviruses; cucumber mosaic virus, tomato aspermy virus and peanut stunt virus. A strain of cucumber mosaic virus (strain CA) has been isolated from peanuts in China, but most of the other cucumoviruses from legumes may be strains of peanut stunt virus. They include soybean stunt, cowpea vein-banding mosaic, cowpea ringspot, Robinia mosaic, and black locust true mosaic viruses.

Luteoviruses have one known representative in Asian legume crops, soybean dwarf virus (synonym: subterranean clover redleaf virus). However, considering the insidiously mild symptoms produced by luteoviruses, and the difficulty in isolating and identifying them, it is probable that many more will be found to be of major importance. The particles of luteoviruses are confined to the phloem cells of plants, and occur in extremely small concentrations

TABLE 7. Yield loss estimates and management practices for economically important virus diseases of food legumes in Asia.

Disease	Yield loss estimates	Management practices
Peanut		
Bud necrosis	Up to 90% (over $80 million in India)	Adjustment of planting dates Close spacing Intercropping with quick growing cereals Growing field resistant cultivars If feasible, elimination of weed hosts acting as virus reservoirs during the off-season
Peanut mottle	Up to 50%	Growing tolerant cultivars Growing non-seed transmission genotypes Planting of virus-free seed
Peanut stripe	Up to 23%	Growing tolerant cultivars Planting of virus-free seed
Peanut clump	Up to 90%	Treatment with soil biocides Soil solorisation, if feasible
Pigeonpea		
Sterility mosaic	(Over $70 million in India)	Growing resistant cultivars
Soybean		
Soybean mosaic	Up to 50% in Thailand	Growing resistant cultivars Planting of virus-free seed
Soybean dwarf	Not available	Growing resistant cultivars
Bean yellow mosaic virus in soybean	Not available	Growing resistant cultivars
Soybean stunt	Not available	Growing resistant cultivars
Mungbean		
Yellow mosaic	Up to 100% in India	Growing resistant cultivars Judicious use of insecticides for whitefly control
Leaf curl	Up to 100% in India	Growing field resistant cultivars
Leaf crinkle	Up to 60% in India	Growing field resistant cultivars
Cowpea		
Cowpea aphid-borne mosaic	Not available	Growing resistant cultivars
Cowpea mosaic	Not available	Growing resistant cultivars
Longbean		
Bunchy stunt	8%–10% in Thailand	Not available

making their serological testing difficult. They are transmitted by aphids in a persistent manner, hence long feeding times are required, both to acquire them and transmit them, and as a consequence they may be reduced by insecticide treatment of crops. They are not seed-borne, nor are they transmitted by sap inoculation, like potyviruses and cucumoviruses, and hence their isolation and identification involve aphid transmission tests.

Tomato Spotted Wilt Virus Group (Tospoviruses) until recently were thought to be a 'mono-specific' group represented worldwide in a great range of crop and wild species by tomato spotted wilt virus. However tests indicate that peanut yellow spot virus, a damaging virus of Thai peanut crops, is a distinct legume-infecting tospovirus. Because of the long incubation period of this thrip-transmitted virus it is possible to control spread *within* a crop by insecticides. However, tomato spotted wilt virus has a very large host range, and the slow-flying vector usually carries in the virus from infected weeds nearby. The virus is best acquired by larval thrips, but they do not become infective until adult, implying virus replication in the vector. Tospoviruses are not seed-borne, but are transmitted by mechanical inoculation. The large, pleomorphic lipid-containing particles of tospoviruses resemble those of the bunyaviruses of animals, and rapidly lose their infectivity in sap; indeed, purification of tospovirus particles for antiserum production is very difficult.

Geminiviruses are another group of plant viruses transmitted by insects; some by whiteflies others by leafhoppers. All are carried in a persistent manner and have a narrow host range, thus making it possible to predict the source of virus-carrying vectors, though as both vector types are strong fliers this may be distant. Few geminiviruses are mechanically transmitted, and, because of their small concentration in plants they are not easy to isolate and characterise. Most geminiviruses cause either leaf curling and crumpling, or very bright yellow mosaics. Soybean crinkle leaf virus, found in Thailand, is a geminivirus, and it is likely that mungbean yellow mosaic virus is also one.

Other single viruses whose taxonomic affiliations are known have been isolated from Asian legumes. For example the furovirus, peanut (Indian) clump virus, is found in particular areas of India. Furoviruses are transmitted through the soil by the zoospores of plasmodiophoraceous fungi, *Polymyxa* species, and so are confined to areas where the vector occurs. Some, including peanut clump, are also seed-borne, and they have a host range covering several families, like most soil-borne viruses. Indian isolates of peanut clump virus are serologically quite distinct from those of the 'type' isolate found in West Africa. This virus virtually destroys infected crops, and constitutes a serious threat to other peanut growing areas with similar soil types. The use of resistant varieties is probably the most effective way to control this virus. The related wheat (soil-borne) mosaic virus in North America has been controlled by resistance, but a similar virus of potatoes is controlled by adding sulfur to the soil.

Another single representative is tobacco ringspot nepovirus, which was isolated from soybeans with bud blight symptoms in Nepal. It probably entered the region in infected seed, and has been maintained by seed and pollen transmission despite the likely absence of its nematode vector. The sole representative of the caulimovirus group reported from legumes in Asia was peanut chlorotic streak found in India. Finally there is pigeonpea proliferation virus, a leafhopper-borne rhabdovirus, reported from Taiwan and Papua New Guinea.

Other Viruses

There are, in addition, many viruses of unknown affiliations. Cowpea mild mottle virus (synonyms: peanut leaf roll virus, peanut crinkle virus; soybean bud blight), a widespread seed-borne virus, is transmitted by whiteflies in a semipersistent manner. Its particles are similar to those of the aphid-borne carlaviruses, but no serological relationships have been found between them. There are also viruses such as groundnut chlorotic spot virus, reported from India, with similarities to peanut yellow spot tospovirus, and mung and urd bean mosaic viruses 1 and 2 which are insufficiently described to predict their affiliations.

Finally we should list some of the better known or more important viruses recorded from the same range of crops in other parts of the world, but not yet isolated from Asia. This list gives an indirect indication of the size of the task confronting quarantine authorities.

Cowpea chlorotic mottle bromovirus
Cowpea green veinbanding potyvirus
Cowpea mosaic comovirus
Cowpea severe mosaic comovirus
Groundnut crinkle carlavirus
Groundnut eyespot potyvirus
Groundnut rosette virus
Groundnut rosette assistor luteovirus
Peanut green mosaic potyvirus
Peanut yellow mottle virus
Soybean mild mosaic cucumo(?) virus

Management Prospects

Before measures can be devised to control the virus diseases of food legumes in Asia, it is necessary to develop the capacity to diagnose accurately the different viruses causing these diseases, and to identify vectors responsible for spreading them in the field. The identification or characterisation of a virus is the single most important step in its control. If it is found that a novel disease is caused by a previously described virus, then most of the previously obtained information of that virus can be safely extrapolated to its new situation, and used in devising control measures. Furthermore, if it is found that a novel disease is caused by a 'new' virus, then its characterisation is important because it is likely that it will be found to fall into one or another of 35+ known virus groups, and then many of the properties of the 'new' virus may be safely predicted from the properties of the previously described members of the group. Experience has shown that the properties shared by most members of each group include ecologically important characters such as the vector type and virus/vector relationship, which it is important to know in order to be able to design an integrated disease management system for each virus. The major groupings into which the known legume viruses of Asia fall are described below, emphasising the properties shared by members of each group.

Several viruses causing economically important diseases are yet to be fully characterised, and their interrelationships with similar viruses occurring in other countries remain to be determined. By establishing in each country well equipped virus research units and providing specialised training in virus characterisation and diagnosis, it should be possible to develop simple and effective methods for virus detection. However, if necessary funds and resources for establishing such virus research units are not available, it should be possible through international cooperation to characterise economically important viruses, utilising facilities available in developed countries.

Antisera and sets of diagnostic hosts are essential for the diagnosis of virus diseases. Unfortunately, virus-free and authentic diagnostic hosts and antisera are not readily available to virologists in many Asian countries, nor are the links with virologists in well-equipped laboratories always strong. Thus we believe it is essential to establish one or two centres in the region to make good this deficiency. Several international organisations including ACIAR, JICA, ICRISAT, IDRC, ADB etc., hopefully could provide the necessary support for establishing banks for sera and diagnostic hosts.

Virus Control

Various methods are available for controlling viruses. Most are inexpensive, but they require unequivocal knowledge of the ecology of the virus being controlled, plus education of and action by the farmers.

One of the least expensive methods of virus control is a change in agronomic practices. For example a change in the crop planting date may ensure that the most susceptible growth stage of the plant, usually the seedling stage, avoids the time when virus-carrying vectors are most active. Another inexpensive measure that can greatly diminish the incidence of viruses is the use of cover crops, or the intercropping of different crop species. Such altered cultural practices could have the greatest immediate impact if applied widely, but in the long term the use of resistant varieties is preferable for it requires no expertise or action by the farmer or extension worker.

Breeding resistant varieties involves the identification of disease hotspots, access to germplasm collections, development of techniques for inducing disease under laboratory and field conditions for evaluating disease resistance. Resistance to a virus should be combined, where possible, with resistance to its vector, especially for semipersistent, circulative and persistent or propagative viruses. Although sources of resistance genes have been identified for several legume viruses, little has been done so far to use this material to develop virus resistant cultivars.

The exchange of germplasm, especially of legumes, may be dangerous and requires the full cooperation of a competent virologist, as legumes are known to harbour several viruses in seed. Rigorous plant quarantine procedures are essential, both in the country of origin and in the importing country. International agricultural research centres have large germplasm collections of groundnut, pigeonpea, chickpea, French bean, faba bean and cowpea. It is essential for virologists and breeders in developing countries to cooperate with the international centres and agencies if reliable data on the identification of causal viruses, assessment of yield losses, identification of sources of resistance and the integrated disease management systems are to be effectively devised.

Food Legume Improvement in Relation to Diseases

Agriculture is an economic endeavour. People raise crops for food for home consumption but in general, most effort is targeted at making money. Many crop scientists conduct their research to learn new information in order to produce publications. These disparate objectives should not be forgotten in discussing the reality of diseases in food legumes in Asia and what can be done about their depredations.

An attempt to influence productivity by reducing disease effects must be done holistically, bearing in mind the reality of existing agriculture, and of attempts to change agriculture in the specific area, location and even microlocation of valley or field where the interaction of crop and its environment, including its pathogens, actually takes place.

It should be obvious, but it is little recognised, that this interaction is dependent upon the genetic nature of the crop, the environmental conditions which influence any host/pathogen relationship, and the presence of co-evolved or new-encounter pathogens (Buddenhagen 1977). The key to all these interactions is an appreciation of the evolution of the existing system.

A different approach to research is needed if it is to influence an existing agroecosystem, which is essentially stable but which has certain disease depredations, as compared with one where attempts are being made to increase productivity per se or where the attempts are basically to introduce a new crop or major modification of the existing cropping system. In Asia, both situations prevail. Diseases of food legumes should be viewed accordingly.

Perusal of the literature on legume diseases in Asia, or elsewhere in the tropics, reveals that the major emphasis is on publications revealing new records, disease losses (in controlled experiments), epidemiology, resistance and control. The control articles have the reader uncertain as to whether a disease is really controlled, controllable under certain conditions beyond the means of the farmers, or whether the article really discusses, instead, attempts at control. The gap between what one reads and what really happens in the farmer's fields at the crop/pathogen level remains obscure.

Thus, one is confronted with great ignorance in trying to make realistic suggestions that might influence future disease depredations on food legumes in tropical Asia.

Disease Losses

It is important for plant pathologists to have high losses due to diseases, and likewise for entomologists. Research is conducted accordingly, measured losses in field plots are high, often, probably artifically high when compared with the reality in farmers' fields. Sometimes one may add up all the losses, and they exceed the crop's yield potential.

Thus, past research on yield loss should be viewed with caution, and new research in this area should be conducted with care and with insight into crop growth, compensation growth, and the potential error between plots and farmers fields. Care should be taken to distinguish between losses following inoculation and losses under natural conditions with natural inoculum.

Two approaches are usually used to calculate losses. One is to inoculate and compare with noninoculated plots or plants. The other is to spray some plots to protect them, leaving others unsprayed. Sometimes the two approaches are combined. The timing of the inoculation in relation to the growth cycle will greatly affect the amount of loss. With diseases affecting individual plants, such as virus diseases, losses may be measured by comparing diseased and healthy plants. Again, the timing of infection may alter loss from 0–100%. Moreover, one cannot multiply individual plant loss times incidence and come out with a realistic figure, since healthy plants adjacent to diseased ones will result in compensation, wherein the healthy plants will grow into the sick plants' space. There have been cases of virus incidence of 30%, where infected plants have no yield, but where there is *no yield loss* on an area basis. This occurred in chickpeas with early infection and good stands, where adjacent healthy plants completely filled the field space. Entomologists who work on crop pests are generally more familiar with this concept of compensation than are plant pathologists.

Errors occur in other ways. The 'control', sprayed to prevent a fungal or bacterial disease, may be incompletely controlled and some level of disease is taken as the zero comparison. Measuring disease in the control plots and adjusting in some way to zero disease does not work since one does not know the relationship between amount of disease and actual yield loss. In fact, that relationship changes with amount of disease, from high to low, as severity decreases. In indeterminate crops it is surprising how much disease can occur with essentially no yield loss.

Protectant sprays may alter normal yield by increasing or depressing crop growth separately from their protectant affect. This happens with Furadan, used as a means of preventing insect pest attack. It stimulates growth per se, giving an unrealistic high loss to the unsprayed plots. The opposite may occur, or further, a protectant spray may allow the increase of a non-target disease, or it may decrease all diseases, giving an unrealistic high loss for the target pathogen.

The best way to obtain realistic yield loss figures is to have essentially isogenic lines, one of which has resistance genes, and measure their comparative yields in farmers' fields under normal growing conditions. Since such isogenic lines seldom exist (because plant breeders do not make them) this ideal method seldom can be used.

Barring this, the best recourse is to measure yield in farmers' fields wherein, for fungal or bacterial or nematode pathogens, parts of the field are protected chemically with fairly specific chemicals. For virus diseases, it is almost impossible since it is difficult to protect plants from infection, at least for stylet-borne viruses. One can, however, make an attempt with properly chosen insecticides, applied often, to prevent virus transmission and thereby have virus-free plots, or sections of fields, for yield comparisons.

Often, plant breeders or agronomists concerned with a crop will have a better idea of what is the real importance of certain diseases than the plant pathologist, since they are concerned with production and overall field performance, rather than only with the disease. Their judgment is probably less biased than that of pathologists. They must consider performance as a whole and then probably better understand all the nuances of crop management which also affect yield, as well as all the other stresses. In one estimate for crops in the USA it was estimated that losses due to physical environmental factors were 66%, compared with only 9% for all diseases and insect pests. Although one may question this estimate, since it was based on average yields vs. record high yields, it does emphasise that crop yield potential is hardly approached, due to factors other than disease. The pathologist tries to compare yield depression due to disease with actual yield without disease. He seldom thinks of actual yield in relation to potential yield.

As a final caveat it should be mentioned that plant pathologists have a vested interest in showing that diseases cause high yield losses. Research support to plant pathologists is based on two assumptions: (1) that diseases do cause considerable losses, and (2) that research on plant diseases will reduce such losses. But do they, and will it?

Certainly some diseases do cause important losses. These vary in importance from place to place and time to time, depending on many different, complex and interacting factors. Also, some research on plant diseases may reduce disease losses, but probably less so for third-world agriculture than most people think. Research that leads to improvements in breeding strategy and methods and thereby leads to new varieties, which will have a negative influence on important pathogens, is a most promising investment. This will be elaborated in a later section of this paper.

Evolution, Co-evolution and Geographical Dispersion

The present stage in farmers' fields, wherein the interplay of crop and pathogen takes place, has a long history, rooted first in natural evolution of microorganism/virus with evolution of the ancestors of our crop species. This evolution proceeded differently in different continents, and regions within continents. Not only do the crops have centres of origin, but their pathogens have as well, and the pathosystems that result are often quite different. Crop diseases may be analysed with profit in terms of whether they are co-evolved with the crop, not co-evolved, new encounter or re-encounter diseases (Buddenhagen 1977). Often, important diseases have an ancient evolution with the crop or its close relatives, but alternatively they may result from disequilibrium, wherein the crop has evolved in the absence of the pathogen which now attacks it so severely. Such a pathogen, however, usually evolved on a related species or genus and thus it is 'ready' for the new-encounter, as man moves his crop into new areas. Epidemics may result. Another form of disequilibrium is created when man isolates his crop genetically from its pathogens (by introducing genes for resistance), and the pathogens re-encounter their hosts later through mutation and selection. Epidemics result.

With the exception of mungbeans (and pigeonpeas in eastern India), the food legumes that are the subject of these proceedings are not indigenous to tropical Asia. Thus, their diseases in tropical Asia were either introduced with them, or were pathogens already in tropical Asia which have opportunistically colonised them after introduction.

Peanuts, South American in origin, are the most distant introduction geographically and genetically. Although cowpeas are African, other *Vigna* species are Asian, and one would expect many of their pathogens would be lying in wait for their exotic African cousin. Soybean also, although originating in northeast China, has *Glycine* relatives in tropical Asia, Australia, the Pacific, and even in Africa. In fact, it is believed that a major disease (*Pyrenochaeta*) of soybeans in eastern Africa came to soybean from an indigenous pasture legume earlier named *Glycine wichitii*, but now considered sufficiently different to be placed in a separate genus, *Neonotonia* (Allen 1983). This *Pyrenochaeta* pathogen obviously detects the close relationship.

Many legume viruses are ancient enough, and they evolved in such a way that they retain a host recognition across several legume species and even genera. Others, however, are much more specific. In most cases the bacterial pathogens are specific for their crop hosts and related wild species.

Many fungal pathogens of food legumes are somewhat omnivorous but probably the serious pathogens are crop (and related species) specific. Rusts are particularly interesting in that some appear to have remained confined to the host of their origin, such as *Puccinia arachidis* on peanuts, spreading worldwide from the centre of origin in recent years as commerce and plant breeders moved seed. Others are specific but have not yet reached the crop in all its locations, such as *Uredo cajani* of pigeonpeas. Others such as *Uromyces appendiculatus* and *Phakospora pachyrhizi* are quite food-legume omnivorous, attaching to many of the food legumes, indicating an ancient evolution. Although the latter species may be tribe or more broadly specific, formae specialis may exist as in the small cereal rusts, but studies are insufficient to know. *P. pachyrhizi* on cowpeas in West Africa apparently cannot attack soybeans (Allen 1983).

Much remains to be learned about the identity, spread and evolution of many of the legume pathogens. The importance of all this to agriculture in Asia lies in two aspects: (1) knowing what effort should be put to restricting spread to presently uninfected regions; (2) knowing what we are really breeding against (or for) in our breeding programs.

Ecosystem Focus and Agricultural Change

Diseases of crops have different potential, depending on the ecosystem they are in. In dry climates only insect-vectored pathogens (usually viruses) and soil-borne pathogens are sufficiently favoured to be damaging. In the lowland humid tropics many pathogens are favoured epidemiologically, with rainsplash dispersal, and leaf surfaces sufficiently wet to enable abundant penetration. Off-season pathogen survival also differs in different places, due to climatic factors acting directly on an inoculum reservoir as well as indirectly by influencing presence of alternate or alternative hosts.

Weak or opportunistic pathogens do little damage in locations where a crop is highly adapted. In such locations the diseases of importance are those which evolved with the crop and its close relatives, and which are caused by highly specialised pathogens. Common beans, for instance, when they are grown in the lowland wet tropics, are attacked by many more pathogens than when grown at cooler and drier locations at higher altitudes, similar to those where they evolved.

Agriculture in Asia is changing as economic factors and research efforts provide new opportunities to farmers and others. Food-legume production has already changed over traditional times and it can be expected to change further. If economic opportunity, seed availability and extension activities all exist, any given crop can be expected to expand in area or intensity. Any such expansion in space or time will provide new opportunity for epidemics. Thus, the importance of plant diseases also will change. They will become more important with cropping intensity and with efforts to increase production. With fertiliser inputs, insecticide sprays and larger surface areas of crop, pathogens will be favoured. Pathogen damage will not only increase, but a given amount of damage will be more costly in reducing profits on a more highly managed crop.

Thus, any intervention at reducing disease losses must be considered both in the light of the existing agroecosystem of local concern, and also of that system in a state of change. The degree of change anticipated must be judged subjectively, and it will differ in different regions, countries, and individual areas of countries.

Possible Interventions

What can researchers or extension people do to actually influence disease losses? The first requisite is to attempt to put oneself in the farmer's position and thus to appreciate the difficulties he faces in relation to taking any new action in relation to his crop. This is not as easy as it may seem because researchers and extension people are not farmers, nor do they work in the fields. They do not think very much in terms of economic returns for effort, nor of risk in relation to borrowing money for a presumed but ephemeral payoff.

CULTURAL PRACTICE

This is the time-honoured means by which farmers attempt to maintain their production. In each place, farmers have learned to plant and harvest at certain times, to rotate crops in certain ways, etc. A component of their existing practices (often a large component) results in reducing disease and pest depredations to manageable levels. Often this component is not understood, until interventions to change existing cultural practices are made and disease and pest levels then increase.

There may be cases where improvements can be made in existing cultural practices, based on scientific analysis, that will actually reduce primary inoculum or epidemic rate. Whether or not such changes are practicable at the farmer level and will actually return more than the effort required is a second and very important aspect to consider before attempting to convince people to do things differently. If we include spraying chemicals as part of 'cultural practices' then all the difficulties involved must be considered, and in very practical terms.

This does not discount the fact that interventions to change existing cultural practices should not, sometimes, be attempted. There may be times and places where they actually will be adopted, will work, will be economically profitable, and will become the new 'norm' of cultural practices. However, it is most likely that the opportunities for making positive interventions in cultural practices, actually resulting in farmer use which decreases diseases sufficiently to increase profits over effort, will be rare. Very careful analysis at a very practical level is required to identify such cases.

REDUCTION OF SEED-BORNE INOCULUM

This is an area which we consider to have great promise in reducing losses to food legumes in Asia. This is because so many pathogens of food legumes are seed-borne and thus initial foci for epidemics and maintenance of the pathogens through time are, to a large extent, mediated through a connection with the seed. Seed-borne inoculum is probably the major source of the original introduction of the legume pathogens into Asia, and new pathogens, especially viruses, can be expected to be in the process of introduction as plant breeders and agronomists bring in variety trials from distant places where other diseases occur.

In recent experiments to assess the level of infection of bean common mosaic virus in farmers' landrace bean seed in Uganda, virus frequency ranged from 20 to 70% (Buddenhagen, Owera and Brown, unpubl.). This example, although far from Asia, gives an idea of the means of maintaining over time a common legume virus.

Pathogens may be seed-borne internally, externally, or they may be just 'with' the seed and the debris normally present in bags of seed. These different sites need to be assessed as one attempts to take practical action to reduce seed-borne inoculum. Fungicide and bactericide treatments of seed lots may reduce but may not eradicate all internally borne inoculum. Viruses cannot be so eliminated at present. Cloth bags may recontaminate seed lots where the treated seed is rebagged. Seed grown in some dry areas will carry much less inoculum than seed grown in wetter areas. In the USA, whole seed industries have been established in the dry western states just because seed produced there is free of the bacterial and fungal pathogens that occur as major problems in the wetter production areas. The development of a clean-seed industry, with proper regulation, inspection, treatment, guarantees, etc., is a major contributor to high agricultural productivity in the USA and elsewhere. The question of the actual situation of such activity now in Asia for food legumes and of how analysis, research, extension and regulation should be applied to improve the seed industry for seed health in each country needs to be addressed urgently.

For each major disease one needs to know the degree to which primary inoculum each season comes from the seed source. If abundant inoculum is already in the field, then clean seed will not help. If, however, inoculum is regionally reintroduced on seed and otherwise largely absent, regional efforts at cleaning up seed are merited. In the humid tropics where off-season rainfall is common, many fastidious pathogens, both fungal and bacterial, are often largely eliminated in old fields. Seed may be the major perpetuator of such pathogens. Research is needed to establish which diseases work this way and are thus amenable to control through clean seed.

The rate of epidemic buildup from primary foci to general spread throughout a field needs to be known to have an idea of how effective cleaning up the seed might be. If one contaminated seed in a thousand can rapidly restart an effective epidemic, it should be obvious that a clean seed program which cannot guarantee a lower incidence would be ineffective. Often, analysis of the seed-borne nature of diseases is based on testing 1000 seed, even though one knows that maybe 70 000–200 000 seed are planted per hectare.

Dry areas or dry seasons can be utilised, with furrow irrigation, to develop a clean seed industry. To make a clean seed industry work, however, farmers over large areas need to buy and use clean seed. They have to want clean seed enough to pay for it and it has to be available nearby when they need it. Thus, a complex system of production, transportation, distribution and commerce is required. Agricultural systems should evolve in this direction if they are to become more productive and more competitive. There are many difficulties involved, of which we are well aware. Efforts in each area should be directed at these difficulties, for the eventual benefit of the farmer and the consumer. Lessons from the rice story in Asia are insufficient, since the relative importance of seed-borne inoculum compared with field inoculum is much lower in rice than in food legumes.

Finally, the entrance of the private sector in relation to clean seed production, distribution and promotion should be considered. Government-run seed operations are notoriously inefficient. Incentives for producing high quality seed are low. As technology in an area evolves, the private sector has incentives for doing a better job, as witness the small agricultural machinery businesses in Asia today. Their involvement in a clean-seed industry should be stimulated as well. For food legumes, where margins on non-hybrid seed will be low, one route might be to attempt to interest the companies in Asia newly involved with hybrid maize to also include food legumes.

The discussion on clean seed leads naturally to the use of new varieties, since it is 'new varieties' which provide the major pump for agricultural change. And seed of the new varieties needs to be grown and distributed. Thus, new varieties can be linked with clean seed, and the cycle can be repeated.

NEW VARIETAL DEVELOPMENT AND DISEASE RESISTANCE

It is the authors' contention that the major opportunity to reduce disease depredations in third world agriculture is by developing new varieties with increased resistance. Much has been written on this subject (Allen 1983; Buddenhagen 1977, 1983a–e; Buddenhagen and de Ponti 1983; Christiansen and

Lewis 1982; Johnson 1984; Lamberti et al. 1983; Nelson 1973; Russell 1978; Simmonds 1970; Soto et al. 1982). It appears that much investment in new varietal development results in new varieties that are still attacked by many pathogens and pests. The diseases written about 50 or 20 years ago are still with us as important diseases. Papers published on disease resistance, genes for resistance, genetics of resistance, etc. are abundant, but the diseases seem to pay little attention. Resistance is either ephemeral or insufficient or it is geographically or ecologically circumscribed.

Thus, considerable research opportunity remains for plant pathologists (and entomologists) to become more involved with plant breeders' activities, so that better products will result. This is not an easy task, since the training of plant breeders, pathologists and entomologists differs so much. Unfortunately, isolated training in each discipline is not commensurate with the needs of developmental agriculture nor of the needs in varietal development. Efforts are required to develop team approaches to varietal development, wherein rewards are shared beyond the plant breeder. Plant pathologists need to develop direct involvement with plant breeders in varietal development so that, indeed, they can finally have a major role in reducing disease losses — a goal that should be at the heart of their profession.

Developing new varieties is essentially an endeavour to obtain maximum suitability of a plant genotype for an ecosystem. Any ecosystem contains many microorganisms, viruses and insects ready to interact with a new variety in complex ways. To understand such a system sufficiently to be able to obtain resistance that is both stable and adequate is an enormous task. It needs many disciplines and great teamwork in breeding and selection. It is not enough to leave the task to plant breeders or simply to supply them with inoculum or disease scores. It is not enough to run multilocation yield trials on a few varieties developed far away in other ecosystems where the local pathogens and environments were different.

The best approach is to have local breeding programs where much genetic material is seen in plots representing the pressures of the target farms. Recombining the best materials by crossing should proceed in a recurrent selection methodology for several cycles. Pathogen and pest challenge should be adequate and uniform. Differences in performance would thereby reflect genetic differences, and heritability for resistance performance would be high. If properly carried out with a wide genetic base in the original material, superior varieties should result.

Often, however, most investment is in testing a few varieties which performed well somewhere else, and analysis of the local needs is neglected. Moreover, the great genetic resource of the species is not exposed to the local problems, nor are the best materials recombined genetically. Also, pathogen challenge is either erratic or overwhelming, so that small genetic advantages in resistance cannot be detected. Short-range objectives of producing a new variety quickly overwhelm a slow but steady approach that will result in durable resistance in adapted material. The breeder may know of the presence of resistance in material considered too rustic or low-yielding to be of use. Methods of challenge and judgment of resistance and tolerance remain largely unresearched. Other objectives — especially yield potential — dominate improvement programs. International institutes often dominate approaches in large regions, and exert their influence through getting local scientists to conduct variety trials of various sorts, using protocols developed at headquarters for scoring of characters. Such activities may not be very relevant to the needs of the area or to the opportunities for developing local creative research or actual local breeding programs.

In any case, varieties are compared or developed and they are issued for use. Any lack of sufficient resistance in such varieties reflects either selection of plants or genotypes in plots, known to have insufficient resistance from the start, or it reflects a gap in performance (or perception of performance) on breeders' plots from performance in farmers' fields in relation to disease.

Thus, a major problem is the cryptic error represented in breeders or yield trial plots. Reducing this cryptic error is a major *resolvable* contribution that can be made by a breeder/pathologist team. When it is reduced to nearly zero, new varieties will have sufficient resistance.

To circumscribe a target area for a new variety and to study the crop throughout that area can help greatly in breeding so as to prevent the ascendancy of now minor pathogens as well as suppress the continuance of the now major ones. Picking and using selected trial sites in the target area that have different ecological influences on different pathogens will enable selection of more stable resistance. On-site breeding and selection can contribute greatly toward developing varieties with ecosystem balance to all local stresses and with stable disease resistance.

For the food legumes, a breeding target to reduce seed transmission, especially for viruses, is a very real opportunity, not present for many other crops. If legume viruses could be blocked genetically from being perpetuated in seed, their depredation would be much less. Efforts should be made to select on this basis where immunity is not available.

For viruses and other systemic pathogens, breeding and selecting for tolerance should be attempted (Buddenhagen 1981, 1983a–e; Soto et al. 1982). This is a neglected approach which has great potential to reduce virus epidemics to insignificance, as has been demonstrated for maize streak virus in Africa (Soto et al. 1982). The approach enables the elimination of escapes in selection and the development of materials wherein the effects of minor genes which enhance performance when infected can be seen and selected. The net result for maize was to block strain specificity as well as to block within-field spread. Similar approaches applied to food legumes should eliminate viruses as important pathogens.

The problem of developing horizontal vs vertical resistance has been elaborated in detail elsewhere (Buddenhagen 1983c; Buddenhagen and de Ponti 1983; Johnson 1984; Simmonds 1979). Suffice to say that no evidence indicates that current strategies and methods of approach, targeted at horizontal and durable resistance, are unsound. On the contrary, all evidence indicates that there are ways to obtain resistance that works across considerable pathogen diversity and across time.

Much remains to be done as science and technology attempt to improve food legume production in Asia. Emphasis on creative research and on teamwork in varietal improvement for stress, disease and insect resistance will be the key to progress.

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Genetic Limits to Improvement of Food Legumes

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AGRICULTURAL producers are concerned with the production of particular species over time and space. As a result, a central objective of agricultural scientists is the improvement of the productivity of a particular species in specific environments and of its adaptation to a range of production environments. This may involve genetic or environmental modification, or both, designed to alleviate limits to productivity or adaptation. Genetic improvement involves a modification of the genotype to produce a more appropriate phenotypic expression in particular environments. Agricultural production inevitably involves modification of the environment to relieve a particular stress or limit to productivity. This may either negate or alter the need for genetic modification, or change the probability of its success in the short or longer term.

For those cases where the differences in plant performance relate mainly to one specific limitation, such as a disease which devastates production, the strategy of crop improvement is relatively clear — either identification and incorporation of genetic resistance or the use of cultural or chemical control measures. More commonly, however, agricultural environments impose quite complex challenges with many factors varying simultaneously, and there may be a range of responses by different genotypes to these challenges. In these situations, relative differences among genotypes become important, the nature of the differences and of the appropriate resolution become less clear, and the objective design of alternative strategies of crop improvement becomes more complex.

In practice, improvements in productivity and adaptation depend upon the manipulation of both the genetics and the environment of the plant, and concurrent manipulation is likely to result in optimum performance. Thus, genetic manipulation is only one aspect of crop improvement, and may not be the most appropriate means of resolution of the primary limit to productivity or adaptation.

The practice of plant breeding is a technology which is by definition mission-orientated and multidisciplinary, and directed to the genetic modification of aspects of the morphology or physiology of the target species. Since the objectives of genetic improvement commonly are complex, breeding requires integration of knowledge in genetics, biometry, physiology, chemistry, pathology, entomology and other disciplines in addition to its own research base.

This paper is intended as an overview of the potential for food legume improvement within Asian farming systems, with particular consideration of genetic limits to productivity and adaptation and their possible resolution. The paper is based upon a conceptual framework presented by Byth et al. (1983) in the general context of agricultural plant improvement.

Tropical Food Legume Improvement: Current Status

Asia is considered to be a centre of origin for several food legumes: China — soybean, adzuki bean and rice bean; India — green gram, black gram and pigeonpea. Some of these had spread to other areas of South and Southeast Asia several hundred years ago. Other food legumes such as peanut, cowpea and common bean spread from their centres of origin in South America, Africa or Central America to Asia many hundreds of thousands of years ago. Natural or directed selection over this period has resulted in the evolution of many local land races of these crops in the various regions.

In more recent times there has been an escalation of the genetic exploitation of the environment by man. The pattern of activities involved can best be described as crop adaptation, viz. exploitation of chance introductions, planned introduction of new cultivars and species, limited local breeding for specific aspects of adaptation and culminating in large scale national and international breeding programs. There has been a parallel escalation in

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the scientific study of specific biological and physical factors limiting productivity or adaptation of agricultural species to particular environments.

For various reasons, the tropical food legumes as a group are in the early stages of this cycle. Despite their historical importance as components of farming systems, and in human and animal nutrition, they have been subjected to relatively little systematic study and remain relatively wild and undomesticated for agricultural use compared to the major cereals. Scientific knowlege of their production, improvement and use is quite limited in most cases. There are significant national and international collections and even active research programs for some of the species, and some of the major tropical food legumes are charter species of one or more of the international agricultural research centres and agencies; for example, soybean at IITA, AVRDC and INTSOY, mungbean at AVRDC, groundnut and pigeonpea at ICRISAT, and chickpea at ICRISAT and ICARDA. In addition, there are significant outreach research programs from these centres for some crops. While this establishes a focus for research into these species which can be exploited by national scientists, even these crops remain grossly under-researched and scientifically neglected internationally. The situation is even worse for those food legumes of more regional importance.

Various national programs for the genetic improvement of particular tropical food legumes have been established but they often are restricted in size, duration, objectives or region of inference. Consequently, in practice, improvement for most food legumes in many countries depends on introduction of genetic material developed elsewhere. The role of introduction varies with the level of development and adoption of the species. For new species in an area, such as pigeonpea in Indonesia or Thailand, the basic objective is to introduce whole genomes as lines with direct or indirect potential as cultivars. By contrast, where there is significant current use of the crop, this approach is modified to emphasise introduction of specific genes or characters required to overcome known constraints to production or use.

The role of food legumes in tropical and subtropical farming systems has been considered by Wood and Myers elsewhere in these proceedings. It is clear that food legumes are produced in a great diversity of environments and farming systems, and that these production environments continually change in response to changes in the overall farming system. In recent decades, there has been a tendency for food legume production in many Asian countries to be increasingly relegated to more marginal cropping land as a result of technical improvements and economic incentives for cereal grains. In part as a result, food legumes are regarded as low yielding, high risk crops (Rao and van Oppen, these proceedings), and there is reluctance by farmers to utilise inputs. This creates a centripital situation through which low and erratic yields of tropical food legumes are assured.

It is imperative that plant improvement is directed to the primary problems within particular production systems. This requires that the systems are identified and described, that research is designed and conducted in the most effective manner to optimise advance within these systems, and that new production systems be developed to improve productivity and to extend the adaptation of the crop. Accomplishment of these objectives is complicated by the relatively limited scientific knowledge of the production, improvement and use of most tropical food legume crops, and by the somewhat canalised approach commonly adopted to the improvement of the traditional system per se.

While the existence of traditional systems of use must be respected and actions taken to improve their effectiveness, potentially more efficient systems must be actively researched. In general, these will involve culture of food legumes in less marginal environments and/or the use of management inputs which currently are not used. Breeding objectives defined and researched under suboptimal management may be irrelevant or even counterproductive under improved management. Conversely, simple cultural changes in traditional systems can create different limitations and new breeding objectives. It is imperative that food legume improvement programs maintain a broad perspective of opportunities for improvement in productivity and adaptation, in order that the real needs of current or potential production systems may be addressed.

Improvement of Genetic Potential

In this section some of the opportunities for genotypic improvement are considered — through removing some limitations to production, preventing loss from biotic factors or by improving product quality.

Limits to Production

ESTABLISHMENT

Poor establishment is one of the most important and basic limitations to production, and reduces or negates much of the value of other inputs to development. Major establishment problems exist in many food legume crops. Poor seed viability may result from conditions under which the previous crop was grown, conditions during seed storage, and mechanical damage (Heslehurst et al., these proceedings). Genetic manipulation of tolerance to weathering and physical damage, and of storage life, may be warranted. Resistance to weathering is associated with hardseededness in mungbean and selection for hardseededness is being conducted in Australia (Imrie et al., these proceedings). ICRISAT is conducting selection for dormancy in early maturing peanuts to avoid seed germination before the crop is harvested. Reduced oxidative deterioration of seed during storage may be possible by the development of more appropriate levels of various fatty acids and selection is currently being conducted in peanuts for improved product quality (shelf life). Soybean germplasm has been identified that is resistant to field weathering and to seed deterioration in storage (Dashiel et al., 1985).

Mechanical damage during handling or sowing is more common in large-seeded genotypes of peanut and other food legumes. Small-seeded soybean cultivars germinate well in excessively moist soils in Indonesia (Sumarno 1985). Kueneman (1982) found that in Nigeria seed size in soybean was negatively correlated with emergence following weathering stress. However, the more limited seed reserves of small seed may affect the capacity of seedlings to emerge from depth or in surface crusting situations. Thus selection for small seed size to avoid mechanical damage may be counterproductive to good emergence potential per se, and investigation of other genetic mechanisms for avoidance of mechanical damage is justified.

PHENOLOGICAL ADAPTATION AND CROP DURATION

Selection for phenological adaptation to agricultural environments is one of the major objectives in genetic improvement of food legumes. Two general objectives exist, viz. stress avoidance by tailoring plant growth to avoid absolute environmental limits and/or to schedule the most sensitive phases of growth during favourable seasonal periods, and optimisation of production by designing agronomic systems to complement phenology.

In many tropical food legumes, phenological change due to photoperiodic response or a photoperiod x temperature interaction response is substantial. For example, the introduction of improved soybean varieties from temperate regions to the tropics has been unsuccessful because they are not adapted to the photoperiod and temperature regimes exising in the tropics. In Southeast Asia, soybeans are grown from 0 to 19°N so that there is a requirement for cultivars with either minimal sensitivity to photoperiod and temperature or with a range of appropriate photoperiodic responses at these latitudes.

In most tropical food legumes there is a wide range of differential genotypic response to photoperiod, to suboptimal temperatures and to high and low temperature extremes (Lawn and Williams, these proceedings). Thus the potential exists for genetic manipulation of these species to select cultivars with appropriate phenological responses. This manipulation will be most effective when it is based on a detailed understanding of genotype x climate interactions. The inheritance of phenological response in most tropical food legumes is poorly understood but involves a relatively large number of genes in some cases, e.g. in pigeonpea (Byth et al. 1983).

Limitations imposed by phenological change due to photoperiodic response may be partly overcome by agronomic management such as altered plant density and arrangement, and this can extend the range of improved cultivars over latitudes and sowing dates.

Optimum crop duration is often influenced by the cropping system into which the food legume must fit; for example, in sequential cropping systems based on rice in lowland areas or corn in upland areas, early maturity of soybeans (Hidayat 1985) and peanut is often a requirement. Genetic insensitivity to photoperiod exists in some food legumes such as soybean and pigeonpea, and can be used to reduce crop duration and expand the potential area of cultivation of the crop. However, consideration also has to be given to the relative yield potential of different phenological groups within the species, and the extent to which yield is constrained by the use of very short season genotypes. Where the yield potential of longer season materials is greater, research into alternative farming systems is necessary. The overall productivity of the farming system inevitably is a major consideration in the improvement of each of the components of that system.

PRODUCTION AND DISTRIBUTION OF BIOMASS

Differences exist among and within the food legumes species for biomass production. Often, these are related to differences in phenology. Biomass production is important in so far as it relates to full radiation interception prior to flowering. During the reproductive phase, production of biomass per se is relatively less important than its partitioning into seed and non-seed components (the harvest index, or HI). Agronomic practices such as plant density or chemical application can alter HI. For example, application of a growth retardant to wet-season peanut crops in Thailand reduced excessive vegetative growth and increased pod yield (Montien 1986).

Substantial genetic differences in HI have been demonstrated in many food legumes (Singh and Shrivastava 1981; Lawn 1979). In soybean and pigeonpea, genetic differences in phenological response can be used to manipulate HI. Photoperiod effects have been found to influence assimilate partitioning and HI in peanuts, and there are genetic differences in this response (Ketring et al. 1982). However, for many food legumes grown in the tropics, genetic differences in distribution of biomass within species are relatively unexploited, compared to that which has occurred in, for example, semi-dwarf wheat.

Biomass production and distribution may also interact with other aspects of food legume improvement. For example, there is increasing evidence that some forms of host plant resistance to disease may occur at the expense of stored host energy and this may limit plant growth and yield relative to potential growth and yield (Smedegaard-Petersen and Tolstrup 1985). Cultivars with high HI may have less assimilate available for canopy maintenance and this may influence the relative susceptibility of genotypes to foliar disease (Duncan et al. 1978). In addition, relatively little is known for most tropical crop legumes regarding the role of vegetative organs both in current photosynthesis and as a reserve from which assimilates may be translocated to the seed during reproduction. Change in the nature of the environment may have significant influence on these processes. Thus a change in one component of the system may lead to a whole series of further changes, not all of which may be desirable in low to medium input agriculture.

PLANT MORPHOLOGY AND HABIT

In most crop plants, domestication and subsequent improvement has involved significant modification of plant morphology and habit, both to increase productivity and to improve harvestability. Examination of new and often unconventional characteristics is a valid experimental aim in breeding, to contribute to our knowledge of plant behaviour and of the limitations of current plant morphology for specific applications.

There are numerous examples of this in the food legumes, e.g. lodging and shattering resistance in soybean, the incorporation of photoperiod insensitivity and botanical determinance in pigeonpea to attain compact canopies with synchronous flowering and podding at the terminal meristems suitable for mechanical harvesting (Wallis et al. 1986), and the use of perenniality in pigeonpea to enable ratoon cropping and a flexible response and homeostasis under stress conditions.

Breeders may be excessively conservative in designing and implementing morphological change, to avoid problems of acceptance and to attempt production of plants that compensate for the inefficiencies in cultural practices otherwise avoidable through improved management. For example, while an indeterminate habit and asynchronous flowering may reduce the risk of crop failure due to incidence of periods of stress during reproduction, this increased stability of yield may occur at the expense of the higher yield potential possible in favourable environments from determinate and synchronous genotypes. Simply, alternative mechanisms for attaining stability exist and their broader implications need to be considered.

STRESS RESISTANCE OR TOLERANCE

Excessively low or high levels of any environmental factor may impose a stress on growing plants. The food legumes are grown in more marginal environments within Asian farming systems than are the major ceral grains, and as a result complex stresses commonly arise which reflect the interactions of many factors. Some of these stresses may be reduced or eliminated through management, for example, through the application of fertilisers to overcome or reduce nutritional stress, irrigation to relieve water stress, and the drainage of waterlogged soils. However, in practice, any field crop will experience a complex of unavoidable stresses, particularly due to extremes of climate. Compared to C_4 species, food legumes with C_3 metabolism are inferior producers under conditions of high temperature and radiation and low moisture (Huber and Sankhla 1976). Despite evidence of genotypic variation within C_3 species for photosynthetic efficiency, the potential for genetic improvement of productivity by raising photosynthetic capacity appears small (Lawn and Williams these proceedings).

For many food legumes in Asia, tolerance of both drought and waterlogged conditions is listed as a requirement by plant scientists because these crops are grown during both wet and dry seasons. Differences exist among and within species for drought tolerance. In peanuts, genetic differences in water use efficiency have been demonstrated in Australia (Hubick, Farquhar and Shorter, unpubl.), while at ICRISAT genotypes have been identified which are more tolerant of early or mid-season drought (ICRISAT 1985). Drought resistance in cowpea has been improved by selection for early appearance of mature pods, which is associated with earlier partitioning of assimilates to the reproductive sink (Hall and Grantz 1981). Wet soil culture of soybeans is one option for achieving high productivity under waterlogged conditions

(Troedson et al. 1985), and genetic variability for components of this adaptation has been identified (Hartley, Lawn and Byth, unpubl.).

Some genetic improvement will flow from stress avoidance due to better phenological adaptation (e.g. suitable flowering times and habits, and from perenniality in pigeonpea). However genetic tolerance per se to stress conditions is likely to be critical to the success of many of these crops. Past experience suggests that achieving such tolerance will not be an easy task in most crop plants. For example, genetic manipulation of tolerance of moisture stress will require the identification of appropriate mechanisms and the development of selection criteria and screening strategies suitable for use in large breeding populations. Line source irrigation techniques (Hanks et al. 1976) and carbon isotope discrimination (Farquhar and Richards 1984) may prove useful in this regard.

NUTRITIONAL ADAPTATION

There is evidence that differences between plants in reaction to nutrient availability are genetically determined, and that it is possible to select for response to improved nutrition. In many cases, the greatest genetic improvements in yield are obtained in high input systems. For those crops grown under irrigation or in the higher rainfall areas, gross mineral deficiencies may be corrected and genotypes selected that respond to improved nutrition, particularly in the absence of disease constraints.

In some regions, food legumes are grown on acid soils of inherently low fertility, and selection is being attempted for ability to grow under conditions of high saturation for Al and Mn, and low exchangeable Ca and Mg. For example in the Philippines, peanut genotypes have been identified with apparent tolerance to acid soil infertility (Gapasin and Umali 1985). However the nutritional adaptation of peanuts is complicated by the specific requirement for reasonably high levels of exchangeable Ca in the pod zone. Genotypic differences exist in pigeonpea for tolerance of high levels of Al saturation (Cowie et al., these proceedings), and in soybean for Mn toxicity (Mascarenhas et al. 1985) and Zn deficiency (Hunter et al. 1981; Rose et al. 1981).

Chlorosis caused by iron deficiency is common in peanuts and soybean in high pH soils where there is an excess of bicarbonates. Breeding programs at ICRISAT (Gibbons 1986) and in Israel (Hartzook 1984) have identified iron-efficient peanut genotypes able to withstand low iron availability. Soybean genetic material with high levels of resistance to iron chlorosis has been developed (Prohaska and Fehr 1981).

The low and erratic yields of food legumes grown in the dry season in Asia often are related to the degree of moisture stress. In this situation, nutritional problems are often complex and difficult to define and handle genetically. In principle, breeding for nutritional adaptation is a complex area which should not be entered lightly. Where specific problems are identified, such as Al and Mn toxicity or Zn and Fe deficiency, genetic resolution should be considered as one alternative, but not in isolation.

BROAD VERSUS NARROW ADAPTATION

A common breeding objective is to develop cultivars with high and stable yield over a range of production environments. Inevitably breeders must sacrifice performance in some environments in order to attain an acceptable level of overall performance; that is, broad adaptation involves specific sacrifices, and limits are placed on performance in particular environments because of the range of environments which the breeder must consider.

Evenson et al. (1978) defined cultivar *stability* in terms of yield variability over years at a site and cultivar *adaptability* in terms of yield variability across sites averaged over years. Plant breeders must be concerned with both stability and adaptability when selecting among breeding lines. Stability and adaptability should be closely related if genotype x environment interactions are caused by unpredictable environmental variables such as rainfall, rather than by predictable ones, such as soil type differences that vary across sites but not years.

In choosing among possible cultivars, a farmer would be interested mainly in their relative stability at the farm site, or conversely in the relative amount of risk associated with the use of each for a given yield level at that site. Where genetic differences in performance are relatable to factors associated with particular locations, they can be exploited by development of regional breeding or selection programs if adequate resources exist. However current resources in most Asian countries do not permit such a proliferation of programs for the food legumes, so that a strategy to develop broadly adapted cultivars is appropriate. Given that many food legumes are grown under conditions in which moisture stress is virtually assured in most years, it is likely that cultivars may require broad stability even if they possess narrow adaptation.

Biotic Factors

Development of pest and disease resistance is a major objective of both national and international food legume improvement programs. An emphasis on protective breeding is not surprising: the problems are economically significant, the objectives are easily defined, and selection can be conducted in discrete programs. Genetically resistant varieties have many advantages over other forms of control, although past experience in many crop species has shown that genetic resistance may not be durable. In some instances this has resulted in a cyclical process of identification and incorporation of new sources of resistance. While this can be effective, it does divert resources and selection pressure from other problems for which a genetic resolution is appropriate.

It is doubtful that any of the tropical crop legumes could justify the type and scale of program which has been implemented internationally for genetic resistance to rust disease in wheat. Rather, for those pathogens which have the potential to develop considerable genetic variability in large natural populations, it may be appropriate for breeding programs in the food legumes to place greater emphasis on selection for partial resistance (due to either horizontal or quantitative vertical resistance). In this regard, rust resistance identified in cultivated peanuts is of the rate-limiting or partial type, and both race-specific and horizontal resistance to rust in soybean have been identified. The useful life of resistance genes may be extended by applying integrated control measures in which genetic resistance, chemical treatment and cultural management of the crop could each play a role. However, the implementation of integrated control in the complex farming systems and small farm sizes of Asia presents major problems.

Viral diseases of food legumes species, such as peanut mottle virus (PMV), can be quite serious in the tropics, particularly when insect vectors are most active. Peanut germplasm tolerant to PMV has been identified and is being used in the ICRISAT breeding program. Most Indonesian peanut germplasm is quite resistant to bacterial wilt when compared with introduced germplasm, although differences among local cultivars in their tolerance of the disease are apparent at various inoculum densities. Here tolerance is defined as cultivar yield in the presence of the pathogen versus yield in its absence. These examples suggest that breeding for tolerance to systemic pathogens such as viruses and bacteria would be a useful strategy in food legumes.

Continuing disease problems require or are receiving attention in several food legumes in Asia, e.g. rust, anthracnose, downy mildew and bacterial pustule in soybeans; cercospora leafspot in mung beans; rust, cercospora leafspots, pod rots and *Aspergillus flavus* in peanuts; and fusarium wilt, phytophthora root rot and sterility mosaic virus in pigeonpea. Demand for disease-resistant cultivars is certain to increase in the future as legumes receive higher research priority and yield loss caused by disease is more widely recognised.

Insect pests are economically serious in most food legumes in Asia, e.g. the pod-borer complex (*Maruca* and *Heliothis*) and various sucking bugs on pigeonpea and soybeans, and beanfly (*Melanagromyza*) on soybean and mungbean. Three basic approaches to genetic improvement in pest resistance exist; crop scheduling by choice of appropriate phenology to reduce or avoid economic damage; identification and incorporation of host plant resistance; and development of tolerance. Non-genetic control is also possible, and integrated pest management utilising all systems is optimal. Host plant resistance is part of integrated pest management research in pigeonpea, peanut and soybean. However progress in breeding for insect resistance has been slower than that for disease resistance.

In some legumes such as pigeonpea, durable host plant resistance in agronomically desirable cultivars could have basic influence on the relevance of the production system per se. The availability of such material could lead to change in management of the crop in order to optimise yield per unit area or per day, rather than to reduce the probability of insect damage.

Beneficial biotic factors have received only limited attention by plant breeders. The legume-*Rhizobium* symbiosis is important to the nitrogen balance of the entire farming system as well as to the growth and development of the legume crop (Myers and Wood, these proceedings) and therefore justifies attention. The value of the symbiotic relationship may be improved by exploiting variability among the bacterial strains, among the legume host genotypes, or both. Considerable advances have been made in this area. For example in peanuts, selection at ICRISAT (Gibbons 1986) among host genotypes for increased nitrogen fixation has identified superior genetic material, and cultivars have been identified in the Philippines which differ in nitrogenase activity under partial shade conditions (Gapasin and Umali 1986). In soybean, major differences in nitrogen fixation result from particular host/strain combinations, and so-called supernodulating genotypes have been identified (Carroll et al. 1985). The importance and manipulation of the symbiosis are discussed in detail by Beck and Roughley (these proceedings) and will not be considered further here.

With respect to manipulation of the host, two extremes are selected of genotypes that exhibit specific reactions with particular *Rhizobium* strains and selection of promiscuous genotypes that form an effective symbiosis with a range of native *Rhizobia*. In view of the difficulty of production and dissemination of specialised strains in Asian farming systems, and potential problems associated with their competitive ability against native strains, we favour the approach of selecting promiscuous host genotypes. Promiscuous soybean genotypes have been identified at IITA and promiscuity appears to be conditioned by a few major genes (Dashiell et al. 1985).

Attainment of an adequate symbiosis clearly is vital to viable food legume production. However, although further genetic improvement of legume host genotypes could improve the host-*Rhizobium* symbiosis, the justification for allocation of breeding resources specifically to this activity would need to be considered carefully in relation to the importance of other constraints to productivity amenable to genetic resolution.

Beneficial association with vesicular-arbuscular mycorrhizal fungi (VAM) exists in some food legumes, particularly with respect to phosphorus nutrition, but has received limited genetic attention to date. Varietal differences in response to VAM inoculation of peanuts have been noted in the Philippines (Gapasin and Umali 1986).

Breeding for Product Quality

In the present context, product quality refers to any genetic characteristic which influences the market price and acceptance of the product. Food legumes are used for human consumption in many Asian countries and for oil crushing in others, and some seed and seed by-products also are used in animal feeds. Hence quality aspects of existing or new varieties are relevant considerations in food legume breeding programs. Breeding for quality is receiving greater attention in developed countries, due to a growing discrimination by processors and consumers, and is stimulated by the increased technical capability available to breeders. In Asia, aesthetic considerations are relatively more important than nutritional value in determining acceptance of legumes as food (Wijeratne and Nelson, these proceedings). Quality aspects would include oil content of soybeans and peanuts, fatty acid composition of peanut oil because of its influence on oxidative rancidity, flavour and texture of peanut kernels, and flavour, texture, protein content and cooking qualities of pigeonpea.

However, emphasis on quality in breeding programs has a hidden cost because it retards genetic improvement in other characters. There is a finite limit to selection pressure. Close liaison of breeders, processors and consumer groups is necessary in order to use breeding resources most efficiently; that is, to ensure that quality criteria reflect the real needs of the market and that the stringency of quality requirements, including raising the nutritional value of legumes, is in balance with other objectives.

Improved Breeding Procedures

Expansion of Genetic Variability

There is an increasing recognition of the importance of access to genetic diversity in cultivated and wild forms of food legumes, and of the need to conserve vanishing germplasm. Significant national or international collections exist for many of the major food legumes, and the diversity they contain should be exploited by national program scientists.

Unfortunately plant breeders probably make insufficient use of plant collections. In part, this results from inadequate communication regarding the content of collections, but there is also a need for improved procedures for documentation and use of data from such large collections. Assessment and screening of collections are relatively simple procedures for easily identifiable traits such as disease resistance. However, characterisation of accessions for less readily identifiable characters such as degree of tolerance of insect attack or of adverse nutritional conditions, and of adaptive characters such as response to temperature, photoperiod, water stress or waterlogging, is much more complex and may require multi-environment evaluation. For large collections this may require allocation of considerable resources, and careful development of the descriptors used for documentation is essential.

Increasingly, plant breeders are finding useful genes in related wild species of cultivated food legumes; for example from *Vigna radiata* var. *sublobata* for stress tolerance (Lawn et al. these proceedings), from *Glycine soja* and perennial *Glycine* species for rust resistance (Brown et al. 1985), and from various *Atylosia* species for resistance to *Heliothis* and disease and for high protein content in pigeonpea (van der Maesen et al. 1981). Genic or chromosomal barriers to hybridisation and recombination often restrict access to such genes, and specialised procedures often are required to overcome such barriers (Grant et al. 1984 in soybeans; Chen et al. 1977, and Fery 1980 in mungbean). Such research is best carried out in centralised programs, with derived progeny compatible with cultivated forms being distributed to national programs as appropriate. This approach has been successfully applied at ICRISAT and at North Carolina State University in the utilisation of diploid *Arachis* species for improvement of the tetraploid cultivated peanuts (see Moss 1985).

Recent progress in tissue and haploid culture in some agricultural plants, and in somatic hybridisation in other organisms, suggests that genetic engineering may have future application in plant breeding. However, there has been only limited progress in the tropical food legumes, e.g. Mehta and Ram (1980); Sinha et al. (1983); Kumar et al. (1984). In view of the complexity of environmental adaptation in agricultural plants, these approaches have limited contemporary relevance to adaptive traits, and the techniques are most likely to be useful for incorporation of simply inherited characteristics and in overcoming barriers to recombination.

Breeding Methodology

Choosing parents, a key decision in any breeding program, remains a major obstacle, particularly in self-pollinated species and for quantitative characters. Various methods of predicting the usefulness of parents are used, including parental performance, phenotypic stability, estimation of combining ability, multivariate analyses and various biochemical assays, but none has shown general utility. Better guides are necessary.

Most breeders recognise the limited extent of recombination in breeding populations of self-pollinated plants, and various procedures are used to increase this; for example, wide crossing within species, recurrent selection, genetic male sterility, rapid cycling of breeding populations, interspecific hybridisation and multiple or composite crossing. Relatively few comparative studies exist to guide the choice of breeding system, particularly in the tropical food legumes, and each system has been effective in particular situations. Improved guidance on the relevance of different breeding systems is necessary, and maintenance of a diversity of breeding strategies is probably desirable in view of the complexity and range of breeding problems.

Hybrid vigour has been exploited effectively in many crop species. However, F_1 or other heterozygous hybrid cultivars are generally not used in food legumes, despite the expression of significant heterosis for seed yield in some crops (Swindell and Poelman 1976 in mungbean; Byth et al. 1981 and Saxena et al. these proceedings in pigeonpea). There are various reasons for this, including absence of a suitable system of pollination control in most food legumes, and cost or unreliability of hybrid seed production. There has been extensive study of hybrid cultivars in pigeonpea, based on genic male sterility and natural outcrossing by bees (Saxena et al., these proceedings). Apart from the potential use of hybrid cultivars of pigeonpea in low labour cost countries, there is unlikely to be any significant use of hybrid cultivars of food legume crops in Asian farming systems in the foreseeable future.

Rapid Generation Turnover

The length of most breeding programs (up to 10 or more generations) adversely influences their cost effectiveness. Techniques which accelerate generation turnover allow more rapid determination of the value of crosses and lines, and make programs more responsive to contemporary demand. One example is the single seed descent system or its modifications to produce random near-homozygous lines for evaluation (Brim 1966; Empig and Fehr 1971). For short-duration food legumes in Asia, it is possible to use several crop seasons per year to turn over generations, each with or without selection depending on the selection objective and the factors influencing adaptation.

Reducing the duration of a breeding cycle commonly involves a compromise. While single seed descent allows earlier evaluation of fixed lines and avoids bias in selection in the early segregating generations, it also is labour intensive, invests resources in deriving and testing inferior random lines, and does not allow early generation selection where this is feasible.

Management Level of the Selection Environment

In any crop improvement program, the level of management input appropriate in the breeding phase is open to debate, and ranges from optimal management to average farmer technology. Cultural inputs in this context are simply study tools for a purpose, and should be used as such in applied research. The basic objective of breeding is to identify genetic differences, and effective discrimination is prejudiced by any factor that reduces genetic expression or increases error. Thus precise experimentation is critical in all circumstances, particularly with respect to the use of uniform test sites and the attainment of appropriate and uniform plant population. Testing in uncontrolled and erratic environments across sites and years (e.g. in fields with weed infestation or nutritional variability) inevitably elicits error and genotype x environment interactions that confound selection.

The central issue is determination of what constitutes an appropriate challenge for discrimination among genotypes. For quantitative characters, genetic advance is by gradual accumulation of favourable genes each with a small effect, and this means small gains per generation of selection. Precise experiments are therefore required to detect these small differences among genotypes, and it is pointless to attempt selection in conditions so adverse that little or no genetic variation can be detected. Similarly for qualitative characters, the test environment should reflect the specific challenge of interest, and genotypic response to this should not be confounded by other variables in the environment. This does not imply use of nonlimiting test regimes. However, it does mean control of error and the use of adequate environmental management such as supplemental irrigation, crop protection and weed control to avoid stresses that will confound the intended discrimination, particularly during the selection phase. Subsequent evaluation of selection under 'farm' conditions is critical, and this will indicate the validity and relevance of the selection strategies imposed in breeding.

Selection for Disease or Pest Resistance

For adaptive traits such as qualitative disease resistance which are often under the control of major genes, genetic advance is usually stepwise. Here, the appropriate environmental challenge involves exposure to a reasonably high level of the pathogen. By contrast, selection for partial or rate-limiting types of resistance should not be conducted with unrealistically high levels of disease incidence that may obscure relatively small genetic differences in plant response. The gradient and low dose challenge methods (Buddenhagen and de Ponti 1983) have been proposed to achieve this in heterogeneous breeding populations. The gradient method involves assessment of disease progression in time and space from a point source, while in the low dose method, components of host plant response to an appropriate dose, such as latent period, lesion size and spore production, often are used as selection criteria.

The extent and nature of integration of breeding for disease and pest resistance or tolerance with the general quantitative breeding for agronomic traits of the crop is debatable. Breeding for resistance should be conducted separately from, but complementary to, the main quantitative programs, especially if resistance occurs in poor agronomic backgrounds. The primary objectives of these programs are complementary but different, and should not be confounded. Thus, while breeding for resistance may involve controlled or augmented pathogen or pest populations, the quantitative yield program should be protected from significant disease or insect attack that can bias selection in early generations. The yield program should, however, incorporate parentage known to possess disease or pest resistance, and in later generations evaluation of breeding lines could be conducted simultaneously in 'protected' environments for yield potential and in 'unprotected' environments for resistance. Selection would then be on the basis of joint performance across evaluation environments. Alternatively the quantitive program may include only final testing of elite lines for resistance.

Selection for Monoculture or Intercrop Production

Intercropping of food legumes with other crops is a common practice in Asian farming systems, and is an important factor influencing the overall productivity of agricultural land. However deliberate genetic improvement for such systems presents considerable additional problems of experimental design, selection and evaluation, and requires careful consideration prior to implementation.

Intercrop systems are diverse, differing both in the species and agronomic management used and in the basic objective of the practice. In principle, breeding for improved adaptation involves exploitation of favourable genotype x environment interactions. The associated crop is an additional component of the environment of the target species, and as a result environmental interactions within intercrops may be greater and more complex than in monocrops. There must be concern regarding the extent to which favourable interactions may be identified which can be extrapolated across variable production environments and intercrop systems. Regardless, the precision of discrimination among legume genotypes in intercrop situations is likely to be reduced by the additional confounding factors and the increased error in the environment.

Selection within intercrop systems is only justified if significant differences exist between monocrop and intercrop for genotypic performance or genotype x environment interactions. Where this exists, the preferred research is to identify the characters causing these differences, and selection for them in monocrop followed by final evaluation under intercropping. This strategy is more likely to result in genetic advance for the character(s), and thus for performance in mixed stands, than is selection within specific intercrop situations per se. By analogy, selection of pasture legumes for legumes–grass swards has been successfully achieved by identification of elite legume genotypes in pure stand followed by evaluation of these in mixed swards.

Testing Procedures

Multi-environmental evaluation trials of breeding material are a regular feature of all programs of genetic improvement. They may be international, national, regional or local in perspective, and may include on-farm testing. Regardless, these trials are important because they are the primary point of contact between scientific contributions to plant improvement and the diversity of the production environment. Therefore the results of these trials provide valuable information which has implications in two directions — to the potential clients (regional breeders, agronomist and farmers), and to the core breeding program with respect to the value and relevance of its breeding populations and selection strategies.

The analysis and interpretation of data from such trial series varies. However it generally is restricted and insufficient to provide a basis for objective discrimination among the entries on performance in a range of environments, or among the test environments. Improved techniques of analysis which assist in interpretation of such large data sets exist, such as joint linear regression and pattern analysis, and these are considered in some detail by Byth and Mungomery (1981) and Shorter et al. (1986). These approaches facilitate the identification and description, and hence the genetic manipulation, of any systematic variation in the response of genotypes to a range of production environments. They also assist in the identification of test environments which may facilitate discrimination of various kinds.

While most breeders recognise the importance of genotype x environment interaction in assessing the relative importance of cultivars and breeding lines, its significance in the conduct of early generation testing is less well appreciated. It is crucial that the genetic material under test be relevant to the real limitations of the production environment, and it may be necessary to implement local testing and selection within early generation segregating populations, where the advanced stable lines available exhibit poor local adaptation. Equally, better understanding of the factors influencing environmental adaptation may enable development of more effective and reduced or phased testing programs through improved choice of the test environment(s).

Varietal Release and Pure Seed Production

Research to identify and resolve constraints at the research station is essential, but that knowledge will not improve productivity or adaptation until it becomes farm practice. In terms of resolution of genetic constraints, this means that an adequate supply of good quality seed of the improved varieties must be assured to farmers on a continuing basis and at a reasonable cost.

In practice, there has been only limited adoption by farmers in most Asian countries of improved cultivars of food legume crops, and most of the production continues to be of local land races. There are various reasons for this, but in most cases it reflects, in part, inadequate local availability of seed of improved cultivars.

Procedures for varietal release, and for increase and maintenance of seed stocks, vary among countries. For the food legume crops in many Asian countries, initial seed increase is undertaken on government farms but a wide diversity of means of subsequent distribution exists. Commonly, individual farmers access small quantities of seed of the improved variety and increase it for their own use or subsequent sale. The effectiveness of these types of distribution is inhibited by inadequate and inefficient seed increase procedures and by ineffective distribution, and this may grossly delay access by farmers to improved cultivars.

There is a requirement in programs for maintenance of genetic purity and quality of seed of improved cultivars for farmers. In the absence of schemes which certify trueness to genetic type and freedom from seed-borne disease initially, and which minimise reduction in quality during seed increase, the perceived value of new cultivars by farmers inevitably must decline.

In some cases, inadequacy of seed storage on-farm and of access to new seed off-farm forces farmers to engage in a cyclic process of seed production across regions and/or seasons. This is particularly so in those food legumes with poor storage characteristics, e.g. soybean and peanut. As a result, improved cultivars may be grown for seed increase in environments in which they are not well adapted, and there can be pressure to adopt compromise cultivars which are not optimally adapted to any one season or region of production. The obvious solution to this problem is the identification of specialised off-season seed production facilities, or the development and provision of adequate seed storage facilities, coupled with incentives to farmers to purchase that seed. Aspects of seed storage of legume seed in the tropics are considered by Heslehurst et al. (these proceedings).

Conclusions

The primary objective of any agricultural plant improvement program is achievement of an advance in productivity and adaptation. This may arise from the manipulation of both the genetics or the environment of the plant, and represent either the release of an improved cultivar or the development of improved management, or both.

For all agricultural species, production occurs in a wide diversity of environments that differ in the type, intensity and timing of the challenges they impose. Within these environments, farming systems continually evolve in response to human needs, availability of technology and capital, and environmental change. Research can be highly effective in resolving particular limits, and in some cases this improvement can be extrapolated to the other environments. More commonly, however, large interactions of genotypes x environment restrict this. Thus plant improvement based on an ad hoc approach is inevitably reactive in nature and remedial in emphasis, and its results are likely to be restricted in relevance in both time and space for agricultural systems characterised by diversity and change of the production environment.

Research resources are limited, and it follows that the fundamental challenge in plant improvement is to generalise any advances in productivity and adaptation across the whole range of farming systems and environments. Sustained improvement in the longer term, and the ability to extend those improvements to other production environments, are most likely to arise from the deliberate development over time of a more fundamental scientific understanding of the mechanisms and processes influencing adaptation of the species.

While these principles apply to the food legumes, their improvement is complicated by a number of factors, viz., the large number of species involved, some of which are of only local or regional importance; the limited scientific knowledge of these species; the wide range of habit and use, and great responsiveness to environmental change, which conditions flexibility of adaptation to a range of roles within farming systems. Borlaug (1973) considered that simultaneous improvement of all the food legumes was impractical and that research should be concentrated on a smaller number (8 or 9) of species of high priority chosen on the basis of genetic potential for seed yield, cultural/climatic requirements, disease and insect problems, and nutritional properties. While there is logic in concentrating on the most important of the tropical food legumes, this philosophy has inherent limitations. First, legume crops of significant importance regionally would remain scientifically neglected, which would reflect on the nature of productivity of farming systems in those regions. Secondly, resources are limited, and it is quite impractical to consider establishment of a reseach infrastructure equivalent to that devoted to each of the major cereal crops for each of the more important food legumes.

While crop-based research into the improvement of each of the tropical food legumes of international or regional importance is both justified and necessary, there is a need to avoid unnecessary duplication. Regional devolution of research is justified only to the extent that effective general models through which the results of research may be extrapolated to other environments are unavailable. In this context, national research into particular tropical food legumes is commonly limited in scale and fragmented across institutions and disciplines. Coordinated research, incorporating appropriate investigations at the national and international centres and complemented by adaptive regional research into particular problems of local production systems, may be a more realistic strategy of improvement. This may even be extended to encompass joint programs on a number of food legume crops where the mechanism or process under study is generally applicable.

Plant improvement may be directed at the improvement of the potential for productivity, to the resolution of specific limits to expression of that potential, or it may address both issues. The nature of the program depends largely on the nature of the production environments. Certain objectives can be generalised across the entire range of production environments, such as disease and insect resistance, ability to tolerate acid soil conditions, effectiveness of nitrogen fixation, specific chemical composition of the seed etc., and may be termed 'production system - neutral' in that they have potential value regardless of the level of productivity sought or attained. Conversely, 'technology-dependent' objectives have particular relevance only in environments in which intensification of production is practiced, and these may include the improvement of the genetic potential for yield in favourable environments, ability to respond to increased availability of nutrients, etc. It is important to distinguish between these types of objectives in the design of improvement programs; for example, quantitative breeding to increase yield potential per se is inappropriate in situations where the yield is uniformly low as a result of one or more specific limits to growth and development. While quantitative breeding may be effective in these circumstances, this will result from unconscious resolution of those specific limits which could have been attained more simply and cheaply via a direct program of genetic manipulation or environmental modification.

Where genetic resolution of a limit to productivity or adaptation is feasible, implementation of breeding may be appropriate; for example, for the control of foliar diseases in peanut or soybean. However, breeding is a relatively slow process, relevant to the medium/long term, whereas substantial advances may be possible and economic in the short term from agronomic or cultural manipulation. A program involving concurrent breeding and other approaches may be justified to attain both immediate and longer term resolution.

While breeding programs commonly are perceived to be large and expensive relative to other disciplinary research, the general validity of this is doubtful. Most breeding programs emphasise labour and field facilities rather than laboratory and equipment costs, and programs with specific objectives can be quite modest in cost.

In general, plant improvement is at least as effective as many other fields of agricultural research, and many Asian countries, in view of their dependence on arable agriculture, may be underinvesting in the area. This is particularly so for the food legumes, for which per caput availability is declining in some countries while imports are expanding in others (Rao and von Oppen, these proceedings). Unlike the major cereal grains and other crops, in which research results from other countries can be exploited by transfer of technology, Asian countries must accept major responsibility for the improvement of those tropical food legumes which are of regional importance in Asian farming systems.

In Asian regions there is a substantial gap between actual and potential production of most food legumes. Although there are many reasons for this, it is true that greater genetic exploitation of Asian cropping systems can result from better use of current genetic resources and by the application of current technology. Difficulties often occur in applying available technology to the small farmer situation common in Asia. For example, control of foliar diseases of peanuts with fungicides in Indonesia may not always be compatible with the socioeconomic conditions under which the crop is grown. Further, the complex farming systems may exacerbate insect and disease incidence, and militate against their control.

In some Asian countries, food legume research tends to be fragmented with respect to institutional involvement and disciplinary skills. A responsive research infrastructure, and effective extension and adoption of research findings, are crucial to the improvement in productivity and adaptation of the food legumes. The extension worker has a crucial role, and effective communication between extension and research personnel is essential. Plant improvement research should combine individual initiative with integrated problem-orientation, and a model based on the international plant improvement centres may enable effective deployment of staff, utilisation of genetic resources, coordinated evaluation programs, and adequate scale and continuity of programs including the associated disciplines.

Ultimately the success of any plant improvement program depends on the dedication, enthusiasm, motivation and ingenuity of the individuals involved. Thus an effective program must include provision for continued training of staff, adequate financial reward and peer recognition of achievements. The most effective plant improvement is done by motivated scientists working in well serviced, integrated and multidisciplinary teams.

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Limits to Productivity and Adaptation Due to Preharvest and Postharvest Factors

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MOST crop production research is directed towards factors that contribute to the maximisation of yield potential. Preceding papers have dealt with the genetic factors that influence choice of cultivar, and the climatic, edaphic, nutritional, biological and management factors that are responsible for determining the potential yield and quality of that cultivar.

This paper is concerned with the factors that influence the realisation of that potential. It examines the limits imposed by, and the losses due to, both extrinsic and intrinsic factors affecting seed during the maturation, harvest, and storage periods. Whereas previous papers in these proceedings have been mostly concerned with additions to yield, this paper deals mostly with yield and quality reductions, and how they may be minimised in order to retain the yield potential already developed.

Interactions occur between factors contributing to yield losses. Particular attention is paid to interactions between genotype, climate, and biological factors.

It is also recognised that events and processes occurring in the preharvest period can affect losses incurred during the harvest and storage periods. The ability to maintain yield and quality of seed through harvest and storage depends on the quality of seed presented at each stage of the production process.

In discussing seed quality the end use of the seed must be borne in mind. Seed destined for use in planting has different requirements to that which will be processed or used directly as food.

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Source of Limits

Many of the problems associated with productivity limits in both the pre- and post-harvest stages of food legume production arise from changes brought about in seed characters. The changes have occurred during the course of domestication of the major food legumes such as soybean, mungbean, and cowpea. Similarly, current adaptation problems, particularly in soybean, have been induced by the extension of production from its temperate origins to tropical regions, or to seasons in which it is difficult to produce high quality seed. The tendency in Asia to select for photoinsensitivity and short crop duration to permit flexibility in cropping systems also contribute to adaptational problems.

The main changes to seeds that occurred during domestication of cultivated legumes were an increase in size and a reduction in seedcoat thickness compared with the small seed with tough pericarps characteristic of their wild relatives (Smartt 1978). These changes made seeds of cultivated varieties more vulnerable to physical damage (Dickson 1980; McDonald 1985) and more prone to insect attack and fungal infection during harvest and storage operations. Changes in chemical composition, such as selection against antimetabolites to make the product more attractive as a human food, may also decrease insect resistance (Birch et al. 1985).

The second major change has been the decrease in hardseededness (Lush and Evans 1980; Smartt 1978) which permits rapid imbibition of water and predisposes the seed to deleterious changes generally referred to as weather damage (Delouche 1980).

Preharvest Factors

The preharvest period commences at the time of physiological maturity when the seed reaches maximum dry weight and severs its vascular connection with the parent plant. The seed is then an independent entity and it matures by dehydration until harvest which is preferably delayed until water content is about 14–15%. During this period the seed is vulnerable to the vagaries of weather, and to insect and disease attack. These problems are preferably counteracted by genetic resistance.

GENETIC FACTORS

As mentioned above, genetic limits mostly derive from applied selection and management during domestication of the species. Not all selection has had a negative impact on seed vulnerability. Whereas wild species generally shatter to provide a seed dispersal mechanism, reduced shattering is the normal state of cultivated crop varieties. However, shattering can be a serious problem, particularly in soybean where the level of shatter resistance is less well developed than in other food legumes (Smartt 1978). The amount of shattering varies with the season of growth, being most serious in crops that mature during the dry season. In most species shattering is predominantly under monogenic control (Fery 1980) and responds to selection. Further reduction in the incidence of shattering may be anticipated as landrace varieties are replaced by improved cultivars, derived from breeding programs in which selection for shatter resistance is practised.

Susceptibility to weather damage, due primarily to the absence of hardseededness and reduced seedcoat thickness, has contributed more to loss of yield and quality than any other character. Particular attention is being paid to the resolution of this problem in breeding programs (Dickson 1980; Imrie et al. 1984; Kueneman 1982). Heritability of weather resistance in the field was very low in soybean (Kueneman 1982) and mungbean (Imrie 1983), but studies of specific characters contributing to weather resistance, such as hardseededness, have shown genetic control to be due in some cases to one or a few major genes and amenable to selection (Kilen and Hartwig 1978; Imrie et al., these proceedings; Lawn et al., these proceedings). In other cases hardseededness appears to be under multigenic control (Dickson 1980; Kaveeta and Srinives 1985; Kueneman 1982).

Legume pods can also contribute to protection from weather damage. In mungbeans a controlled screening test identified good resistance to weather damage in lines that had no hard seed (R.W. Williams, pers. comm.). Differences could be largely attributed to pod characters. In soybean, Tekrony et al. (1980b) recommended selection for thick and/or dense pod walls. No information is available on the inheritance of genotypic differences in pod characters.

Seeds that readily imbibe water are preferred for sprouting and for cooking and this is one reason why selection against hardseededness has been practiced. But hardseededness is readily broken by abrasive or heat scarification, and decreases progressively in storage. The return to the ancestral state should not prove any great disadvantage, except possibly in the field where volunteer plants derived from hard seeds could be considered weeds in subsequent crops, or where failure to break hardseededness of planting seed may lead to poor or uneven germination.

The avoidance of weather damage also contributes to reduction of preharvest losses. In mungbeans, selection for synchrony of maturity (Park and Yang 1978), which reduces the period of vulnerability in the field, has been effective. Lines in which 80% of pods can be harvested at the first pick have been bred. Avoidance through phenological control, which causes the crop to mature during dry rather than rainy periods, is being used in Northern Australia (Putland and Imrie, these proceedings).

CLIMATIC FACTORS

High temperature and relative humidity, and frequent or excessive rainfall are the conditions that cause deterioration of seed during the preharvest period in crops such as soybean and mungbean and during curing of peanuts (Andrews 1982; Delouche 1980). These are also the conditions that ripening crops, particularly those sown in early wet and wet seasons, experience in the tropics. Conversely, hot dry weather tends to increase the proportion of hard seeds (Rolston 1978) and thus improves resistance to weather damage and quality for storage.

The main consequences of damage caused by adverse climatic conditions are seed death, reduced vigour, and increased susceptibility to infection by pathogens, to physical damage, and to deterioration during storage. These effects are more severe for seed destined for replanting than for seed produced for processing and consumption, except in the case of mungbeans or other legumes to be used for sprouting.

Rainfall, and/or high humidity during seed ripening can delay ripening and consequently increase respiration, which reduces the supply of stored assimilates in the cotyledons (Howell et al. 1959). This can reduce seed vigour. Most damage due to rainfall results from cyclic wetting and drying of mature seed. The alternate swelling and contraction associated with imbibition and dehydration causes membrane rupture which releases cell contents, and cracking of cotyledons and seedcoats in addition to prolonging the period of respiration (Andrews 1982). At the other end of the scale, drought during seed maturation, such as could be experienced by crops sown at the end of the wet season, can cause seed development to be interrupted and small shrivelled seed to be produced (Delouche 1980). High temperatures accentuate moisture effects when both conditions occur together. Physiological processes during wetting increase in rate as temperature increases. Similarly, the rate of drying is greater at high temperatures. In the absence of rainfall, high temperature can also have an adverse effect on seed germinability and field emergence of soybean (Green et al. 1965).

In addition to their primary effects, rainfall and high temperature have a secondary effect through providing an optimum environment for the growth of bacterial and fungal pathogens on seed (Nicholson and Sinclair 1971; Onesirosan 1983). Also, when heavy rain makes field access difficult and causes harvest delays, the period of vulnerability is extended, and seed quality decline inevitably occurs (Tekrony et al. 1980). This is probably more applicable to peanuts than to other species.

Although temperatures in the tropics are adequate for the growth of food legumes throughout the year (Lawn and Williams, these proceedings), and various cropping systems are used to take advantage of this (Wood and Myers, these proceedings), we might consider that most current cultivars are not well adapted to growth during seasons when maturity coincides with a high rainfall period. In addition to their susceptibility to weather damage, and pest attack, cultivars with an indeterminate growth habit have an extended maturity phase and consequently an extended period of vulnerability to seed damage. Lantican and Garaza (1977) found that in the Philippines soybean cultivars such as 'Bragg' and 'Hill' had both the desired crop duration and good synchrony of maturity whereas others such as 'Improved Pelican' and 'Biloxi' had poor uniformity. The importance of uniformity of maturity in extending the range of adaptation is also recognised in mungbeans (Park and Yang 1978).

EDAPHIC FACTORS

Soil physical and nutritional factors have only small effects on seed production and quality during the preharvest period. Nutritional deficiencies and disorders mostly affect growth and seed set prior to maturation and those seeds that do develop are rarely mineral deficient (Austin 1972). However when mineral deficiencies do occur they can have an effect on the quality of seed with respect to germination and seedling growth when that seed is subsequently sown (Mugnisjah and Nakamura 1984): Low calcium and boron levels in peanuts, which occur in Thailand (mentioned in other papers in these proceedings), can cause seedling abnormalities (Delouche 1980) but these are readily overcome with fertiliser application. Conversely, in soybeans, seed produced in an area with a high molybdenum status can be satisfactorily grown in Mo deficient soils without Mo application (Harris et al. 1965).

In peanuts the soil physical status can affect kernel development. Brown spots on the shell can result from poor aeration (Mantell and Goldin 1964) which can occur in wet and compacted soils. However, heavy or poorly drained soils are not normally used for peanut production.

BIOTIC FACTORS

Pathogens and insect pests cause losses during the preharvest period, and their occurrence at this stage can also lead to further substantial losses during storage.

There is ample evidence that pathogenic infections of legume seeds are extensive and may have severe effects (Andrews 1982; Sinclair 1982). At least 80 pathogens, including 66 species of fungi, have been recorded in or on soybean seeds (Sinclair 1982). Bacterial and viral infections are less important than fungi in causing seed quality decline and loss but because they are seed-borne their occurrence in seed can predispose the subsequent crop to infection and reduced production.

Most research on fungal infection of seed has been concerned with effects on viability and vigour for germination. Fungal species most commonly associated with reduced germination in soybeans include *Phomopsis* spp. (*Diaporthe phaseolorum* var *sojae*), *Cercospora kikuchii, Cercospora sojina, Colletotrichum dematium* var *truncata* and *Fusarium* spp (Sinclair 1982; Tekrony et al. 1980b). Similar species have also been found on mungbean seed (Nik 1983).

Seed quality for processing and consumption can also be decreased by infection with both pathogenic and saprophytic fungi. Perhaps the most serious problem is in peanuts where infection with *Aspergillus flavus* leads to production of aflatoxin which, in high concentration, can render the seed unsuitable for consumption. Although infection occurs during the harvest period, fungal development mostly occurs during storage. Other species of *Aspergillus* occur on a range of legumes (Powell et al. 1984). In soybean, infection by *Phomopsis* spp. has been found to increase the percentage of split seeds (Sinclair 1982) and reduce oil and flour quality (Hepperly and Sinclair 1978).

Infections are more prevalent when wet or humid conditions, which permit fungal growth, occur during the preharvest period (Andrews 1982; Sinclair 1982; Onesirosan 1983; Tekrony et al. 1980b). These are also the conditions that promote weather damage. Increased fungal infection occurs following weather damage due to loss of integrity of the protective seedcoat, and the improved availability of cell solutes that provide a medium for fungal growth. Fungal infection also increases if harvesting is delayed (Ndimande et al. 1981; Paschal and Ellis 1978).

Prevention of losses due to seed pathogens may be controlled by breeding for resistance. Several sources of resistance to *Cercospora kikuchii* have been reported and resistance was found to be highly heritable. The potential for breeding for resistance to other pathogens has not been clearly established (Kueneman 1982).

The possibility of using fungicides for control of preharvest pathogens in soybean was investigated by Ndimande et al. (1981). While seed from Benomyl treated plants had less fungal infection and better germination, the fungicide did not prevent subsequent deterioration in viability during storage.

Avoidance of infection by growing seed crops in areas or seasons less conducive to fungal infection is widely practised, and is well recognised in Asia (Na Lampang 1982), but is not always a viable option in the context of Asian cropping systems (Nangju et al. 1980). Where avoidance of unfavourable conditions is a species constraint, the substitution of one species for another, such as mungbean for soybean, might be considered (Na Lampang 1982).

Insect pests cause large production losses in food legumes. The most serious pests, apart from beanfly, are the various caterpillars and sucking bugs that attack seed. These have been discussed in these proceedings by Campbell and Reed and consequently in this section we concentrate on the seed beetles (Bruchids) which infect the crop prior to harvest, and whose damage becomes most evident during storage. The most destructive Bruchid species are *Callosobruchus maculatus* and *C. chinensis*, both of which have a wide host range (Table 1). Adult beetles lay their eggs on ripening pods in the field. Hatching grubs bore through the pods, and into the seed where they feed. After harvest, adults emerge and lay eggs on the seed surface to start another generation in stored seed (Southgate 1978). Total destruction of seed can occur.

TABLE 1. Host range of Bruchid species (Birch et al. 1985).

	Bruchid species	
Plant species	*C. maculatus*	*C. chinensis*
Cajanus cajan	+	+
Cicer arietinum	+	+
Glycine max	0	
Lablab purpureus	+	
Lens culinaris	+	+
Macrotyloma uniflorum		+
Pisum sativum	0	+
Vigna aconitifolia	+	0
Vigna angularis	0	+
Vigna mungo	+	+
Vigna radiata	+	+
Vigna subterranea	+	0
Vigna unguiculata	+	+

+ indigenous, 0 introduced.

Damage to cowpea seed in storage was found to be reduced by mixing 5–10 ml peanut oil with each kilogram of seed (Chin and Yaacob 1978) but the prevention of infection in the field by the incorporation of resistance would be preferable. Resistance is rare but has been detected in cowpea (Adjadi et al. 1985; Redden 1983), mungbean (Talekar and Lin 1981), and several lesser species (Birch et al. 1985). Resistance has been associated with chemical factors such as trypsin inhibitors (Redden 1983), saponins and chemicals with insecticidal activity (Birch et al. 1985), and physical factors such as hairy pods and hard seedcoat (Talekar and Lin 1981). Physical factors such as hairy pods, which prevent egg laying in initial infestation in the field, may offer a more desirable type of resistance than chemical factors, which could affect the nutritional value of the seed.

Resistance in cowpeas was found to be recessive and digenic by Adjadi et al. (1985) while Redden (1983) found digenic control in one cross and a single major gene plus modifiers controlling inheritance in another. Redden et al. (1983) found resistance to be partly associated with levels of trypsin inhibitors, and that these were quantitatively inherited. There appear to be good opportunities to select for resistance, at least in cowpeas.

Harvest and Processing Factors

This section discusses the factors which minimise losses in seed quality from the time that the decision is made to harvest until the seed has been cleaned and is ready for either planting or storage.

These processes can be done either manually or by machine, and whilst the decision as to which to use depends on the socioeconomic circumstances, the principles for maintaining seed quality are the same.

TIME OF HARVEST

Choosing the best time to harvest can ensure both top yields and top quality (Kernick 1961). Full germination capacity and seed viability cannot occur until seed reaches full maturity (Austin 1972), which is generally indicated when a seed has reached its maximum dry weight. At this stage, nutrients are no longer flowing from the mother plant into the seed (Harrington 1972) and seeds of most species can be dried to low levels without loss of viability. To determine maximum dry weight, a seed field can be sampled successively until a steady dry weight is obtained.

The harvest of immature seed is likely to cause excessive heating, greater fungal attack, poor germination and poor vigour, also the seed will deteriorate more rapidly during storage (Kernick 1961; Matsumoto and Sawahata 1965 in Matsumoto 1977; Singh and Gupta 1982; Mugnisjah and Nakamura 1984).

If a harvest is delayed, greater losses due to seed shattering will occur and seed may be exposed to unfavourable climatic conditions such as rainfall, high humidity and high temperature. Poor seed quality due to delayed harvests has been reported by Austin (1972), Agrawal (1980), Delouche (1980), Tekrony et al. (1980a) and Mugnisjah and Nakamura (1984).

The decision to harvest will also depend upon the area of crop to be harvested, method of harvest and the prevailing weather conditions. Planning of harvest operations is much easier in crops maturing during the dry season rather than during the wet season.

THE HARVESTING PROCESS

The harvesting process encompasses all those activities up to the removal of seed from the pod and the discard of most of the pod and other plant material. Whilst these activities are many, they invariably have two distinct elements — a drying phase and a threshing phase.

DRYING PHASE

When the decision to harvest is made, the seed often has a moisture content in excess of 50%. Silbernagel and Burke (1973) recommended cutting and windrowing *Phaseolus vulgaris* when seed moisture content was 40–50%. Peanuts are normally dug, inverted and harvested when the moisture content is 45–50%. The moisture content of seeds and other plant parts, particularly the pods, must be reduced to permit efficient threshing. This can be achieved by: (i) 'droughting' the plants, i.e. removal of irrigation; (ii) spraying the crop with a desiccant; (iii) by cutting the plants and forming windrows or stooks; (iv) by digging the plants up (e.g. peanuts) and inverting them. Droughting will cause the slowest dehydration and the overall consideration as to the best process will depend upon the seed with which this drying should occur.

During this drying period the interaction between temperature and seed moisture content is most important. Whilst temperature is an important factor in seed drying, seed viability can be drastically reduced if high temperatures are experienced whilst seed moisture is very high. A balance between temperature and seed moisture content minimises viability losses during drying. For this reason, the pods should be protected within the windrow from direct sunlight.

THRESHING

The next step involves the removal of the seed from the pod which can involve two separate steps: firstly, removal of pods from other plant material by hand or combine; secondly, removal of seed from the pod by hand or mechanical threshing. Alternatively, seed may be removed in the one operation. Irrespective of the method used, there are several vital factors such as genotypes, seed size and moisture content that can affect seed quality and which should be considered in relation to threshing.

Large seeded legumes are well known for their susceptibility to mechanical damage especially at low seed moisture contents, e.g. *Phaseolus vulgaris* (Wijandi and Copeland 1974), *Glycine max* (Green et al, 1966; Delouche 1972). Seeds of *P. vulgaris* should be threshed at moisture levels of 14–15% and all seed handling completed above 12% (Silbernagel and Burke 1973). Herath et al. (1981) suggested threshing *V. radiata* at 15–20% moisture.

When seed is threshed at levels lower than these, splits and cracks to the testa, cotyledons and embryonic axis occur. However, if seed is threshed at high seed moisture levels, the damage is mainly due to bruising (Mitchell et al. 1955; Moore 1972) which, although it does not have an immediate impact on germination, can lead to loss of vigour and greatly reduced storage life (Moore 1972; Herath 1979). It is therefore important to monitor the seed moisture content prior to threshing. Portable seed moisture measuring devices are very useful for this purpose.

There is an interaction between seed moisture and the severity of the threshing process that seeds can withstand before the level of mechanical damage becomes significant. If the seed moisture level is too low, damage may be decreased by reducing cylinder speeds (Harrington 1972) and/or by threshing more slowly. Field threshing may need to cease during the heat of the day and restart when the moisture content has been increased by dewfall. However, the emphasis is often on trying to thresh as much seed as is possible in a short time period. This may be brought about by impending rain or limited availability of equipment. A balance has to be achieved between losses caused by continuing threshing and potential losses of delaying threshing. The use of rubber, e.g. rubber coated beater bars (Harrington 1972) or a rubber belt thresher (Silbernagel and Burke 1973) can minimise mechanical damage.

There is genetic variation between species, and cultivars within species, in susceptibility to mechanical damage (Butler et al. 1978; Dickson 1975; Dickson and Boettger 1976; Kannenberg and Allard 1964). Susceptibility might be due to seed and/or pod characteristics. If an area or growing season is known to experience unfavourable harvesting conditions, one of the aspects considered in choice of species or cultivars, and as a selection criterion in breeding programs, should be resistance to mechanical damage.

SEED CLEANING

Following threshing, extraneous materials (e.g. pod and plant material, other seeds, diseased seeds) should be removed. Seed moisture levels affect damage levels during cleaning operations in the same way as during threshing.

However, in the movement of seed during cleaning, damage will be reduced if: (i) the distance seed falls is kept to a minimum; (ii) the surface onto which seed falls is soft or is rubberised; (iii) elevators are used rather than augers. The objective is to treat the seed as gently as possible.

Whilst labour costs are low in many tropical areas, labour should be used in such a manner that there is an uninterrupted flow of seed from harvest through threshing, cleaning and drying. Any delays can cause seed to deteriorate because seed moisture is excessive for storage. The use of elevators and conveyors can speed up the flow of seed and should be considered if manual labour cannot be used efficiently and effectively (Gregg 1983). Similarly, machine threshing is much faster than hand threshing and is to be preferred. The cost of seed deterioration has to be balanced against the relative costs of hand and mechanical threshing.

CONCLUSIONS

Accurate monitoring of seed moisture content to minimise mechanical damage during harvesting, threshing and cleaning has been highlighted. However, it must be recognised that the period during which these operations occurs is also a period of seed storage, and the optimum moisture contents for harvest, threshing and cleaning are not satisfactory for long-term storage nor for storage under high temperatures.

Consequently, these operations should be concluded as quickly as possible. Kabeere (1983) blamed delays in harvesting and drying for poor quality soybean seed in Kenya. Getting seed dried immediately after harvest is one of the most critical aspects of seed processing in the tropics (Gregg 1983). Drying is more difficult than in temperate regions because of high seed moisture at harvest, high relative humidities, and high ambient temperatures.

For safe storage, legume seed should be dried to less than 12% and should be kept at such levels (Feistritzer and Kelly 1978).

Unless seed is harvested at times when there is no rainfall and an average humidity of less than 60%, traditional sun-drying methods are not satisfactory. This will be further aggravated if the seed production area is large. Kabeere (1983) reported that drying floors were often congested. Hence, some system of forced-air drying, with or without heat, is preferable. Because seed dryers are expensive to purchase and require considerable technical expertise to operate, the opportunity exists for specialist contractors to undertake this operation in the same way as occurs for harvesting and threshing in some areas.

Storage

The ability to store food sucessfully over long periods of time has been fundamental to human endeavours. Urban populations are placing increasing demand on farming systems to provide a stable and balanced food supply chain. Such a transfer of product from the farming region to the consumer relies heavily on the success of storage operations. Nowhere has this task proved more difficult than in the humid tropics where losses are substantial.

Two major storage categories need to be recognised: (i) seed for edible consumption where we are concerned with the concept of protection; (ii) seed for sowing or sprouting where there is the additional problem of seed viability retention. Clearly, the maintenance of production cycles with improved genotypes depends on supplies of good quality planting seed. This has proved an acute problem, with rapid viability deterioration, and often reliance placed on out of season crops to maintain the cropping cycle.

The quality of legume seed in storage depends on four major factors: (i) initial quality entering storage; (ii) hygiene and protection of the seed; (iii) species and cultivars within species; (iv) the storage environment: temperature, moisture, warehouse design, gases.

INITIAL QUALITY

The quality of material entering storage is fundamental to the success of the storage system. Problems associated with insect infestations (often as eggs on seed entering storage), internal infection of seed and the level of surface microorganisms could be extensively reduced or eliminated in the field. The use of field spraying could provide important advantages for storability of seedlots, with the use of residual antibiotics an interesting concept (P. Berjak, pers. comm.).

The drying process often magnifies problems of later storage, with implications for both protection and viability. High temperature and rapid drying reduce viability (Hill and Johnstone 1985). The spectrum and activity of microflora are determined by water activity and temperature of stored seed (Lacey et al. 1980), with an ecological succession of fungal species from 70% RH to aflatoxin types. Control implies prevention of this ecological chain in the first instance.

As shown in the section on harvest period effects, higher moisture levels are required for harvest than for storage, so drying is frequently necessary.

Tekrony et al. (1980a) showed solar drying to 12% moisture was always associated with a decline in quality, and delay in harvest after 12% moisture was associated with further major declines in both germination and vigour of the seed. Solar drying can be associated with quite high seed temperatures, particularly for black seeded cultivars. The sensitivity of large seeded legumes to mechanical damage is particularly important (Delouche 1975), and increases with the dryness of the seed.

The quality of seed leaving storage will be directly proportional to initial quality (Ellis and Roberts 1980b, 1981) entering storage (Fig. 1), thus emphasising the need for a critical appreciation of pre-storage history, the measurement of quality and selection of suitable seed for storage.

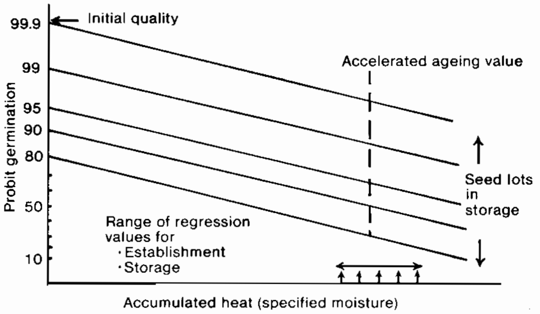

Fig. 1. Parallel probit scale deterioration for seedlots of different initial quality.

Probit regression analysis (Ellis and Roberts 1981; Heslehurst 1986) provides accurate assessment of initial quality, accurate values for the classical accelerated aged values (Delouche and Baskin 1973; Baskin 1981; Matthews 1980, 1981; Powell and Matthews 1981), and a range of regression values (Heslehurst 1986) that can be correlated with storage potential and crop emergence values under field stress conditions (Ellis 1986; Ellis et al. 1986). Furthermore, genetic differences can be quantified.

HYGIENE AND PROTECTION

Storage hygiene is an organised management approach to pest control which incorporates all available measures — physical, biochemical and chemical — to achieve control throughout the handling system (Heather 1983). Even where inspections are made it is easy for incoming infestations not to be noticed. O'Dowd and Dobie (1983) provide an excellent treatment of pests and their control in tropical seed stores.

Residues Spillages and surface dusts represent attractive food supplies for pests, and their destruction (burning, burial) or removal beyond the migration range provides the first important step in raising storage standards and reducing losses. In any grain store stocks should be maintained in an organised manner, sorted according to age and infection risk, and suitably arranged in neat stacks on pallets. Such organisation facilitates subsequent cleaning, minimisation of spillage and dust, ventilation, baiting and fumigation procedures (Hall 1970; Heather 1983).

Chemicals A wide range of chemical options is available for protection, ranging from insecticidal surface fabric treatments, to seed protectants, aerosols and fumigants (Taylor 1975; Bengston 1976, 1978; O'Dowd and Dobie 1983; Champ and Highley 1986). Most registrations relate to cereal grains, with little information available regarding suitability to legumes. Some deleterious effects have been reported (Taylor 1975), and there is a need for more research on protectants for legume crops. As well, control of the bruchid group provides an important difference to cereal pests (Howes and Currie 1964; O'Dowd and Dobie 1983; Giga and Smith 1983).

The development of resistance, as found with malathion, poses a continuing threat for the useful life of insecticides (Hall 1970; Heather 1982, 1986). Management plays an important role in delaying such problems (Heather 1983), and careful rotation of insecticides with fumigation treatment should provide a complete kill of residual populations. Phosphine has provided the benefits of fumigation without deleterious effects on seed germination or food value (O'Dowd and Dobie 1983).

Rodents/Birds Legume seed provides attractive food for rodents and birds. Control begins with building design, proofing procedures and hygiene, and leads to baiting programs. The one-dose warfarin bait has improved rodent control potential, providing that constant vigilance is maintained regarding the numbers, positions and freshness of baits (Hall 1970; Mallis 1945; Hadlington 1971; Woodhouse 1983; Hadlington and Gerozisis 1985).

Periodically problems occur with birds in seed stores, and a variety of controls exist involving exclusion (wire mesh, plastic drapes), trapping, shooting or baiting (Anon 1973; Tyler 1979).

Admixtures/Biological Control/Packages Admixtures of local plants, dusts (woodash, sand), mixed species (small millets with larger seed) or insecticides have been reported to improve storage (Hall 1970).

In seeds for human consumption, insecticides and fungicides may not be desirable, and natural protectants such as peanut oil or soybean oil (1–3 ml/kg of seeds) have been used to suppress weevil reproduction, with no interference to germination rates (Chin and Yaacob 1978).

Biological controls offer fascinating mechanisms (Teakle 1982; Dobie 1984), but little practical application compared to chemical or environmental methods.

One of the most exciting developments in protection has been the use of laminated flexible packaging materials with insect penetration resistance (Cline 1978; Wohlgemuth 1979; Schmidt 1980). Such systems need further testing, and have nil tolerance for initial seed infestation, but provide an important complement to existing packaging systems of viability preservation.

SPECIES AND CULTIVARS

In many crops some varieties are less suitable for insect development than others, showing more resistance to attack (Giga and Smith 1981). In some legumes, the seed pods may provide a very efficient barrier to infestation, compared with shelled seed (Dobie 1984).

Beetles of the family Bruchidae are an important legume seed pest, sticking their eggs to the outside of the seed. Fewer eggs are laid on the seedcoat of rough coated compared to smooth coated varieties. Hard seeds have also been found less susceptible to insect attack (Dobie 1984).

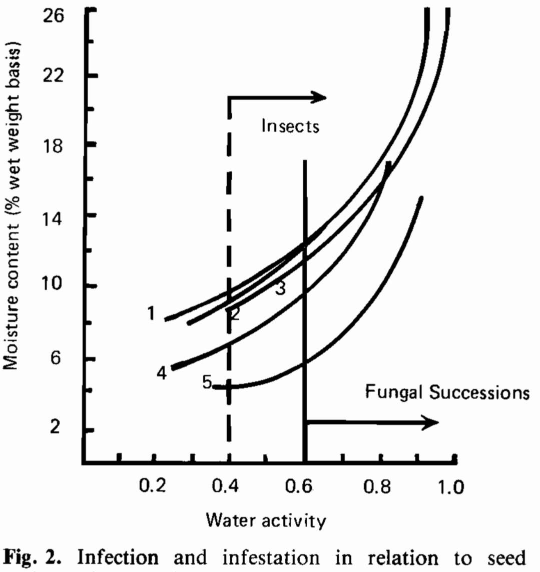

Fig. 2. Infection and infestation in relation to seed moisture for low oil content cereals (1 wheat, 2 barley, 3 maize) and high oil content legumes (4 soybeans, 5 groundnuts).

The higher oil chemical composition of soya bean and groundnut makes them more susceptible to microorganism growth (Fig. 2) than cereals (Lacey et al. 1980), because of the difficulty of reducing the water availability to appropriate levels, and the associated fragility of the seed. A water activity of 0.6 is necessary to limit fungal growth, and this corresponds to 6% seed moisture for groundnut, 7% for soybean and 11% for starchy cereal seeds (Pixton and Warburton 1971). Varietal selection for oil content in soybean could accentuate storage problems, whilst species such as chickpea, mungbean or cowpea with starch or protein storage chemistry are less susceptible to fungal growth. Resistance to field infection of seed remains an untapped area worthy of more intensive investigation. Selection of groundnut cultivars with testa resistance to aflatoxin infection (Graham 1982) highlights the potential in this area.

Viability retention also varies with species. Deterioration of legumes is generally faster than that of rice, and requires much greater drying or cooling for equivalent life spans (Fig. 3) (Ellis et al. 1982; O'Dowd and Dobie 1983; Ellis 1986). Considerable variation exists between the legume species in viability/longevity characteristics (Ellis et al. 1982), with soybean and groundnut notoriously poor (Delouche 1975; Ellis and Roberts 1980a).

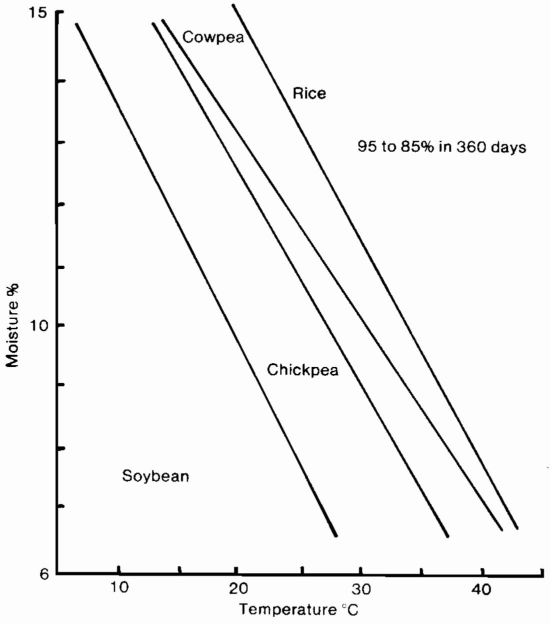

Fig. 3. Species variation in moisture/temperature requirements for 12 months storage.

STORAGE ENVIRONMENTS

Temperature and Moisture Temperature and moisture control the age deterioration viability for seed in storage (Roberts 1972, 1981). They also offer important controls for insect and microorganism growth (Fig. 4), and thus together represent the key to storage deterioration. Fortuitously, cool dry conditions both preserve and protect seed. The growth and reproduction of storage fungi, which contribute to quality losses in seed, are highly

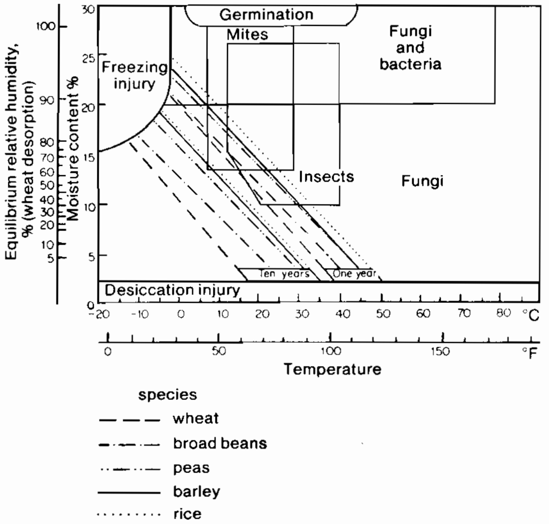

Fig. 4. The relationship between seed moisture content and storage problems at a range of temperatures.

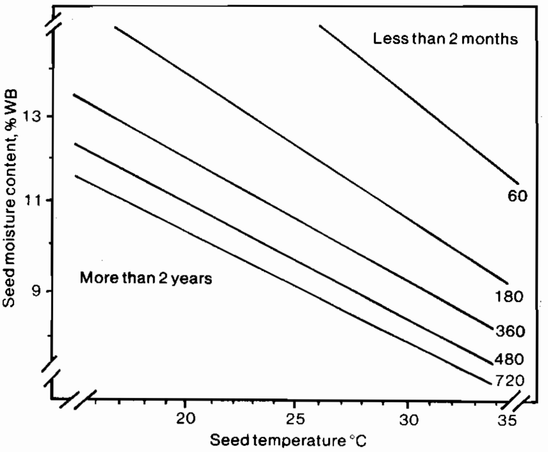

Fig. 5. Storage life isochrones (days) for deterioration (96 to 85%) in viability of chickpea under various combinations of temperature and moisture.

dependent on relative humidity within the seed mass (Christensen 1973; Lacey et al. 1980). The more important storage fungi cannot grow and reproduce in seed or grain in equilibrium with a relative humidity less than 65%. Activities of storage insects also drops sharply at relative humidities below 50% (Fig. 4) (Taylor 1975) although stored product insects are in some cases able to grow at a relative humidity of 40% (Harty and Heather 1984). The uniformity of these conditions within the seed mass is of paramount importance, as isolated moist areas begin a chain of fungal successions (Hill and Johnstone 1985), which generate high temperatures and moisture levels suitable for insects, beginning the problem of moisture migration in storage.

Both moisture and temperature act logarithmically and independently on viability deterioration. A rise or fall of 1% moisture or 5°C can halve or double the life span of seed (Harrington 1963). Improved viability equations relating longevity to moisture and temperature (Ellis and Roberts 1980c) have been developed for soybean, cowpea and chickpea (Ellis et al. 1982). Probit analysis can be utilised to predict required moisture/temperature combinations necessary for quality retention over predetermined storage durations, and allow for variation in initial quality (Fig. 5) (Ellis 1986). This approach (Fig. 6) provides for a better practical guide to location and seasonal effects than those previously used (Harrington 1963; James 1967; Delouche et al. 1973), and allows precise information of the loss of percentage viability that will occur in a specific seedlot when stored for a

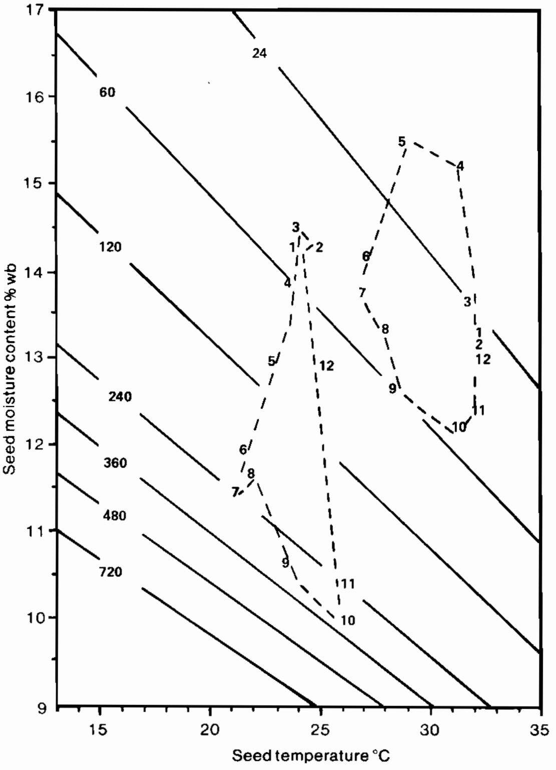

Fig. 6. Climatographs using moisture/temperature and seed deterioration (95 to 85%) life spans (days) for two storage locations with monthly seasonal changes (January = 1 etc).

known period in a known environment. Suggested combinations of temperature and moisture for short term storage (9, 18 or 36 months) of cowpea, chickpea and soybean are tabulated by Ellis (1986). Long-term storage combinations can be calculated accurately from equations (Ellis et al. 1982) or approximated from nomographs (Roberts 1972).

Whilst suffering from the problems of accurate identification of seasonal and diurnal relative humidity values, together with the inertia of seed masses for quick response, the probit analysis (Ellis 1986, Fig. 6) allows comparison of locations in terms of seed deterioration potential, and isolation of seasonal effects.

Aeration/Gases The use of inert gases such as nitrogen and carbon dioxide provide interesting methods for sealed storages (Banks and Annis 1984), but aeration (Elder 1969) of open silos has more potential, particularly where cooling is refrigeration-assisted (Taylor and Elder 1981). Principles are described by Griffiths (1964, 1967), and methods detailed by Bloome et al. (1974a, b) and Bowland (1983). Taylor (1975) detailed effects of atmospheric gases on seed viability, recommending that moisture contents should be at least 2% less than that considered safe for open storage. Ellis et al. (1969) state that oxygen effects in air dry storage are small, and not greater than errors associated with moisture measurement.

Packaging/Warehouses Delouche (1975), Harty and Heather (1984) and Tekroney et al. (1980a) highlight the problem associated with the need to maintain quality in carryover seed from crop to crop. In tropical areas where average temperature may be as high as 25°C, moderate controlled environment storage may be necessary to maintain seed quality. Such systems rely on air-conditioning a well constructed storeroom to less than 22°C, with relative humidity less than 60%, to provide 8–9 months of reasonably good quality, providing intake quality was high (> 90% germination).

However, the bulk of seed is usually too large to accumulate supplies in controlled environmental storage, and the species too short-lived to carryover in routine warehouse storage. Packaging of seed at low moisture levels (< 9%) in moisture-resistant flexible polythene bags provides an important alternative strategy (Justice and Bass 1978; Harty and Heather 1984). Moisture permeability of plastics varies enormously, but can be combined with insect-resistant nylon (100 μ) in laminates. Such packaging systems have important flexibility for gradual distribution, containerisation and the unpredictable seasonal carryover of seed. They cope with the large bulk associated with warehouse storage without the capital cost problems of controlled environments. Avoidance of pesticide application onto seed also becomes feasible and the need for it unnecessary in short term storage packs (Chin and Yaacob 1978). The application of innovative methods using local materials for small on-farm storage of farmer-saved seed in sealed containers is being addressed in many different locations. The principles are well known (drying and sealing), although application has lagged, requiring much extension effort. However, the problem of genetic drift over generations of farmer-saved seed is immense (Dorado and Roberts 1984).

Building design provides an important method of modifying the environment. O'Dowd and Dobie (1983) illustrate ways in which viability losses can be reduced in open seed stores in tropical climates. Appropriate choice of building materials and design lowered warehouse temperature 11°C on average. Insulation provides the key, and designs to deter insect and rodent infestation are important (Harty and Heather 1984).

Wall and roof design should minimise the chances of accumulating seed residues and dust, with use of sharp dust shedding angles instead of horizontal ledges. Waterproof ceilings, walls and floors, together with ease of fumigation are major considerations for design. The effect of solar heating can be minimised with the building orientated east-west, use of wide eaves along the warmest side, reflective exterior walls, and insulation provided by choice of building materials. Well designed ventilation facilitates cooling of the warehouses.

Conclusions

The potential yield at physiological maturity will only be realised if losses during maturation, harvest, and storage are prevented. Most losses occur due to the effects of weather, pathogens, and insect pests reducing both yield and quality of seed as it passes through these production stages. Deleterious changes during the preharvest and harvest periods can increase the level of damage and deterioration sustained during subsequent harvest and storage periods.

Seed yield and quality reduction derive to a large extent from changes to seed physical and chemical properties that have occurred during domestication. Increased seed size, thinner seed coats and reduced levels of hardseededness and antimetabolites have made seeds more vulnerable to physical damage and more prone to insect attack and fungal infection.

Seed characteristics of modern cultivars increase their susceptibility to weather damage, which causes reduced germination and vigour, and makes seeds more susceptible to pathogens and deterioration during storage. Research has indicated that these losses can be reduced by reversing the direction of selection to regress more towards the ancestral type, and by avoiding the culture of crops during seasons and at locations where conditions conducive to high damage levels prevail.

The timing of harvest operations is critical and seed should be harvested at maximum dry weight. Seed moisture content should be closely monitored such that threshing, cleaning and handling are undertaken at approximately 14–15% moisture. At higher levels, e.g. above 20%, bruising can become significant whilst below 12% seed fracture can become substantial.

Care should be taken at all times to handle seed gently, particularly at lower levels of seed moisture, and the use of rubberised surfaces helps minimise damage. Harvesting, threshing and cleaning should be undertaken without delay. Failure to do so will cause seed to deteriorate because the optimal moisture content for such processes is too high for satisfactory storage. The use of manual and mechanical procedures needs to be integrated to this end. If delays occur, the procedures need to be modified or replaced, with seed dried to below 11–12% for safe storage.

The final quality after storage is related to the initial quality of seed entering storage, and is influenced by infection and infestation during storage.

The susceptibility of seed to deterioration, infection and infestation is influenced by cultivar and species. Adoption of hygiene and chemical options provides an important method of protecting seed against infestations. Environmental manipulation provides a major method to control insects and microorganisms and to maintain viability. Probit analysis provides a new method for predicting deterioration levels during storage sequences.

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Utilisation of Legumes as Food

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LEGUMINOUS plants that produce edible parts are generally referred to as food legumes. The term grain-legume is commonly used to denote legumes that produce edible seeds, and to distinguish them from numerous others that produce edible vegetative parts. Grain legumes are the subject of this paper and they will be subsequently referred to as legumes for the sake of simplicity. Two other terms, namely, pulses and oilseeds are also in common use, particularly in the eastern world. The world 'pulse' has been used from biblical times to describe legumes that bear edible dry seeds that are directly consumed by man. In contrast, there are other legumes which have been traditionally used as sources of edible oil rather than for direct consumption. These are called oilseeds.

Legumes of economic importance are produced both in the tropical and temperate zones. A partial list of the more important species, along with the main geographical areas of production, is presented in Table 1. The areas of production are also usually the areas of wide consumption. However, in the case of oilseeds, such as soybean and groundnut, a large proportion of the production enters international trade in raw and processed forms.

Examination of the world production of legumes (Table 2) shows interesting trends. Approximately 75% of the total world output of pulses and 90% of the peanut crop are produced in the developing countries. Asia alone produces 51% of the world pulse crop and 68% of the world peanut crop. In contrast, the developing countries' share of the world soybean crop is only 42%, of which, more than half comes from South America alone. The soybean continues to be a commercial crop, produced largely in the United States. It is exploited primarily for oil and export to the Orient, where it is traditionally consumed. In recent years, many countries in Asia and Africa have focused on the soybean as a potential food crop. More will be said later about this aspect.

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Legumes as a Food Source

In the present context of protein-calorie malnutrition and undernutrition which is so prevalent in the developing world, the potential contribution of legumes to human nutrition cannot be overemphasised. Commonly consumed legumes contain 17–34% protein (Table 3). The potential for protein production from a unit land area is greater for legumes, compared to animal sources. Soybeans and groundnut (peanuts) are unique in that they are rich in both protein and high-quality edible oil. The desire of man for animal foods is universal, irrespective of the economic conditions. However, plant foods continue to be the major source of both calories and protein for people in developing countries. Approximately 90% of the calories and over 80% of the protein in the diets of many Asian countries are derived from plant sources (Table 4). In comparison, the developed countries derive only 70% of the calories and 43% of the dietary protein from plant sources.

A wealth of scientific knowledge has accumulated over the years, concerning the nutritional complementarity between cereals and legumes. The deficiency of the essential amino acid, lysine, in cereal protein is complemented by legume proteins which are richer in lysine content. Likewise, the sulfur-bearing amino acids, which are relatively rich in cereals make up for their deficiency in legume proteins. There is general consensus that the protein quality of cereal/legume combinations providing 50% of total protein in the blend from each ingredient, approaches the quality of milk protein (Bressani and Elias 1974). Legumes such as peas, chickpeas, lentils, green gram, black gram, pigeonpea, horsegram, black beans, bengal gram, peanuts and soybean have been used in the experimental production of blended foods and their nutritional evaluation (Bressani and Elias 1974). The total protein content of dry cereal staples varies from 8–11%, depending on the source. In prepared cereal foods, such as cooked rice and gruels, the protein content is further diluted by hydration. Consequently, weaning and weaned children are

TABLE 1. List of important food legumes

Legume	Common name(s)	Areas of production
Cajanus cajan	Pigeonpea, Red gram, Congo bean	India, Pakistan, Middle East, Africa
Cicer arietinum	Chickpea, Bengal gram	India, Pakistan
Lens esculenta	Lentil, Split pea, Red dhal	Near East, India, Africa, Central and South America
Vigna radiata	Mung bean, Green gram	Asia, Africa
Phaseolus lunatus	Lima bean, Butter bean	Tropical America, West Indies, Madagascar
Phaseolus mungo	Black gram, Urid dhal	India, Iran, Africa, West Indies
Phaseolus vulgaris	Kidney bean, Navy bean, Pinto bean, Haricot bean	North, Central and South America
Pisum sativum	Pea, Green pea, Garden pea	Temperate zones, India, Africa
Vigna unguiculata	Cowpea, Blackeye pea, Kaffir bean	Asia, Africa, China, West Indies
Glycine max	Soybean, Soja	North America, Brazil, China
Arachis hypogaea	Peanut, Groundnut	Asia, Africa, North and Central America
Vicia faba	Faba bean, Broad bean, Horse bean	Temperate zones, Near East, Africa, South America

Source: Siegel and Fawcett (1976); Purseglove (1968)

TABLE 2. Legume production statistics for 1983, ('000t)

	Pulses			Oilseeds	
	Total	Lentils	Chickpea	Soybean	Peanut
World	43662	1496	6827	78566	19792
Developing countries	32599	1323	6737	32718	18092
Asia (excluding USSR)	22337	1189	6243	12352	13410

Source: FAO 1983

TABLE 3. Composition of food legumes (percentages)

Legume	Moisture	Protein	Ash	Fibre	Fat	Carbohydrate
Pigeonpea	10.1	19.2	3.8	8.1	1.5	57.3
Chickpea	9.8	17.1	2.7	3.9	5.3	61.2
Lentil	11.2	25.0	3.3	3.7	1.0	55.8
Mung bean	9.7	23.6	4.0	3.3	1.2	58.2
Lima bean	12.6	20.7	3.7	4.3	1.3	57.3
Black gram	9.7	23.4	4.8	3.8	1.0	57.3
Kidney bean	11.0	22.0	3.6	4.0	1.6	57.8
Pea	10.6	22.5	3.0	4.4	1.0	58.5
Faba bean	14.3	25.4	3.2	7.1	1.5	48.5
Cowpea	11.0	23.4	3.6	3.9	1.3	56.8
Peanut	5.6	26.0	2.3	2.4	47.5	16.2
Soybean	8.0	36.7	4.6	2.4	20.3	28.0

Source: Purseglove 1968; USDA 1968

TABLE 4. Per capita availability of calories and protein in some Asian countries — 1978-1981

Country	Calories			Protein (grams)		
	From Plant Sources	From Animal Sources	% From Plant Sources	From Plant Sources	From Animal Sources	% From Plant Sources
India	1952	104	97.7	44.2	5.5	88.8
Bangladesh	1771	66	86.1	34.4	5.3	86.6
Pakistan	1949	231	89.4	43.0	13.4	76.2
Nepal	1801	132	93.2	39.3	6.7	85.4
China	2180	246	89.9	47.6	11.1	81.2
Sri Lanka	2160	95	95.8	36.3	8.5	81.0
Thailand	2177	152	93.4	34.7	12.2	73.9
Malaysia	2165	353	85.9	31.1	24.9	55.4
Singapore	2477	689	78.3	43.4	38.7	52.9
Indonesia	2320	53	97.8	43.1	5.8	88.3
Burma	2326	94	96.1	53.6	8.0	87.0
Philippines	2176	228	90.5	34.9	19.0	64.7
Developed countries	2355	1030	69.6	42.7	56.2	43.2

Source: FAO 1983

unable to consume sufficient quality of cereal foods to derive their daily protein needs. Blending of legumes with cereals results in increased protein density so that relatively lower volumes are required to derive the protein requirements.

Traditional Methods of Legume Utilisation

A large number of traditional food preparations are made from various species of legumes. These vary with countries and regions, and also with the species which predominate in the respective geographic locations. However, most of these traditional foods can be classified under several simple techniques used in their preparation. These techniques can be summarised as decortication, boiling, grinding, roasting, frying, puffing, germination, fermentation, curdling, and pasta making.

Decortication

Decortication refers to the removal of the seed coat (hull) which results in the separation of the cotyledons. In the rural sector, the decortication process is still a part of the housewife's work in food preparation. In the case of black gram, green gram and cowpeas, where the hull is firmly attached to the cotyledons, water soaking is used to facilitate hull removal. The hulls absorb moisture and swell, thereby facilitating dehulling by gentle rubbing of the seed by hand. The hulls are easily separated from cotyledons by flotation. At this stage, the cotyledons are wet and must be used immediately.

Pounding by mortar and pestle is a common operation in the kitchen in many countries. Pounding of legumes followed by winnowing is also a common method of hull removal. In India and the neighbouring countries, dry dehulled pulses are commonly called dhal. Many types of dhal are centrally processed in mills and sold as a ready-to-cook commodity. Much work has been done in India on the commercial milling of pulses, particularly concentrating on efficiency of decortication and minimising milling losses (Kurien et al. 1972).

Application of dry heat to legumes at various moisture levels for different periods of time improves dehulling efficiency. Dry heating without hydration results in drying of the hull, which becomes brittle. Mechanical means of hull removal are more efficient after such dry heating. On the other hand, when dry heat is applied to partially hydrated legumes, the cotyledons shrink more than the hull. As a result, the hull is loosened from the cotyledon (Kurien and Parpia 1968). Dry heating in the open pan or in a sand bed is commonly adopted in the home.

Boiling

Boiling or cooking of dhal and whole legumes in water is the most common method of preparation. On the Indian subcontinent, dhal, cooked to a soft consistency, is seasoned with spices and condiments and consumed with the cereal staples. Cooked and mashed legume purees are popular in Africa and the Middle East (Siegel and Fawcett 1976). Boiled whole beans such as mung bean, chickpeas and faba bean are also directly consumed with grated coconut or oil sauce. In all these cases, the cooking time required to attain a soft consistency is an important consideration. While certain pulses, such as lentils and mungbean require short cooking time, others such as cowpeas, dry beans, and soybeans require prolonged cooking time.

Roasting

Dry roasted pulses are eaten as snacks in many countries of the semi-arid tropics. Whole chickpeas and cowpeas are popularly consumed this way in Africa, while in India and neighbouring countries, various pulses are directly consumed after roasting. In India, chickpeas are sprinkled with water containing salt to taste, and roasted in a hot sand bed in a dry pan. Roasting achieves a high-temperature, short-time heat treatment, during which the seed attains a pleasing nutty flavour which is well liked by both children and adults. In addition, the heating process improves the nutritional value of pulses due to the inactivation of certain heat labile antinutrients naturally occurring in them (Acharya et al. 1942).

Frying

Frying in hot oil is carried out with preprocessed legumes to produce a variety of food products. Combinations of fully or partially ground legumes and cereals are made into dough and oil fried, to produce popular Indian foods such as waddai and murukku. Oil cakes from dry bean paste made in Brazil, ready-to-eat fried snacks made from ground legume pastes in Nigeria, and filafi made from chickpea paste, are other examples of oil-fried legume foods (Siegel and Fawcett 1976). The constraint against this type of food is the shortage of frying oil in many countries.

Puffing

Puffing of cereals and legumes is a traditional home process in many countries. The process consists of partial hydration of the seed, followed by dry heating at high temperature. The sand bed is commonly used for puffing in the Indian household. Rapid heating causes partial gelatinisation of starch and the vaporisation of internal moisture, causing pressure which eventually results in explosive puffing. The puffing process renders a light and porous texture to the product. Small and medium scale puffing equipment is used for the commercial scale manufacture of these products.

Germination

Germinated legumes (bean sprouts) are a popular food item in the Orient as well as in India to some extent. The production of bean sprouts is done usually at the home or on a small scale. Sprouted soybean and mungbeans are year-round vegetables in Southeast Asia. Sprouting brings about certain desirable chemical changes of nutritional significance. Ascorbic acid, which is absent in dry soybeans, appeared in the first 24 hours during germination and reached a value of 290 mg/100g at the end of three days (McKinney et al. 1958). There was also a rapid disappearance of oligosaccharides, raffinose and stachyose, which are implicated in flatus (Lee et al. 1959). Increases in levels of thiamine, riboflavin, niacin, pyridoxine, biotin and tocopherol during germination of various Indian pulses has also been reported (Siegel and Fawcett 1976).

Fermentation

Fermented food products made from various food raw materials form a significant portion of the diets of Mongolian populations. Such products are specific to countries or regions on account of the characteristic flavours associated with the respective fermentations. Among the food legumes, soybean is the single most important raw material used in fermented food preparation. Some of the important fermented soybean products are shoyu (soy sauce), miso, tempeh, natto, hammanatto, and sufu. With the exception of shoyu, all the other fermented products are produced in the home or as small-scale industries.

Shoyu or soy sauce is typically a commercial product made from cooked whole soybean (or extracted meal) and wheat. The fungus *Aspergillus oryzae* is the organism which produces proteases and amylases which breakdown the protein and carbohydrate substrates during fermentation. Fermentation, followed by ageing, produces the rich flavoured peptides present in shoyu. As a flavouring and seasoning agent, shoyu finds wide acceptance in the West as well. In 1980, Japan alone produced approximately 135 million gallons of shoyu and per capita consumption was 27 grams/day.

Miso is a fermented soybean paste made from soybeans and cereals, mostly rice. The product undergoes two stages in the fermentation. The first stage, which is koji preparation, is an aerobic process involving the fungi *Aspergillus oryzae* and *Aspergillus sojae*. This process yields the enzymes and nutrients required for the second stage of fermentation, which is anaerobic, and involves yeasts and bacteria. Japan alone produces approximately 750 000 t of miso annually and per capita consumption has been estimated at 21 gram/day (Shurtleff and Aoyagi 1983).

Tempeh is a traditional Indonesian food prepared from cooked soybeans by a fermentation using the mould *Rhizopus oligosporus*. The mould binds the soybeans into a cake which is then cut into pieces, fried in oil and used in many preparations. The product is not shelf stable and is therefore made on a small scale or in the home. Large-scale production involves refrigeration storage. Tempeh does not contain salt which is used as a preservative in both miso and shoyu. Tempeh production in East Asia is estimated at 169 000 t per year.

Natto is produced by a bacterial fermentation involving *Bacillus natto Sawamura*, identified as *Bacillus subtilis*. The product has a musty odor and sticky consistency due to polymers produced during fermentation. Natto has a short shelf life and is used in specific regions of Japan.

Sufu is a popular fermented food in China. Sufu making involves the production of soybean protein curd (tofu) and its subsequent fermentation using species of *Mucor* and *Actinomucor*. The mould forms a mycelial mat on the tofu which is then preserved in salt brine containing rice wine. Sufu is consumed directly as a relish, or is cooked with vegetables and meats.

Besides the Oriental fermented soybean foods, there are few fermented legume foods traditionally consumed in other parts of Asia. In India, wet ground black gram and rice batter is naturally fermented and the resulting dough is used for preparing idli and dosai. Likewise, in Africa, ewa and soumbara are food preparations made from fermented legume pastes (Aykroid and Doughty 1964).

Fermented legume foods are of great significance from several considerations. Many of the products are shelf stable, on account of both the products of fermentation and preservatives used in preparation. This is an important aspect in regions where household refrigeration is unavailable. Much evidence has been accumulated to demonstrate that the fermentation processes cause partial breakdown of proteins, resulting in increased digestibility. Furthermore, fermentation has been found to partially inactivate natural antinutrients that are contained in legumes (Liener 1962; Ebine 1972).

Beverage, Protein Curd, and Pasta

The milk-like suspension prepared by wet grinding and filtration of soaked soybean has been a popular beverage of the Chinese people for centuries. The product commonly called soymilk is prepared by a number of methods. The traditional Oriental method uses the cold grinding technique, which results in a characteristic beany flavour which is liked by the Chinese people. However, this flavour is not acceptable to many other populations. As a result, other methods have been developed to minimise the beany flavour (Hand et al. 1964; Mustakes et al. 1971). In all of the above processes, the filtration step results in a residual wet cake (okara) which carries roughly half the protein originally present in the bean. Nelson et al. (1975, 1977) have developed a new process which incorporates all of the soybean solids into the milk and also eliminates the beany flavour. The bland beverage, which can be flavoured according to preference, has become a well-established commercial product in Japan, Taiwan, Hong Kong, Singapore, Korea, Thailand, and in recent times, even in the United States (AOCS 1984). The world soymilk production has been estimated at one million t per year, utilising approximately 130 000 t of dry soybeans.

Soybean curd (tofu) is an equally popular product prepared by precipitation of protein from soymilk, followed by pressing out of whey. As in the case of soymilk, tofu production technology has now advanced from the traditional home scale to the semicontinuous commercial scale. A very versatile product, tofu has gained wide acceptance in many countries where it is not a traditional food.

Pasta products such as noodles are also typical oriental foods. From the point of view of legume utilisation, mung bean noodles are of particular importance. Mung beans contain about 25% protein and also considerable amounts of starch. Traditionally, mung bean flour is mixed with wheat or rice flour in the preparation of noodles. Among common food legumes, mung beans had the lowest concentrations of raffinose and stachyose. Therefore, the flatulence problem was minimal in child feeding (Payumo 1978). Concentrated and isolated mung bean protein has been used in weaning foods such as 'Kaset Protein' prepared in Thailand (Bhumiratana 1978).

Non-traditional Approaches

Composite Flours

The descriptive term 'composite flour' refers to mixtures of wheat flour with other starch and protein sources derived from cereals, roots, legumes, and oilseeds. Flour-based products, both leavened and unleavened, are either traditional or rapidly gaining popularity in developing countries. Bread, for example, has attained universal acceptance. The introduction of protein-rich legumes into cereal flour has great potential for increasing the consumption level of protein in all segments of a population. This concept has been researched since the turn of the century. Unfortunately, the concept has developed in the context of new technlogies in baking, rather than for improved protein nutrition as such. Much of the research in composite flour is centred around the application of new baking technologies and their effect on the baked bread quality as perceived by the consumer in the developed countries. In developing countries, bread is made by traditional batch fermentation, often on a small scale, using manual methods. Therefore, much of the new technology on composite flours is not directly relevant to the needs of developing countries.

Furthermore, the consumer preference for physical characteristics of bread, such as loaf volume, texture, crumb and crust are not universal. In fact, great variation in such characteristics may be seen in bread sold in a given country in the developing regions. Therefore, the need exists for adaptive research in application of the composite flour concept under traditional baking conditions. On the other hand, there are many unleavened products made in developing countries from both wheat flour and other cereal flours. In such cases, the question of loaf volume is not an important consideration. Therein lies great potential for the incorporation of legume protein in larger proportions than is possible in bread making.

The greatest constraint against practical application of the composite flour concept seems to lie in the logistics of its production. Cereal flours are made by a process of dry milling, using conventional milling equipment. The milling of legumes cannot be done in the same process flow, and calls for different methods of dehulling, pretreating and grinding. Once ground, the two types of flour have to be blended in the desired proportion. The overall process involves, among other things, additional capital expenditure for legume milling and blending, transport and storage of legume on-site, and harmonising the two production lines. These and other constraints make composite flour production a process yet to be commercially exploited. The alternative to centralised production is the small-scale manufacture of the legume flour, making it available for blending at the point of utilisation. Some degree of success has been achieved by this approach in Sri Lanka, under the Sri Lanka Soybean Development Program.

Weaning Foods

Uneven distribution of the available food supply among different income groups, and even within the family unit, results in the so-called nutritionally vulnerable groups in populations. The weaning children and pregnant or lactating mothers have been the focus of many nutrition intervention programs designed to alleviate malnutrition in developing countries. Many countries have received cereal/legume blended weaning foods such as corn-soy-blend (CSB), corn-soy-milk (CSM), and instant-corn-soy-milk (ICSM) under the PL480 Food for Peace Program from the United States. For a number of economic reasons, in the mid-1970s, both the donor and recipients of these products recognised that it was desirable to explore ways of processing these products in the recipient countries (Harper and Jansen 1985). As a result, several countries such as Sri Lanka, Costa Rica, Tanzania, Guyana, and Mexico have established local production facilities, manufacturing weaning foods from locally grown cereals and legumes. In addition, Guatemala, Korea, India, Philippines, Thailand, and Ecuador have ongoing research and production level programs for weaning foods under government, private and/or non-profit organisation sponsorship.

In most of the above cases, the product has been utilised for the specific nutrition intervention programs. While the value of such programs cannot be underestimated, the availability of these products to the general consumer could greatly enhance their positive impact on the overall population.

Textured Vegetable Proteins (TVP)

The conversion of vegetable protein materials into food products with meat-like texture has been described as one of the great food inventions of all time (Horan 1974). Soybean is by far the major raw material used in the production of textured protein products. Textured soy protein products are produced by a thermoplastic extrusion process, using defatted soy flour or soy protein concentrate as raw material. The extrusion process imparts a molecularly aligned and expanded structure to the product. Upon rehydration, it takes up over twice its weight of water and possesses a chewiness similar to that of cooked muscle tissue. Textured products are usually used as meat extenders in soups, stews, hamburger patties, curries, sausages, etc. However, they can also be directly cooked and consumed with proper spicing and seasoning. In 1971, the United States approved the use of 30% (wet basis) textured soybean protein as meat extender in the school lunch programs. The major constraints against application of this technology in developing countries is that it is subject to the availability of high quality defatted meal (or concentrate) and the high capital investment involved.

Constraints to Utilisation

Insufficiency

The overall efforts to increase consumption of legumes in a population must be viewed in the context of the production and availability of these legumes. The production aspect of legumes is beyond the scope of this paper. While the green revolution of the 1960s resulted in phenomenal improvements in rice and wheat production in developing countries, its impact on other crops is being felt only in more recent times (Anderson and Hazell 1985). Many countries in Asia and Africa are exploring the potential of highly cost-efficient, but nontraditional legumes such as soybeans for direct human consumption. The success of the attempts to increase consumption of legumes depends, to a great extent, on the development of utilisation strategies hand-in-hand with increasing production.

Sociocultural Factors

Irrespective of the economic status, animal products are the preferred protein foods of any population (with the exception of the strict vegetarian). Where certain legumes are traditionally consumed, they have been built into the diet pattern on their own merits as food items, rather than as sources of protein. For example, curried dhal is consumed in India as a gravy, along with the cereal staple which forms the bulk of the meal. The acceptance of more concentrated legume products depends primarily upon aesthetic properties (flavour, texture, appearance) and their ability to fit into the traditional diet pattern. Their merit as inexpensive protein foods could enhance product acceptance only if the primary criterion is satisfied. Misplaced emphasis on high nutrition at low cost could even be counterproductive. In certain societies, legumes are regarded as 'the meat of the poor'. In such cases, the challenge before the food technologist in product development is even greater.

Antinutrients

A number of biologically active principles which can have adverse nutritional and physiological effects are present in legumes. These have been collectively called antinutritional factors. The more important ones are the trypsin inhibitors, urease, hemagglutinins, goitrogens, saponins, phytic acid and flatulents. Their effects, and methods of removal, have been studied extensively (NAS 1973). Fortunately, the more nutritionally significant factors are heat labile, and as such, can be reduced to safe levels by proper processing. Soybean trypsin inhibitors, which have been shown to inhibit bovine, porcine, ovine, and human trypsin, are the most widely studied. In fact, the degree of their inactivation in a given process can be used as an index for process control.

Among the heat stable factors, flatulents and phytic acid are of some significance. Soybeans, in particular, contain the oligosaccharides raffinose and stachyose, which are not assimilated by man. They, therefore, move to the large intestine where they are fermented by intestinal microflora. The fermentation results in gas formation, causing flatulence. Phytic acid, which has great potential for chelating metal ions can affect the bioavailability of trace elements.

Cooking Time

When legumes are directly consumed, they are cooked until desired tenderness is achieved. Some legumes, such as pulses, are easily tenderised. However, beans are more difficult to cook. Long cooking times of 120 minutes for dry beans (Bressani and Elias 1974), 90–150 minutes for cowpeas (Siegel and Fawcett 1976), and 138 minutes for soybeans (Spata et al. 1974) have been reported. Tenderisation of a given bean during cooking depends on the combined effect of hydration and heating. Increasing the surface area by cracking of beans hastens hydration and heating, thereby resulting in reduced cooking time. In addition, the use of sodium bicarbonate (baking soda) at low concentrations in the cooking water further reduces the cooking time (Nelson et al. 1978). Another approach to the problem of tenderisation is the concept of pre-cooking the bean, so that only a short final cook is required at the point of consumption.

Future Prospects

In the foregoing discussion, several aspects of the total picture on legume utilisation have been analysed. There exists a traditional, country-specific and/or region-specific pattern for utilisation of legumes. The nutritional benefit of legumes in the diet has been widely recognised. Substantial research and development has been carried out in many countries for preprocessing of traditional legumes in order to facilitate wide consumption. Nontraditional concepts of utilisation such as composite flour, weaning foods, TVP, etc., have been advanced. Yet, we are still far removed from the point where the available legume sources are completely exploited for their human food value. The reasons for this existing dilemma are many and complex. But some general observations can be made that are true of the overall situation.

The pulses, as a group, find wide acceptance due to the traditional eating habits. The constraint in the case of pulses seems to be one of supply rather than demand. However, it does not imply that the total output of these crops is available and consumed. In fact, the common pulses are highly susceptible to attack by storage pests, and therefore, postharvest handling and storage is of great importance to narrow the gap between total output and availability. On the other hand, the oilseeds are primarily utilised as sources of edible oil and the protein-rich cake is used for feed purposes. The world production of soybean and peanut together is more than twice the total production of major pulses. The developing countries in 1983 produced as much soybeans as pulses combined (Table 2). In terms of protein yield per unit land area, soybeans surpass all other conventional food sources. They also carry about 20% of high quality oil. Therefore, the direct food use of soybeans and other oilseeds needs serious attention for complete utilisation of the available legume resources.

New Foods

The question often asked is whether people will accept new legume foods which are foreign to their diet. Before considering approaches to answer the question, it is pertinent to point out some historical facts. Products such as bread, canned fish, powdered whole milk, powdered infant milk, and oleomargarine, which are now popular in many developing countries, were once in the category of new or foreign foods. Their successful introduction was conditioned by the fact that complex motivational factors of consumer acceptance were met, both by the intrinsic characteristics of the products and the strategy of presentation. Factors such as compatibility with local eating habits, convenience, ease of preparation, conformation to acceptable concepts of taste, texture and colour, price structure, and good market promotion, played their own roles in gaining consumer acceptance for these products. Therefore, one can be optimistic about the acceptance of new legume foods, provided adequate consideration is given to the factors that influence it. Using soybean as a model, the following suggestions are put forward for the expanded use of legumes.

The Total Approach

Although it may appear ambitious, the target market for soybean foods should ideally include all strata of society. This dictates that a variety of products to suit every economic class should be available. A number of technologies must be developed to meet this need. The most economical approach is to educate the housewife in the poorest segment of the population to prepare foods starting with raw soybeans. This process which involves development of home recipes, training of personnel and extension, is known as the home level activity. A second scale of operation is at the village or community level. Small-scale operations which are labor intensive and require modest capital investment are an integral part of the industry in developing countries. Small privately owned enterprises, institutional feeding programs and cooperative ventures can be identified for the village level production of soybean foods. Low-level technologies for small-scale production must be developed and transferred to such ventures. Split soybeans (and pulses), dry formulated cereal/soy mixtures, soymilk, tempeh, snacks, and tofu are some of the possible products that can be identified for this level of operation. A third scale of operation is at the commercial level. This involves centralised processing for wider markets using higher levels of technology. The possibility of diversifying existing food industries into the area of soybean foods is worthy of serious consideration. Wilson and Henkes (1986) reported that a number of reconstituted cows' milk plants in Thailand are considering diversification into soymilk. The establishment of large-scale industries is, of course, contingent upon prior work on product development, scale up and clear demonstration of economic feasibility. Previous experience of viable village-level operations can stimulate and encourage large-scale investments in more promising products. Although the exact course of product development should be geared to suit a given country, the multifaceted approach at the home, village, and commercial level can contribute greatly to the establishment of a viable soybean food industry.

Promising Technologies

In spite of the diverse food habits of different countries, several technologies of general relevance and high potential can be identified.

Extrusion Cooking

Extrusion cooking is perhaps the most important. Beginning in the 1960s, extrusion technology has developed to a high degree of sophistication. However, we refer to the so called low-cost extrusion cooking (LEC), also called dry extrusion. This is a continuous process of simultaneously mixing and cooking relatively low moisture dry ingredients using a high temperature short-time step. The process is energy efficient and little or no drying is involved after the process. The product can be in the form of expanded pellets and chips or milled into flour. The heating process in the LEC combines the beneficial effect of nutritional value while minimising heating cost. A number of commercial LEC systems are being used in connection with nutrition intervention programs in Asia, Africa, and Latin America (Harper and Jansen 1985). The LEC system can be adapted to process a variety of products other than the weaning type foods made for nutrition intervention. This involves research and development on ingredient formulations based on preference of target populations. Full-fat soy flour, composite flours, soup bases, snacks, and other products with wide application can be produced by low-cost extrusion. This technology is particularly suited to developing countries because of the relatively low capital costs and high throughput. Present trends indicate that low-cost extrusion cooking will gain increasing significance in the processing of foods and feeds.

Weaning Foods

Legume/cereal mixtures of high nutrient densities have become an integral part of the supplementary feeding programs. These products have wide potential for production at different levels of technology. The housewife, in many instances, has access to the raw materials that go into weaning-type foods. However, she lacks the knowledge regarding the optimum combination of ingredients and the possible home approach to converting these ingredients into wholesome foods for weaning children. The development of these techniques and their dissemination to the housewife is a function of a home-level program, as we have outlined before. Weaning foods can also be made at the village level by precooking individual ingredients, followed by drying, grinding and blending in desirable proportions. It would be interesting to explore the possibilities of using existing small and medium scale food processing operations for the production of such foods. For example, rice milling in some countries involves parboiling, drying and milling. These unit operations are highly compatible with the procedures required for medium-scale production of dry formulated weaning foods. Mutual cooperation between research and industry can open the doors to such avenues of production. Dry extrusion, as mentioned before, has become established as a commercial level technology for weaning foods. Extensive use of such technology could make these foods generally available to wider segments of the population and not just for the nutritionally vulnerable.

Oilseed Press Cake

In many countries, mechanical expelling of oil from oilseeds is centred around the production of edible oil and feed-grade press cake. We see the potential for re-orienting the existing process for the production of edible grade press cake from food legumes. From the purely technological standpoint, several criteria are important. The level of hygiene in the existing plants will need upgrading if the cake is to be used for edible purposes. A close look into the expeller performance becomes necessary as regards the heat inactivation of antinutrients in the cake as well as its nutritional value. The process may have to be re-optimised, based on both oil yield and cake quality, rather than on maximum oil recovery alone. Properly processed press cake containing some residual oil is indeed ideal for the formulation of cereal/legume products of high nutrient density.

Upgrading of the press cake from feed grade to food grade adds commercial value to the cake. This in itself, may or may not be adequate to induce rethinking on the part of the expelling industry. Other economic considerations, such as assurance of markets for the food grade cake, the impact on the feed industry, and initial expenditure involved, may present themselves as constraints.

Soybean Beverage and Derived Products

Soybean beverage (soymilk) which was a traditional Chinese product has in recent years gained wide popularity in the Far East and in the Western world. Great progress has been made in improving the flavour characteristics of the traditional product and development of production technology. As a result, turn-key operations for the large scale production and aseptic packaging of soymilk have been established in a number of countries. Outside East and Southeast Asia, the potential of soymilk and derived products is largely unexploited. There is no real basis for comparing soymilk with cows' milk or considering it as a substitute for cows' milk. Nevertheless, it is a nutritious product that can supplement the shortage of cows' milk in many situations. It is evident that the characteristic beany flavour of traditional soymilk is unacceptable to many populations. Also, soymilk is as perishable as cows' milk. The newly developed commercial processes and automated manufacturing systems are highly capital intensive. Therefore, there is what might be called a technology gap between the traditional soymilk process and the commercial processes. Sound techniques that can yield a high quality product at low capital investment are urgently needed for introducing soymilk to new situations. Once again, research in the home and village level technology comes into focus. Of particular significance is the question of shelf life. The traditional method of sterilising or pasteurising liquid milk in glass bottles is rapidly being replaced by plastic containers and more sophisticated sterilisable cartons. Can soymilk be pasteurised in flexible pouches for local sale on a small scale? Is it feasible to produce soymilk for mass feeding in institutions on a daily basis? These are pertinent questions to address, and positive solutions to them can contribute to the success of soymilk in developing countries.

Soymilk can be processed further into derived products such as tofu, yoghurt, curd, and ice cream (toffuti). These products are versatile and can be adapted through research into acceptable preparations in a given situation. The concept of a 'soy dairy' has been evolved around the multiplicity of products that can be made from the bean in the same processing facility. Such concepts are worthy of serious consideration.

In conclusion, it must be pointed out that there can be no single master plan for the expansion of legume utilisation in all situations. The appropriate strategies must be developed for each country's situation. Nor can legume utilisation be considered independent of the overall food and nutrition policy of a given country. The overall success of a program will depend upon the coordinated efforts of policy makers, scientists, nutritionists, and the food industry.

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Utilisation of Food Legumes as Feed

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Food legumes are a valuable source of feed for livestock. The whole seed of most legumes is a rich source of energy and amino acids. For the oilseed legumes, peanuts and soybeans, the meal is a by-product of oil extraction and is used as a protein concentrate. There is also considerable potential to use the residues left after harvesting the seeds as sources of fodder for livestock. In this paper, the relative advantages and limitations of the different components of legumes, in the feeding of livestock, are discussed.

Use of the Whole Seed or Meal

The potential of food legumes as feed for livestock is governed by two factors — their contribution of nutrients to the diet and possible deleterious effects from the presence of anti-nutritional factors.

Legume seeds are sources of energy, fibre, amino acids, minerals, vitamins and essential fatty acids. However, it is their contribution of energy and amino acids that have the greatest economical potential in the feeding of livestock.

As sources of energy, leguminous seeds are rich, generally containing as much, or slightly more, energy than that found in cereals (Table 1).

Their value as sources of amino acids depends on a number of factors, including the concentration and pattern of essential amino acids relative to the animal's needs and the digestibility and availability of the amino acids. The pattern of essential amino acids required by animals depends on the function for which the amino acids are to be used. For example, meat production requires a high concentration of lysine whilst both wool and feather development needs high concentration of sulfur amino acids (methionine and cystine).

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The amino acid pattern in legumes is normally high in lysine (except in peanut meal) and low in sulfur amino acids (Table 2). Tryptophan is also marginal in many legumes. As lysine is normally the first and major limiting amino acid in cereal-based diets for monogastrics, legume proteins are generally considered to be of high protein quality. However, they do need to be used in conjunction with cereals or other proteins rich in sulfur amino acids, or supplemented with free methionine, to prevent sulfur amino acid deficiencies developing. For monogastrics, the digestibility and availability of amino acids in leguminous seeds is also important. Impaired digestibility and availability may result from the presence of high fibre contents, anti-nutritional factors or from damage during processing.

For ruminants, legumes appear to have an advantage relative to cereals in that they cause little disruption to the microflora of the rumen when introduced in high quantities (Bartsch and Valentine 1986). Food legumes contain relatively low levels of starch and high levels of fibre compared to cereals. This results in slower fermentation by rumen microflora and consequently reduced build-ups of volatile fatty acids and lactic acid. This in turn results in minimal effects on rumen pH compared to that which occurs with the sudden introduction of cereal grain to the diet. There is also some evidence that the feeding of legumes has the positive effect of reducing protozoal populations; this would result in an increased supply of bacterial protein to the small intestines (Bartsch and Valentine 1986).

The carbohydrate fraction of lupin, faba bean and soybean is less rapidly fermented than that of the cereal grains, except sorghum, when tested as whole grain or cracked grain (Hosking, Hynd, Radcliffe and Egan unpubl.). Up to 25% of faba bean carbohydrate flowed to the small intestine in sheep fed 300–400 g beans/head/day. With lupins, the percentage was lower. Of the protein contained in lupin and faba bean, the extent of digestion depends upon rate of protein solubilisation, particle breakdown rate and retention time. From 10 to 26%

TABLE 1. Proximate composition (%, air-dry basis) and energy content (MJ/kg, air-dry basis) of legume seeds or meal.

	Chick pea	Faba bean	Field pea	Lupin seed	Mung bean	Navy bean	Peanut meal	Pigeon pea	Soybean seed	Soybean meal
Crude protein	19.5	23.1	23.4	28.9	23.9	22.7	47.4	18.3	37.9	46.7
Dry matter	89.1	90.6	90.7	89.7	89.8	89.7	91.5	88.8	90.9	89.1
Crude fibre	7.0	6.9	6.1	13.0	3.9	4.2	13.1	10.5	5.3	5.2
Ether extract	3.9	1.2	1.2	5.4	1.3	1.5	1.2	3.3	17.4	1.2
Ash	2.9	3.2	3.0	2.8	3.7	4.1	4.5	4.5	4.9	5.9
Nitrogen-free extract	55.7	56.3	57.0	40.2	57.0	57.2	25.3	52.2	25.4	3.01
Energy										
DE — Pig	16.2	13.7	15.5	14.2	15.6	15.6	11.9	13.5	16.9	14.0
ME — Cattle	12.1	13.1	11.3	—	11.4	11.3	10.6	8.0	12.6	11.1
Chick	12.2	—	9.2	8.9	10.5	9.7	9.2	—	13.9	9.3
Pig	14.8	12.9	14.1	—	14.1	14.2	10.2	12.4	14.8	11.9
Sheep	11.5	11.7	10.3	—	11.7	11.7	11.5	8.9	12.6	12.0

Sources: Atlas of Nutritional Data on United States and Canadian Feeds (1971). National Academy of Sciences, Washington D.C.
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TABLE 2. Crude protein (%, air-dry basis) and amino acid composition (g/16gN) of leguminous seeds or meals.

	Chick pea	Faba bean	Field pea	Lupin seed	Mung bean	Navy bean	Peanut meal	Pigeon pea	Soybean meal
Crude protein	23.0	23.2	21.2	23.9	25.1	24.7	50.7	20.4	45.8
Aspartic acid	10.1	10.6	10.8	9.3	10.8		9.9	8.7	10.4
Threonine	3.3	3.5	3.8	3.4	3.2	4.5	2.7	3.9	4.0
Serine	4.7	4.7	4.7	4.9	5.2	6.2	4.7	4.5	5.2
Glutamic acid	16.3	15.0	17.6	21.8	13.8		19.2	20.7	18.5
Proline	4.0	3.3	4.4	4.3			4.5	4.6	5.3
Glycine	3.6	4.7	4.3	3.9	3.2	3.9	5.1	3.8	4.2
Alanine	3.8	4.1	4.3	3.1	4.8		3.7	4.2	4.1
Valine	3.5	4.4	4.7	3.6	6.0	5.2	4.0	4.1	4.6
Cystine	0.9	1.4	1.2	2.2	0.4	0.8	1.3	1.7	1.3
Methionine	1.0	0.8	0.6	0.6	0.8	0.7	0.7	0.8	1.1
Isoleucine	4.2	3.8	4.3	3.9	4.8	4.6	3.4	3.8	4.5
Leucine	7.4	7.3	7.8	7.5	7.2	8.3	6.8	7.1	7.7
Tyrosine	2.6	3.5	3.6	3.7	2.4	3.5	3.9	2.7	3.6
Phenylalanine	5.2	4.1	4.6	3.7	4.8	5.8	4.9	8.4	4.8
Histidine	2.5	2.5	2.7	2.7	2.0	2.8	2.2	3.3	2.7
Lysine	5.8	6.2	7.3	4.7	6.8	6.9	3.3	5.8	6.0
Arginine	9.8	9.4	10.3	10.2	6.0	6.7	12.8	6.2	7.4
Tryptophan	0.64	0.7	0.83	0.60	1.8	1.7	0.83	0.74	1.03

Source: Batterham and Watson, (1985).
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of lupin protein flowed to the small intestine of sheep fed a good quality hay with 100, 200, 300 or 400 g lupins/day, the percentage increasing with increasing intake level.

For faba beans, a maximum value of 15% of dietary protein reaching the small intestine was achieved with an intake of 500 g/day. While resistance of proteins to degradation in the rumen is related to relative insolubility, size and flow behaviour of chewed gram particles contributed to variation among the grain legumes studied. Size, hardness and crushing or fractory characteristics of legume grains need to be examined more closely as factors contributing to the extent of rumen degradation and intestinal digestion.

The contribution of amino acids by legumes to ruminants is of lesser importance than to monogastrics, due to the effects of rumen microflora on the degradation and synthesis of amino acids. However, the degree to which different legumes can avoid microbial breakdown in the rumen (by-pass protein) is an important characteristic, as this influences the amount of the leguminous amino acids reaching the small intestines.

The nutritional value of leguminous proteins may be limited by the presence of antinutritional factors. These factors fall into two main categories:

1. protease inhibitors — these interfere with the enzymic digestion of proteins into their basic amino acid components, e.g. trypsin inhibitors in raw soybean seeds interfere with the enzymic activity of trypsin and impair the digestion of the diet.
2. metabolic inhibitors — these substances interfere with metabolic processes within the animal, e.g. alkaloids in lupin seeds.

The protease inhibitors, trypsin and chymotrypsin, are perhaps the most widely distributed of all antinutritional factors in legumes. However, their concentrations vary, and in many varieties they are so low as to have no detrimental effects as they pass unnoticed. The actual mode of action of trypsin inhibitors is complex. Apart from reducing digestibility by inhibiting trypsin activity, they are thought to induce secondary sulfur amino acid deficiencies. This occurs as they stimulate pancreatic hypertrophy and increase pancreatic secretions, which are rich in sulfur amino acids, and accentuate the already low marginal sulfur amino acid status of the legume (Liener 1976).

Monogastrics are thought to be more susceptible to the effects of antinutritional factors than ruminants. In fact, for ruminants, trypsin inhibitors are not considered to be important (McDonald et al. 1973). However, the presence of and likely effects of antinutritional factors in the digesta components carried from the rumen have not been thoroughly addressed. There is a need for further work in this area, as uncooked soybean meal containing trypsin inhibitor reduced the digestibility of nitrogen in young weaned lambs (Egan and Radcliffe unpubl.).

Fortunately, most antinutritional factors, including trypsin and chymotrypsin inhibitors, are heat labile and may be inactivated by the heat applied during processing or cooking. Others, such as alkaloids in lupin seeds, are insensitive to heat. Fortunately, alkaloids have been removed by plant breeders in the selection of varieties low in alkaloids (sweet lupins) which can safely be used as sources of feed for livestock.

Characteristics of Individual Legumes

Chickpeas (*Cicer arietinum*)

There are two main lines — high fibre (Desi) and low fibre (Kabuli). Both contain approximately 20–24% crude protein, of high quality. Chickpeas contain low levels of trypsin inhibitors and possibly other antinutritional factors. However, in feeding trials with pigs, chickpeas have given similar results, on an equal lysine basis, to soybean meal (Visitpanich et al. 1985a). This indicates that the levels of antinutritional factors present were low and did not influence pig performance.

However, when the same samples of chickpeas were fed to rats, they resulted in reduced performance relative to that produced by soybean meal (Visitpanich et al. 1985a). This indicates that species vary in their tolerance to antinutritional factors and that the results with rats do not necessarily have application as screening tests for other species.

Chickpeas have been fed as the major dietary component (88%) for chicks and have given good performance, provided the diet is supplemented with methionine (Aguilera and Scott 1962). However, autoclaving the seed improved liveweight gains and decreased pancreas size (as a proportion of bodyweight). These responses are consistent with the effects anticipated from the reported low levels of trypsin inhibitors in the seed.

There are indications that the levels of antinutritional factors may differ between varieties of chickpeas. It is therefore essential to ascertain their status before new varieties are fed to livestock.

Faba Bean (*Vicia faba*)

These beans contain approximately **23%** protein of good quality (Tables 1 and 2). There is only limited, and slightly conflicting, information on the effects of the presence of antinutritional factors.

In feeding trials with pigs, Davies (1986) found faba beans to be a sound source of protein at inclusion levels of up to 35% of the diet. This is higher than recommendations of 15–20% by

Simpson (1984). For laying hens (Davidson 1973, 1980) reported the presence of an antinutritional factor in faba beans, particularly at inclusion levels greater than 15%. Autoclaving and heat processing gave inconsistent results, and tannins were not implicated.

These differences in response possibly reflect variations in the presence of antinutritional factors in the different samples of faba bean used in the experiments.

Field Peas (*Pisum sativum*)

Field peas contain approximately 22% crude protein, of good quality, similar to soybean meal. The availability of lysine for pigs and chicks is high (Batterham et al. 1984, and unpublished data). Whilst field peas contain low levels of antinutritional factors, these are normally considered to be of little consequence, and levels up to 40% in the diet of pigs are recommended (Davies 1984).

Field peas have also been shown to be suitable for dairy cows, similar to faba beans and superior to barley (Bartsch et al. 1986).

Lupin Seed (*Lupinus* spp.)

In the past, many varieties of lupin seeds had high alkaloid contents which render the seeds toxic to animals. In recent years there has been the development of newer 'sweet' varieties which are low in alkaloids and are considered safe to use (Hudson 1979). There are two main types grown in Australia, *Lupinus angustifolius* (small round seed) and *L. albus* (large flat seed). *L. albus* seeds contain slightly higher crude protein (approximately 35–45%) and oil (10–15%) compared to *L. angustifolius* seeds (approximately 25–35% crude protein and 5–6% oil) (Hill 1977). In both cultivars, methionine is deficient, tryptophan marginal, and lysine of medium concentration. The meals are fed raw, following coarse crushing. The outer layer is tough, which makes the seeds difficult to crush. This robustness makes lupin seeds fairly resistant to weevil attack.

Lupin-seed meal has a high crude fibre content (12–15%) (Table 1). Despite this, the meals have a high digestible energy content for pigs (15 MJ/kg, air dry basis). The digestion of lupin seed meal by the pig is unusual in that only approximately half the dry matter and energy is digested in the small intestines, the remainder is digested in the hind gut (Taverner and Curic 1983). This latter mode of digestion presumably involves microbial degradation and the synthesis of volatile fatty acids. The efficiency of energy conversion via volatile fatty acids is thought to be less efficient than direct absorption of carbohydrates via the small intestines. As a consequence, the net energy retention of lupin-seed meal has been estimated as lower than that of wheat or field peas (Taverner and Curic 1983).

Availability of lysine in lupin-seed meal has been shown to be low for pigs, ranging from 37 to 64%, with a mean of 53% (Batterham et al. 1984). The reason for this low availability has not been elucidated. As the meal is fed raw following coarse crushing, it is not due to heat damage. In addition, the digestibility of lysine at the terminal ileum is high (83–88%) (Taverner and Curic 1983). There is no beneficial effect of heating the meal (Batterham et al. 1986) and in fact, heating depressed nutritional quality. Thus the low availability may be due to the presence of an unidentified non-heat labile antinutritional factor or to the lysine being absorbed in a form that is inefficiently utilised.

The low availability of lysine is specific to pigs as it is high for rats (81%) and chicks (90%) (Batterham et al. 1984, and unpublished data). Even though lupin has a low lysine availability, high inclusion levels of *L. angustifolius* cultivars (Unicrop, Uniharvest, etc.) are normally recommended for pigs (40%). However, for cultivars of *L. albus* (Hamburg, Ultra, etc.) maximum inclusion levels of 10–15% for pigs are advisable as above these levels inferior pig performance has been recorded. The reasons for this inferior growth performance have not been identified.

Lupin-seed meals have been successfully fed to both broilers (Sourdshiska and Harnisch 1977) and laying hens (Hughes and Orange 1976; Larbier 1980) provided attention is given to dietary amino acid concentrations (particulary methionine, lysine and tryptophan). Autoclaving the seed of *L. albus* for 30 minutes at 120°C increased the metabolisable energy concentration from 8.9 to 11.3 MJ/kg of dry matter for chicks (Molina et al. 1983). As there are no known antinutritional factors in the low alkaloid varieties for chicks, this improvement appears due to changes in the structure of the carbohydrate fractions.

Lupin-seed meal has been shown to be particularly beneficial for dairy cattle (Bartsch and Valentine 1986; Bartsch et al. 1986). This appears to arise from the low starch and high fibre contents causing minimal changes to the rates of fermentation and lactic acid production in the rumen. It is necessary, however, to crush the seed prior to feeding to ensure adequate digestibility.

Mung Beans and Black Gram (*Vigna radiata, Vigna mungo*)

These contain approximately 22–25% protein of good quality. There is uncertainty about the levels of antinutritional factors in these meals for livestock and so far there is little research available on their feeding quality for animals. As a consequence maximum inclusion levels of 10–15% are normally recommended.

Navy Beans (*Phaseolus vulgaris*)

Navy beans contain approximately 22–25% of good quality crude protein. They contain high concentrations of haemagglutinins, plus trypsin and chymotrypsin inhibitors, and are toxic if fed raw (Liener 1976; Hove et al. 1978; Weder 1981). Substantial heat processing, generally using moist heat, is needed to inactivate the antinutritional factors (Williams et al. 1984). However, following adequate processing, the meals are of good protein quality for livestock.

Peanuts (*Arachis hypogaea*)

Peanuts, also commonly called groundnuts, are grown as an oilseed crop. The seeds are not normally fed to livestock, as the high unsaturated fatty acid content results in oily fat deposits in animals. The seed is extracted for oil and the meal used as a protein concentrate. The profile of amino acids for peanut meal differs from the majority of other leguminous seeds in that it is medium to low in lysine content (Table 2).

During processing, the meal is susceptible to processing damage, with an availability of lysine for pigs of 57% (Batterham et al. 1984). Chicks, however, are less susceptible to these effects, and the availability of lysine is high (approximately 90%; Major and Batterham unpubl.).

There are no known antinutritional factors in the meal. However, both the seed and the meal are susceptible to the presence of aflatoxin-producing moulds, particularly under moist conditions. Care must be taken during the harvesting and processing of the crop and during storage of the processed meal to avoid aflatoxin contamination.

Pigeonpea (*Cajanus cajan*)

Pigeonpeas have 20–25% crude protein, and a similar amino acid profile to other high quality legumes. They contain antitryptic factors and tannins, both of which are thought to depress growth performance via depressing digestion and nutrient utilisation (Visitpanich et al. 1985b).

For pigs, heating the seeds at 110°C for fifteen minutes overcame the antinutritional factors, and growth performance similar to that obtained for pigs fed soybean meal was recorded (Visitpanich et al. 1985b). However, chicks appear more tolerant to the antinutritional factors and the meals may be fed raw following crushing (S. A. George, pers. comm.).

Attempts to improve the protein quality of the seeds by imbibing them in alkali to remove the effects of tannins have given variable responses (see Visitpanich et al. 1985b).

Soybean (*Glycine max*)

Soybeans contain approximately 36% crude protein and 20% oil. The seeds may be fed whole but are normally extracted for oil and the meal used as a protein concentrate.

The raw seed contains high concentrations of antinutritional factors, particularly trypsin and chymotrypsin inhibitors and haemaggulutinins. These are normally inactivated during processing. If the seed is fed whole, some form of heat processing is necessary to inactivate the antinutritional factors. Only relatively mild processing is required, in the order of 110–115°C for a few minutes. A urease test (OACC method 22–90 or AOCS method Ba 9–58) may be used to assess adequacy of processing.

When the whole seed is processed, it is marketed as a full-fat soybean meal. It is used particularly in diets where high energy and protein are required, e.g. chicks and weaner pigs. However, the pig's digestive system is not fully developed before 4–5 weeks and thus high levels of soybean meal are not fully utilised by piglets. Full-fat soybean meal is also used in diets for horses and ruminants.

Soybean meal is either marketed as expeller (7–8% residual oil) or solvent extracted (0.5–2% oil). The protein content depends on the level of oil and crude fibre in the meal and varies from 44 to 50%. The protein quality of the meal is high, although it is marginal in the sulfur amino acids.

Because of the uniformity and quality of processed soybean meal, it is one of the most highly acceptable sources of protein concentrate for the feeding of livestock. It has become an 'international' protein, particulary valuable in research for allowing performance responses of livestock to be compared in different locations on diets containing a protein concentrate of reputed high, uniform quality.

Crop Residues and Byproducts as Feed for Ruminants

The harvest index for food legumes varies greatly, both between species and between cultivars within a species. The different plant morphologies result in a range of leaf:stem ratios. The stage of maturity at which harvest is made results in variations in the nature of the residues which may, as for cowpeas picked as immature pods, still be green; or may, as for soybeans, be harvested at maturity when the plant stem is drying. The method of harvest, likewise, leaves some food legume straws and stubbles in the field, while for others the whole plant is harvested and the legume seed recovered by whole-vine threshing. The latter procedure can result in stem, leaf and pod/hull residues being separated as different components for subsequent use as animal feeds. Consequently the feeding value of the crop residue needs to be described quite specifically not in terms of analysis of samples of bulk material other than edible seed, but in terms of the classes of standing or harvested fractions, and the postharvest treatments in grain recovery (Khajarern and Khajarern 1984).

As with most crop plants, there is considerable dry matter loss, decreased protein and soluble carbohydrate content and increasing fibre content with approaching maturity of the plant. However, for most of the common food legumes, the stem material is of better digestibility and nitrogen content than cereal straws. Leaf digestibility is high, but for some legume crop residues at maturity may contribute little to the material recoverable by animals grazing stubbles, or hand fed vine-threshed materials.

For example, soybean straw is readily accepted by animals, contains 6–7% crude protein, and has an organic matter digestibility of 35–50%. Reported intakes range from 1.4 to 3.0% of liveweight, and as a broad rule, intake decreases with decreasing nitrogen content and digestibility. Furthermore, acceptability and intake is not solely governed by these factors. Ayres et al. (1986) examined soybean stubbles as feed for sheep, dividing material into three grades depending in part, on extent of weathering. In vitro digestibility of dry matter ranged from 38.4% down to 14.7%, and protein content was 2.6–3.1%. With a better quality stubble material, consisting of 80.9% stem, 18% pod, 0.9% seed and 0.2% leaf fragment, organic matter digestibility was about 50% but intake was only 1.0% of liveweight. Since supplementation with urea and molasses did little to improve intake, digestibility or animal performance, simple nitrogen deficiency was not the limiting factor.

When harvested as in Thailand (Cheva-Isarakul and Saengdee 1985), the soybean is cut by hand and field dried to about 10% moisture content before threshing. Leaf and pod residues, and stem, separate during threshing. The stem material will typically have an organic matter digestibility of 25–30%, whereas the leaf and pod material will be 50–60% digestible (Gupta et al. 1978). While intake of stem may be as low as 1.5% of liveweight, the intake of leaf/pod fraction fed alone can be up to 3.8% of liveweight of the animal (Cheva-Isarakul and Saengdee 1985). Between cultivars grown in different environments, including those studied in the USA and Japan, there is a wide range in chemical composition and digestibility of soybean residues. The view that the description of soybean harvest residues is often inadequate is supported by Ayres et al. (1986). It is probable that data on soybean hay (unharvested crop) and soybean stubble (residue following harvest) have been combined into reports on composition and nutritional value of 'straw'. There is a need for variability in feeding value to be partitioned into variation arising from plant morphology, and harvesting procedures. At the low end of the scale, intake of digestible energy will not support liveweight maintenance, whereas at the upper end, quite respectable gains are made by sheep (120 g/d) and by cattle (600 g/d).

Cowpeas are regarded as a dual purpose crop (Viswanath 1978) raised for grains for human consumption and fodder for animal production. Green or dry pods may be hand harvested, leaving green stem and leaf material which can constitute 50–70% of the harvestable biomass. This material has 14–16% crude protein and a digestibility of 55–65% (Bhaid and Talaptra 1965). This residue will support growth in goats. However, if the crop is allowed to mature, protein content falls to 10–11%, and digestibility to 45–55% (Roxas et al. 1985). Intake of these hand harvested residues is reduced to about 1.8% of liveweight and maintenance of liveweight of animals become questionable. If there is substantial dry matter loss of residues of vines cut at harvest time, fibre content is increased per unit organic matter, and this together with leaf loss will further reduce digestibility and protein content.

Pigeonpeas harvested mechanically at maturity, yield 10–25% seed, and a residue of leaf, stem and pod in proportions which vary with plant maturity type, environment and harvester separation efficiency. Where practiced, defoliation prior to harvesting results in a high pod residue. In hand harvesting, larger stem material may be set aside for fuel, and leaf and pod are the main residues used for livestock feeding. Whiteman and Norton (1982) report that with pigeonpea pods (7.5% crude protein, 44% dry matter digestibility) intake by sheep was 1.6% of liveweight, and liveweight loss occurred. When pangola grass (16.3% crude protein, 50% dry matter digestibility) was included at 66% of the diet, overall digestibility was similar to that of the pangola grass alone. Intake was 2.6% of liveweight, greater than that for either the grass alone or the pigeonpea pods alone. These results suggest that the nutritive value of pods is limited by deficiencies which can be overcome by combination in a mixed diet. Pigeonpea harvest trash, of mixed pod, leaf and stem, was of higher feeding value than pod alone. Again the comment can be made that the proportion of leaf within the mixture will have a major effect on protein content and nutritive value. Limitation to animal performance was suggested by

Whiteman and Norton (1982) to arise from the low sulfur content of the trash constituents. Of importance, however, is the recognition that the feeding value of harvest residue is dependent on the level of availability. If able to select (as in the Whiteman and Norton (1982) studies), cattle may choose a higher proportion of powdered leaf material increasing the protein content and digestibility above that of the material selected by sheep or goats. The question of selective preference raises at least one aspect of differences between species, and between animals adapted or trained to different feeds and feeding systems. While these lie beyond the scope of the present paper, such considerations must be accommodated in tests of feeding value of these classes of feedstuffs.

There is paucity of information on the composition and digestibility of residues of other tropical food legumes. Certainly mungbean, peanut, chickpeas, lablab bean, ricebean, swordbean and jackbean provide forage materials and residues for use as animal feeds. However, little systematic work on the use of the harvest residue is available. What does exist is estimates of protein content and digestibility for the vegetative materials during growth, and some piecemeal information on harvest residues which are poorly described. Even the systems of feeding in villages — grazing the residues over a short time post-harvest, storage for more long-term feeding, or opportunistic feeding with a cycle of use of shrub, tree leaf and crop residues (e.g. three-strata system; Nitis 1986) — have not been thoroughly explored.

Use of the residues as supplements to other feedstuffs is often reported but the specific composition of the residues fed and the basal diet so supplemented leave real questions of the complementarity for ruminant nutrition. Far more research in this area is warranted.

Conclusions

Leguminous seeds are a sound source of energy, equivalent or higher in content to cereals. Their amino acid profile is normally of high quality, due to the balance of amino acids relative to lysine. Characteristically, most leguminous proteins are low in the sulfur amino acids, cystine and methionine. However, methionine is available commercially in a feed-grade form and deficiencies in sulfur amino acids can readily be overcome. Attention should also be given to lysine and tryptophan levels in diets containing high concentrations of food legumes, as they may also become limiting. Most legumes have the advantage that they can be fed raw, following coarse crushing. This is particularly advantageous as these crops can be used as a 'homegrown' source of protein.

The major limitation of the feeding of leguminous proteins is the concern about levels of antinutritional factors in these seeds. This is an area where there is only limited information on the types of factors, the distribution in different seeds, their modes of action and maximum tolerance levels for the different species.

There is a need to provide information on the levels of antinutritional factors in the different grain legumes, and to ascertain if their distribution is related to variety or agronomic characteristics. At the same time, there is a need to critically define the tolerances of livestock (both monogastrics and ruminants and for all production systems) to the different antinutritional factors. Only when this information is available will it be possible to more adequately define the full potential of leguminous seeds and the feeding of livestock for Asian farming systems.

There is also considerable potential for the use of crop residues in the feeding of ruminants. However, due to differences in times of harvest and the methods of harvesting, crop residues vary considerably in their nutritional value. There is a need for further research in this area to describe more accurately the nutritional value of the different components of the residues and the potential feeding systems for ruminants.

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Short Communications

THESE papers addressed the major limits and aspects of food legumes in particular production systems, and were used as a basis for group discussion. They have been grouped into the following classifications:

Socioeconomic factors
Management in irrigated farming systems
Management in rainfed farming systems
Environmental factors
Edaphic factors
Nitrogen fixation
Biological factors
Genetic factors
Processing and utilisation

Each session chairperson reviewed the papers submitted to the respective group. The review precedes the papers in each section.

Authors and Titles of Short Communications

Socioeconomic Factors 208

Review of contributed papers — T.S. Walker

Dauphin, F. and Rachim, A. — The role of socioeconomic factors in low soybean yields in Garut, W. Java.

Haque, F., Gupta, A.K. and Abedin, Z. — The logic of intercropping pulse in rainfed Bangladesh: A preliminary assessment of farmers' views.

Herath, H.M.G. — Some socioeconomic constraints to legume cultivation in Sri Lanka.

Ingram, R.K. and Lancini, J.B. — Small farmer constraints to adopting food legume crops in the lower north of Thailand.

Jabbar, M.A. — Consequences of a foodgrain biased production policy in Bangladesh.

Kaul, A.K. — Food legumes in Bangladeshi farming systems — nutritional considerations.

Singh, R.K. — Socioeconomic factors limiting food legume production in Indian farming systems.

Tiwari, A.S. — Food legumes make cropping systems remunerative.

Management in Irrigated Farming Systems 217

Review of contributed papers — B.S. Dahiya

Beg, A. — Performance of soybean on fallow land in Pakistan after main crops of wheat, rice and cotton.

Del Rosario, D.A. and Santos, P.J.A. — Adaptability of selected legumes and cereals to post-rice conditions.

Gowda, C.L.L. — The potential of chickpea after rice.

McNeil, D.L. and Eagleton, G.E. — Irrigated food legume production in northwestern Australia.

Pandey, R.K. — Maximising soybean productivity after lowland rice through optimising the crop management practices.

Sangakkara, U.R. — Legumes for intensification of rice-based farming systems of mid-country Sri Lanka.

Singh, B.B. — '60-day' cowpea varieties for Asian farming systems.

Sumarno — Response of soybean genotypes to land preparation after flooded rice.

Veeranna, V.S. — Productivity of legume-based cropping systems in the traditional rice monocrop region of South India.

Verma, M.M., Sandhu, S.S. and Sekhon, H.S. — Summer mungbean in a wheat–rice cropping system — potential and limitations.

Management in Rainfed Farming Systems 226

Review of contributed papers — A. Patanothai

Ali, M. — Weed management in pigeonpea-based intercropping.

Anecksamphant, C., Trethewie, R.J. and Williams, C.N. — Legumes in rice-based upland cropping systems.

Beech, D.F. — Production of peanuts in Burma. 1. Background to research.

Beech, D.F. — Production of peanuts in Burma. 2. Research on nutrition.

Bell, M.J., Shorter, R. and Mayer, R. — Serial sowing date studies on peanuts (*Arachis hypogaea* L.) in southeast Queensland.

Chatterjee, B.N. and Bhattacharyya, K.K. — Food legumes under intensive cropping systems in India.

Chatterjee, B.N., Bhattacharyya, K.K., Sengupta, K. and Ghosh, R.K. — Pre-sowing seed treatments for legumes.

Chauhan, Y.S., Venkataratnam, N. and Johansen, C. — The agronomy of multiple harvest pigeonpea.

Chinchest, A. — Mungbean in cropping systems in Thailand.

Choudhary, M.A. and Pandey, R.K. — Extending limits to legume crop establishment in rainfed lowland rice.

Dahiya, B.S. — Selecting food legume cultivars for multiple cropping systems.

Eksomtramage, T. and Troedson, R.J. — Effects of density and water supply on growth of pigeonpea seedlings.

Gibson, T.A. — Legume ley farming — a low-cost method of overcoming soil fertility limitations in an upland agricultural system.

Gutteridge, R.C., Topark-Ngarm, A. and Humphreys, L.R. — Incorporation of legumes into farming systems in northeast Thailand.

Jain, K.C. and Faris, D.G. — The potential of medium-duration pigeonpea.

Karsono, S. and Sumarno — Population density in pigeonpea in Indonesia.

Khatiwada, M.K. — The production of food legumes in the Himalayan range.

Laosuwan, P., Sripana, P., Sriisongkram, P. and Tongsomsri, A. — Potential of food legumes as intercrops with young rubber.

Pillai, G.R., Varughese, K., Mathew, J. and Santhakumari, G. — Intercropping food legumes with cassava in a rice-based farming system.

Sangakkara, U.R. — Legumes in rainfed farming systems in Sri Lanka.

Sangakkara, U.R. — Some problems associated with seed sources in grain legumes — a case study.

Sangakkara, U.R. — Yields of legumes in mixed cropping systems.

Singh, B. — Pulse production in Fiji.

Sivan, P., Chand, V., Singh, B.D. and Meekin, J.S. — Pigeonpea genotype evaluation in Fiji.

Sukarin, W., Troedson, R.J., Wallis, E.S. and Byth, D.E. — Effects of time of sowing on phenology of pigeonpea in Thailand.

Suwardjo, H. and Sukmana, S. — The use of *Mucuna* sp. in upland farming systems for improving soil productivity.

Yadavendra, J.P., Patel, A.R., Shah, R.M. and Saxena, K.B. — Relay intercropping of pigeonpea in groundnut.

Environmental Factors 247

Review of contributed papers — A. Pookpakdi

Chatterjee, B.N., Bhattacharyya, K.K. and Miah, A.A. — Growth analysis of ricebean.

Eagleton, G.E. and Sandover, S. — The phenology of mungbeans in northwestern Australia.

Farquhar, G.D. and Hubick, K.T. — Measurement of carbon isotope composition to seek and exploit variation in water-use efficiency.

Govil, J.N., Singh, S.P. and Ram, Hayat — Growth analysis in relation to pigeonpea improvement.

Summerfield, R.J. and Roberts, E.H. — Photo-thermal regulation of flowering in food legumes and implications for screening germplasm.

Thirathon, A., Byth, D.E., Fischer, K.S. and Whiteman, P.C. — Effect on sink development of changes in assimilate supply during different growth stages of short-season pigeonpea.

Thirathon, A., Byth, D.E., Fischer, K.S. and Whiteman, P.C. — Relationship between leaf area, radiation interception and dry matter production after flowering in short-season pigeonpea.

Thirathon, A., Byth, D.E., Fischer, K.S. and Whiteman, P.C. — Compensatory ability of pigeonpea to a reduction in sink capacity.

Wagley, S.K. — Environmental stress on pulses (legume) productivity.

Edaphic Factors 255

Review of contributed papers — P. Keerati-Kasikorn

Bell, R.W., Brady, D., Plaskett, D., Kirk, G. and Loneragan, J.F. — Diagnosis of nutrient deficiencies in peanut and soybean.

Cowie, A.L., Rayment, G.E. and Chand, V. — Responses of pigeonpea (*Cajanus cajan*) on lime on an oxisol in Fiji.

Hiranburana, N. and Chawachati, C. — Boron status and sorption characteristics of selected soils in northern Thailand.

Hsu, Chi and Chin, Zuping — Nutrient balances of important cropping systems in the Tai Lake region, China.

Jalali, B.L. — Relevance of V-A mycorrhizal system in increasing crop productivity in legume crops.

Keerati-Kasikorn, P., Panya, P., Bell, R.W. and Loneragan, J.F. — Nutrient deficiencies affecting peanut production in soils of northeast Thailand.

Kirk, G. and Loneragan, J.F. — Boron deficiency in soybean and peanut.

Knobel, W. — Influence of salt stress on the development of nodules of food legumes.

Lim, E.S. — Production of groundnuts on tin-tailing soils in Malaysia.

Mahmood, M., Bell, R.W., Plaskett, D. and Loneragan, J.F. — Ascorbate oxidase activity in peanut: relation to copper and growth.

Netsangtip, R., Rerkasem, B., Bell, R.W. and Loneragan, J.F. — A field survey of boron deficiency in peanuts grown in the Chiang Mai valley.

Othman, W.M.W. and Ismail, M.S. — Effects of applied nitrogen and detopping on seed yield of mungbean.

Plaskett, D. — Analytical techniques for elemental analysis in plant tissues.

Ratanarat, S., Parkpian, P. and Phetchawee, S. — Iron deficiency in peanut on black calcareous soils.

Rerkasem, B., Netsangtip, R., Pridisripipat, S., Loneragan, J.F. and Bell, R.W. — Boron deficiency in grain legumes.

Nitrogen Fixation 268

Review of contributed papers — R.J. Roughley

Boonkerd, N., Angsusingh, S., Tawatpan, J., Sansopa, L. and Thananusont, V. — Effect of adhesives on inoculant adhesion, rhizobial survival and nodulation.

Brockwell, J. and Gault, R.R. — Symbiotic relationships between *Glycine* spp. and rhizobia.

Faizah, A.W. — Response of soybean to inoculation with selected strains of *Rhizobium japonicum*.

Herridge, D.F. — Strategies to improve N fixation by food legumes.

Kimani, P.M. — Response of pigeonpea genotype to inoculation with rhizobia and phosphate fertiliser application.

Lumyong, S. and Thongtoa, S. — Cross inoculation between SJ4, SJ5 and two traditional Thai soybean cultivars.

Ofori, F., Pate, J.S. and Stern, W.R. — Evaluation of N_2 fixation in a maize/cowpea intercrop system using ^{15}N methods.

O'Hara, G.W., Franklin, M. and Dilworth, M.J. — Sulfur nutrition of free-living and symbiotic *Bradyrhizobium japonicum* and *Bradyrhizobium* sp. (*Arachis*).

Paterno, E.S., Sison, L.Q., Torres, F.G., Lancini, J.B. and Mendoza, H.T. — Response of soybean to inoculation with *Bradyrhizobium japonicum.*

Peoples, M.B., Herridge, D.F. and Bergersen, F.J. — Quantification of biological nitrogen fixation in food legumes.

Peoples, M., Sudin, M.N., Wahab, F.A., Kewi, C. and Moris, N. — Use of xylem sap analysis to evaluate the nitrogen fixing status of field-grown groundnut (*Arachis hypogaea* L.).

Rerkasem, K., Rerkasem, B. and Wongwatana, S. — Nitrogen nutrition in legume/ non-legume intercrops.

Roughley, R.J., Herridge, D.F. and Brockwell, J. — Population dynamics of soybean inoculants in the field.

Sangakkara, U.R. — Nodulation patterns of selected legumes in two rice soils of Sri Lanka.

Sangakkara, U.R. and Cho, C.M. — Relationship between fertiliser N and N fixation in lentils and soybeans.

Senaratne, R. and Hardarson G. — Estimation of residual effect of faba bean and pea on two succeeding cereals using ^{15}N methodology.

Shan-Ling, Lu, San-Di, Min and Xiao-Xian, Jiang — Effect of seed pelleting on rhizobial survival on inoculated seed and on yield.

Sundram, J., Roughley, R.J. and Date, R.A. — Response of *Arachis hypogea* to *Rhizobium* inoculation in acid soils in Malaysia.

Thompson, J.A., Bhromsiri, A. and Shutsrirung, A. — Soybean rhizobia of northern Thailand.

Wesselmann, A. — Influence of different daylength on the development of nodules of food legumes.

Biological Factors 284

Review of contributed papers — G.J. Persley

Bilapate, G.G. — Life-tables and key mortality factors for field population of *Heliothis armigera* on pigeonpea.

Chauhan, R. and Ombir — Management of insect pests of chickpea.

Hanounik, S.B. and Saxena, M.C. — Multiple disease resistance in faba beans.

Hayward, A.C., Machmud, M. and Hifni, H.R. — Susceptibility of peanut cultivars to bacterial wilt in Indonesia: effect of method of inoculation and isolate source.

Kumar, J., Chand, V., Singh, B. and Meekin, J.S. — Stem canker disease of pigeonpea in Fiji.

Lateef, S.S., Sithananthan, S. and Reed, W. — Insect resistant pigeonpea is feasible.

Machmud, M. and Middleton, K.J. — Evaluation of bacterial wilt resistance in peanut.

McNeil, D.L. and Bennett, D.W. — Management systems for peanut leaf diseases in northwestern Australia.

Middleton, K.J., Machmud, M. and Rizvi, S.A. — Indonesian peanut disease survey.

Opina, O.S. and Valencia, L.D. — Cohort life and reproductivity tables of *Puccinia arachidis* causing rust of peanut.

Pachinburavan, A. and Siriwong, P. — Effects of rust disease on yield of cowpea.

Pamplona, P. and Tinapay, S. — The potential of new generation post-emergence herbicides for increasing food legume production in the Philippines.

Rajapakse, R.H.S. and Charles, S.K. — Laboratory observations on rate of development and oviposition of *Callosobruchus maculatus* on different varieties of green gram.

Raju, T.N. and Nene, Y.L. — The value of disease resistant pigeonpea.

Rizvi, S.A., Wakman, W. and Rahamma, S. — Food legume improvement constraints in Indonesia — a disease survey.

Sachan, J.N. — Pigeonpea pest management in India under major farming systems.

Sehgal, V.K., Sen, A. and Singh, K.V. — Resistance in peas, *Pisum sativum* L., against pea leaf miner *Chromatomyia horticola*.

Sehgal, V.K. and Ujagir, R. — Pigeonpea crop phenology and damage by major insect pests at Pantnagar, India.

Singh, G. — Durable resistance in chickpea to *Ascochyta* blight.

Singh, G., Kapoor, S. and Verma, M.M. — Use of multiple disease resistance to remove limits imposed in chickpea production by major diseases.

Verma, M.M. and Singh, G. — Genetic control of chickpea blight (*Ascochyta rabiei*) a serious bottleneck in chickpea production.

Wang, T.C. and Tschanz, A.T. — Effect of soybean development on bacterial pustule.

Wongkaew, S. — Virus diseases of food legumes: the situation in Thailand.

Genetic Factors 304

Review of contributed papers — R. Shorter

Ariyanayagam, R.P. and James, D. — Self-inhibition of fertilisation — a potential cause of floral and pod abscission in pigeonpea.

Bell, M., Shorter, R., Middleton, K., Sadikin, S. and Machmud, M. — Peanut improvement in Indonesia.

Byth, D.E., Wallis, E.S., Troedson, R.J. and Meekin, J.S. — Objectives and progress of the ACIAR/University of Queensland pigeonpea improvement project.

Cheah, C.H. — Extending the genetic limits of yield components by the induction of micromutations in *Phaseolus vulgaris*.

Chomchalow, N. — Status of food legume genetic resources in Southeast Asia.

Dubey, S.D. and Asthana, A.N. — Selection of plant type for resistance to waterlogging in pigeonpea (*Cajanus cajan*).

Faris, D.G., Saxena, K.B., Singh, U. and Reddy, L.J. — The promise of high protein pigeonpea.

Field, S. and Kameli, J. — Food legumes for the calcareous soils of Timor.

Govil, J.N., Murty, B.R., Rana, B.S. and Mehra, R.B. — Biological adaptability in chickpea.

Gupta, S.C., Saxena, K.B., Faris, D.G. and Sharma, D. — Promising pigeonpea varieties from ICRISAT.

Herath, W. — Progress on the improvement of winged bean.

Imrie, B.C., Williams, R.W. and Lawn, R.J. — Breeding for resistance to weather damage in mungbean.

Lal, S. — Status of research on pulses in India.

Lawn, R.J., Williams, R.W. and Imrie, B.C. — Wild germplasm as a source of tolerance to environmental stresses in mungbean.

Maheshwari, R.V. and Mathur, R.L. — Gene action estimates for yield traits of chickpea in India.

Malik, B.A. — Food legume cultivar releases to improve farming systems in Pakistan.

Mehra, R.B., Singh, S.P., Das, P.K. and Govil, J.N. — Analysis of adaptability in pigeonpeas.

Prakash, K.S. and Aradhya, K.M. — Implications of intergenotypic interactions in food legume breeding with special reference to cowpea.

Putland, P.S. and Imrie, B.C. — Interactions between crop duration and yield in mungbean.

Remanandan, P. — Genetic variation in pigeonpea germplasm.

Saxena, K.B., Faris, D.G. and Gupta, S.C. — The potential of early maturing pigeonpea hybrids.

Shaikh, M.A.Q. — Improved food legume genotypes for Bangladeshi farming systems.

Shanmugasundaram, S. — Crop improvement research on legumes at AVRDC.

Shorter, R. and Middleton, K.J. — Rust resistance in peanuts.

Singh, D.N. — Influence of water stress on pollen fertility in mungbean.

Singh, S.P., Govil, J.N., Mehra, R.B. and Ram, Hayat — Morpho-physiological considerations for maximisation of productivity in early pigeonpea.

Singh, V.P. and Tomer, Y.S. — Breeding pigeonpea cultivars for intensive agriculture.

Sumarno, Karsono, S., Meekin, J.S. and Troedson, R.J. — Evaluation of short-season pigeonpea lines in Indonesia.

Processing and Utilisation 327

Review of contributed papers — G.J. Persley

Anambuk, V., Chandrawong, P., Thongprapai, W. and Limphapayom, W. — Processing and utilisation of soybean in Thailand.

Bhat, R.V. — Naturally occurring toxins in legumes and their elimination with special reference to *Lathyrus sativus*.

Chitra, R. and Sadasivam, S. — Investigations on trypsin inhibitor of black gram (*Vigna mungo*) for better utilisation.

Heslehurst, M.R. and Hohenhaus, R. — Laboratory predictions of bean seed shelf life during storage.

Poulter, N.H. — Technical factors limiting the implementation of legume-based milk-type foods in developing countries.

Singh, U., Jambunathan, R., Saxena, K.B. and Faris, D.G. — Nutritive value of green and mature pigeonpea seed.

Tiwari, K. and Tiwari, A.S. — Nutritional quality components of pigeonpea and chickpea.

Widowati, S. and Damardjati, D.S. — Physical, chemical and nutritional evaluation of pigeonpea and its processed products in Indonesia.

Section 1

Socioeconomic Factors

Review of Contributed Papers

T.S. Walker*

THIS review provides an overview of the limits to productivity and adaptation of food legumes by drawing on the reviewer's experience, knowlege of the literature, and conceptual framework for the workshop, the contributed papers/posters, and discussion at the workshop. The review is organised into three sections, encapsulated by the following questions:

1. What socioeconomic constraints limit the productivity and adaptation of food legumes in Asia?
2. What economic limits are misperceived?
3. What is the role of economists in contributing information to overcome those perceived limits?

Socioeconomic Limits and their Implications

Food legume productivity (at least in India) appears constrained more by supply limitations than by restricted demand. The payoff involved in 'getting the technology right' holds more attraction than investing in the removal of what very well may turn out to be illusory (at worst) or nonbinding (at best) constraints. For that reason this review focuses on ways to enhance the effectiveness of generating and transferring food legume technology in this section.

Underinvestment in Agricultural Research

Impressionistic and some cited evidence at the workshop suggests that research investment in food legumes has not approached a level proportional to their share in the value of agricultural production. This appears to be true, but some 'harder numbers' are needed to determine the magnitude of the investment gap.

The paper by Jabbar also points out that grain legumes have been discriminated against in food policy favouring cereal-based self-sufficiency strategies. Jabbar enumerates several adverse effects of such strategies, especially on the livestock and fisheries sectors of the Bangladeshi economy. His arguments about the nutritional consequences of such strategies are open to question, but it is acknowledged that such policies have distorted input and output markets — the question is how much. What is the domestic resource cost of producing cererals vis-à-vis food legumes? If all inputs and outputs were priced at their opportunity costs, a larger allocation for food legumes would be reached than if the value of agricultural production were used as a benchmark.

The last factor favouring a larger research expenditure on food legumes relates to what economists know as human capital. In many agricultural research programs in Asia, incentives are such that the best people, particularly plant breeders, self select themselves towards crops with higher profiles where the prospects for technical success are brighter. Unless reward structures are changed, more resources will have to be invested to generate the same quantum of research output.

Problems of Focus

Compared to other commodity groups, particularly cereals, agricultural research on food legumes appears potentially more uncertain, because information on researchable problems in the target environment is often fragementary or not readily available.

A multiplicity of species, competing end uses, and farming systems (ranging from cash-motivated, commercial production of some oilseeds to subsistence-orientated, home garden production of some pulses) potentially pose daunting problems for food legume improvement scientists. One of the

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more challenging issues is highlighted by Ingram and Lancini. When does a national agricultural research program target resources to improve a locally preferred minor pulse (in this case black gram) instead of continuing with a crop like mungbean which receives more international research support? How do research administrators gauge the amount of genetic progress being made on one crop when attempting to ascertain the desirability of switching to another food legume with a less intensively sampled yield distribution? There may not be any transparent answers to those questions, but one can (trivially) state that research administrators and scientists should be in tune with emerging market trends in utilisation and with basic research developments that abruptly shift yield distributions and the corresponding prospects for genetic progress.

Two aspects of research focus are discussed in the contributed papers. Haque et al. and Kaul note that food legumes are usually intercropped and stress the importance of selecting material under intercropped conditions. In a dissenting view, Herath states that intercropping is more unstable than sole cropping and that small farmers' risk aversion prevents them from incorporating food legumes into intercropping systems. Perhaps Sri Lankan conditions are different to the rest of South Asia where the evidence is overwhelming that food legumes are and will continue to be major components in intercropping systems. The critical question is: at what stage of technology development should the knowledge that food legumes are extensively grown in intercropping systems be utilised? That question is addressed by Byth et al. (Genetic Factors Section), who recommended that advanced material should be tested but not bred or screened in intercrop conditions. Presumably, the information contained in the Haque et al. paper on component ratios in farmers' fields would be useful to scientists in testing advanced lines under intercropping conditions.

The other aspect of research focus relates to the often alluded to high protein status of food legumes. Kaul's emphasis on enhancing production and productivity rather than quantitatively increasing protein content or quality is endorsed. The protein status of food legumes is overrated for several reasons. First, almost all nutritional evidence now indicates that protein deficiencies are rare in poor urban and rural households in Asia; caloric, vitamin, and mineral deficiencies are much more common. Secondly, other studies have shown — much like von Leibig's law of the minimum — that a threshold amount of calories has to be ingested before additional protein intake can be efficiently absorbed and assimilated. Lastly, the average cost per unit of nutrient is not a criterion used by consumers in deciding what food to purchase or by producers in determining what crops to grow. For example, recent work in Bangladesh incidates that a proportional price subsidy on potatoes would be more effective in stimulating protein intake among the poorest households than an equivalent subsidy on pulses although the average cost of protein derived from potatoes is over 11 times greater than for pulses.

Deficient Public Sector Infrastructure

In addition to an underinvestment in agricultural research, food legume productivity is potentially limited by deficient infrastructure in a few strategic areas. Because pesticide use is rapidly increasing in Asia and because chemical control will be the cornerstone of food legume protection in the immediate and medium-term future, investing in the diffusion of information on when to spray should yield handsome dividends. Extension programs should be selectively strengthened to improve the delivery of information on (crude) economic thresholds. Likewise, inoculant quality control could be significantly improved through judicious government intervention in several Asian countries.

Weak Private Sector Research and Production Incentives

Several papers at the workshop have underscored many of the difficulties encountered in producing and storing food legume seed. Additionally, Byth et al. indicate that (with the possible exception of pigeonpea) the prospects for hybridisation are bleak. Does this mean that the public sector will have to share most of the responsibility for food legume improvement? Without greater private sector participation, the goal of increasing food legume productivity may not be reached. Biotechnology is one area where greater private sector participation could pay in the longer term. What are constraints to and incentives for greater private sector participation in grain legume research in Asia? Some research is needed to answer that question as a first step for removing the constraints and improving the incentives.

Unfavourable Trade Policies

Conspicuous by its absence at the workshop has been any mention of specific trade policies that have hampered the development of export markets. We know that some export trade restrictions have adversely affected India's share in the market for confectionary groundnuts. Tariff and nontariff barriers in developed countries are likely to be especially damaging the prospective international trade.

Although not a food legume, the experience with dried cassava chips is illustrative. The EEC's abrupt imposition of a quota on dried cassava imports severely hurt many poor farm households in Thailand and Indonesia in the early 1980s. If pressures for increasing protection are not resisted, the market potential for food legumes in Asia will be curtailed.

Misperceived Socioeconomic Constraints

Often socioeconomic constraints are only in the eye of the beholder and do not hold up under greater scrutiny. The paper by Dauphin and Rachim presents an apt illustration of the dominance of technical over socioeconomic factors in explaining interhousehold variation in yield. That paper also reinforces the belief that the rural poor in Asia would be better served if social scientists spent less time in drawing up detailed typologies of farm households and allocated more effort to interdisciplinary research. This would result in a better understanding of the other subtle ecological variation that conditions the incidence of yield reducers in farmers' fields.

Several other candidates for the title of socioeconomic constraints put forth at this workshop would receive few votes from economists. Price stabilisation is not a necessary condition for the diffusion of improved varietal technologies. For example, coarse cereals in India have not benefited from price stabilisation in India, yet modern finger millet varieties, pearl millet hybrids and sorghum hybrids are widely adopted by rainfed producers in Karnataka, Gujarat, and Maharashtra respectively. A large part of the explanation for the differences in varietal diffusion between coarse cereals and food legumes, like *desi* chickpea, lies in the much faster rate of genetic progress in the former relative to the latter. Also, marketing research shows that markets for the major food legumes, like chickpea and pigeonpea in India, are better integrated than are markets for the coarse cereals, pearl millet and sorghum. Better market integration should translate into enhanced price stability for the major food legumes vis-à-vis the coarse cereals.

Cries of exploitation by middlemen also usually fall on deaf ears with economists. In an otherwise excellent contribution, R.K. Singh's recommendation to invest in mini dal mills to reduce middlemen's marketing margins begs a number of questions. What is restricting entry into dal milling? If mini dal mills were competitive, what inhibits their development? Are dal marketing margins increasing over time? If so, why? How does the profitability of dal milling compare with similar processing activities like rice milling?

Role of Economic Research

By way of summary, the following priority areas for economics research are highlighted:

1. Estimating the size of pre- and post-harvest yield reducers, crude economic thresholds, and economic tradeoffs between levels of varietal resistance and chemical control;
2. Calculating the domestic resource cost of producing food legumes vis-à-vis other competing commodities and predicting the effects of bringing subsidised market prices in line with social cost;
3. Monitoring trends in interregional and international comparative advantage and analysing distortions to the interregional and international trade of food legumes;
4. Identifying constraints to and incentives for greater private sector participation in food legume seed research and production.

The first area falls squarely within the domain of economists working with biological scientists in national and international agricultural research programs and centres. Areas (2), (3), and (4) are more adequately addressed by economists stationed in national, regional, or international research organisations, such as the Thailand Development Research Institute (TDRI), the Coarse Grain, Pulses, Roots, and Tubers Center (CGPRTC), and the International Food Policy Research Institute (IFPRI) respectively.

Economist are well trained to carry out research in those four areas, but public sector economists are not perceived as having a comparative advantage in conducting studies on demand utilisation and product introduction. These hinge on the identification of opportunities which, in turn, are product, country, and time specific. Identifying such opportunities is critical to the spread of food legumes in Southeast Asia; however, economists in the private sector and enterpreneurs knowledgeable about local demand conditions would seem better placed to undertake such studies.

The Role of Socioeconomic Factors in Low Soybean Yields in Garut, West Java

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It is generally believed that low soybean yields observed in Java may be linked to insufficient use of cash inputs, particularly fertilisers and pesticides and would be thus ultimately related to socioeconomic factors. Surveys conducted in the early phases of the Soybean Yield Gap Analysis Project (SYGAP is a cooperative project of the CGPRT Centre, CAER, BORIF, MARIF and CIRAD, with financial support from EEC) would seem to disprove this assumption, for the Garut area.

Preliminary surveys served to identify major cropping systems, and to ensure that input supply and marketing of the grain were adequate. A detailed survey of 23 farms was then conducted in Wanaraja, the major producing area. Selection of respondents was made to reflect as much as possible the existing variety of situations. Information was collected on: family and labour, land, cropping systems, soybean cultural practices, farm inputs and outputs, and off-farm activities.

A brief description of each farm was made on the basis of resources, options, and economic results. It was thus possible to identify six farm types:

1. large farms (>0.6 ha), efficient, with high output.
2. large farms, low output, but investing in land and citrus.
3. medium farms (0.3–0.6 ha), can however invest, since there are few children or sufficient off-farm resources.
4. small to medium farms, very dynamic, investing in capital intensive crops.
5. marginal farms (<0.15 ha), stagnant, household income largely from wage earnings.
6. medium or large farms, efficient, but do not invest because of age or family size.

Farm characteristics differ widely between the six types. However, average inputs used for soybean and resulting mean yields seem relatively similar to the six types, in spite of relatively large individual variations (Table 1).

TABLE 1. Major farm characteristics and soybean inputs and outputs for the six farm types; Wanaraja survey, 1985.

Type	Holding (ha)	Orchard % holdg.	Family size[1]	Labour[2] In	Labour[2] Out	GFCI[3] :	Soy. inputs & outputs Fert.	Soy. inputs & outputs PC[4]	Soy. inputs & outputs Lab.[5]	(kg/ha) yield
1	1.31	22	2.5	217	0	724 :	102	2.5	205	703
2	0.98	12	2.7	40	20	304 :	138	2.4	173	576
3	0.33	34	2.8	25	28	428 :	93	1.5	220	607
4	0.34	28	3.9	21	47	1221 :	90	1.4	223	657
5	0.14	00	3.0	5	63	729 :	120	2.5	244	777
6	0.60	03	4.2	24	62	1510 :	146	2.3	168	810

[1]Adult equivalents.
[2]working days.
[3]gross farm cash income ($/ha).
[4]No. of pesticide applications.
[5]working days/ha.
Fert: kg nutrient/ha.

Besides the fact that fertilisers and pesticides are much subsidised, this situation may be best understood if we admit that technical rather than socioeconomic factors are responsible for low yields. Regression analyses confirm that only a small part of the yield variability (27%) may be explained by input levels, including labour use.

Another finding of the survey is that in spite of the high prices and easy marketing of soybean, this crop may rapidly lose ground to its major competitors in the Garut area, i.e. fruit trees, upland rice, and possibly groundnut, if yields remain at present levels.

On-farm trials are now conducted to investigate yield reductions by various factors, including in particular insect pests, especially agromyzids (*Ophiomyia phaseoli* and *Melanogromyza sojae*).

The Logic of Intercropping Pulse in Rainfed Bangladesh: a Preliminary Assessment of Farmers' Views

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THE variation in temperature, soil moisture, inherent soil fertility, competition/complementarity with other crops, length of growing period, topography management and application of inputs are factors that influence productivity of pulses as sole or intercrops. The variation in some of these factors has been considered so large that breeding of specific plant types is considered risky because of 'the vulnerability of genetic uniformity of a monoculture over a vast area' (Sharma and Jodha 1982). The review of literature shows two problems under-researched: (i) what is the logic of various ratios in which pulses are mixed with oil seeds or cereals under different edaphic and climatic factors; and (ii) what are the implications of understanding this logic for breeding different plant types for different agroclimatic regions.

Selecting segregating populations under intercrop or mixed crop condition is also related to these aspects. To understand above aspects of lentil/mustard, chickpea/mustard, chickpea/linseed, lentil/mustard/linseed and chickpea/mustard/linseed combinations, 30 farmers at Bagerpara Farming System Research site of Bangladesh Agricultural Research Institute at Jessore were interviewed. On the 47% of the survey area under pulses, the ratio of sole to mixed crop lentil was 1:4.95 whereas sole to mixed crop gram was 1:1.3. The seed rate was higher generally when soil moisture and soil fertility were less, clods were greater and sowing was late.

In case of lentil/mustard the main ratio was 40 kg lentil:7 kg mustard seed per ha. However, the range was from 12:2 to 20:3. Sometimes lentil was also sown in rows about 2 metres apart in a mixture, since harvesting the earlier maturing mustard disturbed the other crop. Generally, on less fertile soil the proportion of lentil was higher than mustard. In the case of the chickpea/mustard combination the ratio ranged from 16:3 to 20:3. Compared to lentil/mustard, the proportion of chickpea in the chickpea/mustard combination was higher in most cases. Four types of risks were identified. In the order of importance these were: early Rabi/winter rainfall; late Rabi rainfall; pest problems and early soil drying. In the case of early Rabi rainfall, crust formation that affected clod formation was noted. Farmers seem to wait for rainfall expected around the full moon of Kartik (September/October). One of the indigenous practices for controlling pests was cultivation of coriander with chickpea where it was assumed to keep the pests away (particularly Pod Borer).

We have generated a large number of hypotheses (not all of which are reported here) regarding the logic used by farmers for precise combinations chosen by them under different conditions. Further work on these issues will serve two main objectives: (i) it will help plant breeders in selection of lines under intercrop/mixed conditions; and (ii) rather than maximising yields of individual crops, breeders might try to maximise the biomass yields (grains as well as fodder) of total crop combinations along with ensuring the lesser risk. This objective would include pulse-livestock interactions (Gupta 1986).

Sharma, D. and Jodha, N.S. 1982. Constraint and prospects of pulses production in semi-arid regions of India, ICRISAT, cp 107, Hyderabad.

Gupta, A.K. 1986. Matching farmers concerns with technologists' objectives: a study of scientific goal setting in dry region, CMA, IIM, Ahmedabad, mimeo.

Some Socioeconomic Constraints to Legume Cultivation in Sri Lanka

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MULTIPLE cropping systems, particularly with legumes, are considered a promising way of increasing food availability, and a source of protein. Growing of legumes in multiple and intercropping systems involves intensive agricultural patterns; particularly the application of fertiliser, pesticides and other aspects of crop care. While the yields are obviously greater, the higher capital-intensive nature discourages farmers from adopting such systems (Upasena and Fernando 1973). This is particularly important, because only very small farmers grow legumes. A recent survey in Sri Lanka on the winged bean indicated that 70% of the growers had less than 0.4 ha of land (Aluvihare and Herath 1984).

Cropping systems with legumes for small farmers should be labour intensive. Labour is one resource available to the farmers at low cost. An experiment of intercropping mung and corn resulted in a reduction of total labour. This may cause labour displacement, an undesirable trend in rural areas. Future effort in improving legumes should be directed towards less capital intensive but more labour intensive systems.

The low tolerance to risk of small farmers dissuades them from adopting legumes in intercropping systems. In addition to being capital intensive, there is evidence that intercropping systems are less stable. Harwood and Price (1977) indicated that crop failure often occurred after considerable intercropping competition had already taken place, and they concluded that sole cropping can give greater stability. Most small farmers in Sri Lanka prefer to grow legumes only when they are easy to grow, require less care and grow under unfavourable conditions (i.e. infertile soils, frequent water stresses etc.).

There is not an active market for legumes. Most legumes are marketed in the village kiosk and the prices of legumes are about half that of other vegetables such as brinjals and tomatoes (Aluvihare and Herath 1984). Price fluctuations of legumes are a rule rather than an exception. Appropriate processing techniques and processed products are not available in Sri Lanka, thus limiting the market potential. Current methods of food preparation are crude, and appropriate technology for processing common legumes such as beans are an urgent need (Axelson et al. 1982).

A survey indicated that many farmers are not aware of the protein value of legumes, and legume cultivation is done more as a tradition. Intensive and systematic cultivation requires enhanced awareness of the protein value of legumes amongst small farmers (Aluvihare and Herath 1984).

Aluvihare, P.B. and Herath, H.M.W. 1984. Winged bean cultivation in the Kandy district, unpublished.

Axelson, M.T. et al. 1982. Consumption and use of the winged bean by Sri Lankan villagers. Ecology of food and nutrition 12, 127–137.

Harwood, R.R. and Price, E.C. 1977. Multiple Cropping in Tropical Asia. In: Multiple Cropping, R.E. Papendick (ed.), Madison, Wisconsin.

Upasena, S.H. and Fernando, G.W.E. 1973. The Intercropping Patterns in Sri Lanka, R.R.I. (SL) Bulletin, 8(1): 23.

Small Farmer Constraints to Adopting Food Legume Crops in the Lower North of Thailand

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The Pichit Land Reform Area Rural Development Support Project is an integrated rural development project covering some 50 000 hectares in Pichit Province. The project aims to stabilise and increase farm incomes in the face of limitations from dependence on rainfed cropping systems. Activities include utilisation of shallow groundwater aquifers for irrigation, drainage of seasonally flooded areas, and improvement in the quality of extension advice and organisation. Average farm size is 4.5 hectares, often including both lowland for rice production, and upland areas for other field crops.

The project wishes to identify cropping system improvements specific to groundwater use in Pichit. Mungbean (*Vigna radiata*) has been introduced recently by the Department of Agricultural Extension (DOAE) as an alternative to black gram. The extension agency has also undertaken an active program to promote soybean production. The development of a cropping system involving food crop legumes is seen by farmers as a desirable means of reducing dependence on the present rice-based cropping systems. A high priority for legumes in the cropping system is also justified for the following reasons: fertility status of both land classes; the crop water requirements for these legume crops is less than for a dry season irrigated rice crop; social issues such as maintaining family unity during the dry season, and the economic advantages associated with stabilisation of household income.

Major constraints to farmer adoption of food crop legumes are:

— lack of area/soil specific *Rhizobium* packages to maximise the production potential and gain advantages provided by biological nitrogen fixation;

— soil fertility depleting management practices, especially low adoption of stubble retention;

— water distribution constraints;

— competition between activities for the farmer's labour, especially at critical times such as harvest;

— farmers have to travel a minimum of 30 kilometres to buy agricultural supplies;

— limited research and extension on the preferred legume crop, black gram;

— high household debt burden.

National agricultural development agencies generally base their advice on research station experiments. Farmers understand that these recommendations are at most times suitable if resource allocation is not involved in the decision-making process. Hence farmers select components of 'technology packages' and modify them under their own farm environment. Provision of credit by commercial lending institutions in the form of a 'loan package' does not allow flexibility in crop inputs. Farmers are risk aversive; thus a prime consideration for development and extension of technology is not to increase the potential risk to the farmer.

Despite these constraints, farmer adoption of mungbean as a dry season crop has been encouraging. Yields, however, have been disappointing, ranging from 0.38 to 0.5 t/ha. The project's direct support of public and private institutions addressing the constraints outlined will hopefully achieve significant increases in farmer adoption of food crop legumes and yield.

* Views expressed are those of the authors and not necessarily those of the Australian Government or the project's managing agents.

Consequences of a Foodgrain Biased Production Policy in Bangladesh

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SELF-SUFFICIENCY in foodgrains, rice and wheat is the main objective of the food production policy in Bangladesh. One reason for this is that the diet of 60–70% of the population is energy deficient, due to inadequate foodgrain consumption. Also, foodgrain imports have risen from 4% of domestic production is the 1950s to 15% in the 1970s. Dependence on food aid is considered undesirable.

The strategies for self-sufficiency are:

— high yielding variety seeds, fertiliser, irrigation for high yields and intensity of cropping;
— flood control and drainage to expand area planted to high yielding varieties;
— subsidy on seed, fertiliser, irrigation, pesticides, credit (rate of subsidy decreased over time);
— major extension and research on foodgrains, and substantial foreign aid for above activities.

These strategies have produced an acreage shift in favour of foodgrains, and productivity of foodgrain, potato and tobacco have increased. However, all other crop production has decreased, and the growth rate of foodgrain is not enough for self-sufficiency. Fish production has been affected by irrigation, drainage, and flood control, while livestock production has been affected by reduced quantity and quality of feeds (crop by-products). The overall effect has been that average quality of human nutrition has deteriorated.

The conclusion is that more balance between crop, fishery and livestock production is needed. The integrated nature of farming was broken by the seed-fertiliser technology because the alternative specialised agriculture was not planned properly. The foodgrain biased policy and strategy has stunted the overall growth of agriculture.

Food Legumes in Bangladeshi Farming Systems — Nutritional Considerations

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FISH and pulses have been the traditional rich source of proteins in Bangladesh. In recent years the per capita availability of both these foods has decreased. The reduction in production, area under cultivation and productivity of pulse crops is alarming.

Low-yielding winter pulse crops, namely lentil, chickpea, pigeonpea, field peas, mungbean and black gram are being replaced gradually by wheat, irrigated 'boro' rice and lately cotton. Lathyrus acreage, generally restricted to low-lying areas, has remained unchanged, however, except in places where irrigation has been introduced or campaigns have been launched against this crop for its neurotoxicity (Gowda and Kaul 1982).

Since 1984, concerted efforts have been made through the national Farming Systems Research (FSR) program and on-farm research network to incorporate newly released pulse varieties in the cropping patterns. Simultaneously, incorporation of various beans in the homestead gardens and cultivation of pigeonpea on the sloping flanks of national highways is gaining popularity.

From the nutritional viewpoint, emphasis is laid on enhancing the production and productivity rather than quantitatively increasing protein content or quality. The strategy aims at increasing the availability of pulses to at least 10 g per capita per day through interventions that are compatible with the prevalent crop production goals. The following approaches are being followed:

1. promotion of short-duration mungbean, black gram and pigeonpea cultivars in the summer months (March through July);
2. yield improvements in rainfed chickpea and lentil through breeding;
3. agronomic research on various inter, mixed and relay cropping options;
4. detoxification of lathyrus through low cost techniques and through breeding for low toxin varieties.

Closely associated with the poor human and soil health is the deplorable condition of milch and draft cattle. Lack of good fodder is one of the key constraints of the livestock sector. The role of food legumes as a source of protein-rich fodder is being emphasised through the FSR.

In Bangladesh, food legumes need to be promoted more as 'catch' and inter crops rather than as sole crops. Research emphasis is therefore shifting onto breeding of pulses for rainfed conditions, earliness and suitability as intercrops.

Gowda, C.L.L. and Kaul, A.K. 1982. Pulses in Bangladesh, FAO/BARRI, 472. Bangladesh Bureau of Statistics 1984. Statistical Yearbook of Bangladesh.

Socioeconomic Factors Limiting Food Legume Production in Indian Farming Systems

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Socioeconomic factors are a major constraint to food legume production. In India, food legumes are mostly grown in rainfed situations intercropped with cereal crops and with low inputs. The deep root system of these crops, compared to cereal crops, enhances productivity and survival under water stress conditions. There is a diversity in area, production and type of food legumes within current agroecological systems. A single legume production strategy cannot meet the requirements of varying climatic and soil factors and location specific strategies are therefore required.

The stagnating yield of food legumes against major cereals (rice and wheat) has changed the yield ratios from 1.57 to 2.40 during the period from 1967-68 to 1984-85, and has led to a decrease in the area under food legumes. The low profitability of food legumes is another factor in the declining area. The return over variable costs indicates that unless productivity of food legumes is increased, the prevailing market prices will not provide sufficient incentives to farmers. The coefficients of variation of yield from 1970-71 to 1984-85 for chickpea, pigeonpea, urdbean, mungbean, rice and wheat were similar at 10.7, 9.9, 10.1, 14.6, 10.6 and 14.1%, respectively. However, the period with downward trend was relatively larger for grain legume (7-8 years) as compared to cereals (4 years for wheat and 6 years for rice). The price spread is very high. The producer's share in consumer's rupee varies from 49-63%, compared to 80% for wheat (Table 1). Wholesale price variation for whole and split grain (Dal) ranged from 28 to 58% (pigeonpea) and from 10 to 55% (chickpea) during 1972-73 to 1982-83 in Kanpur market of Uttar Pradesh.

TABLE 1. Price spread in food legume and cereal in some States (Saini and Bhatia 1986).

Crop	State	Year	Price (Rs.) Farm harvest	Price (Rs.) Retail	Farm price as percentage of retail price
Chickpea	Madhya Pradesh	1983-84	358.00	625.00	49.28
Pigeonpea	Uttar Pradesh	1982-83	389.00	615.00	63.25
Wheat	Punjab	1983-84	152.00	189.00	80.42

Studies at ICRISAT (Jodha 1979) reveal that intercropping and diversification can minimise crop fluctuations and number of total crop failures, thereby helping to stabilise income and food supply (Singh and Walker 1982). Experiments under AICARP (ICAR) gave good results by introducing and improving the yield of food legumes after rice and wheat.

These findings emphasise the need to recast the existing priorities of research and lay more stress on development of high yielding short season food legumes, and evolving plant types suited to intercropping situation under rainfed conditions. Development of postharvest technology (like mini Dal Mill in area of production) and organised marketing (farmers' cooperative) will go a long way in improving the socioeconomic condition of farmers.

Saini, C.R. and Bhatia, M.S. 1986. Maximising Pulse Production Conf. 1986.
Jodha, N.S. 1979. Some dimensions of traditional farming in semi-arid tropical India, ICRISAT.
Singh, R.P. and Walker, T.S. 1982. Determinants and implications of crop failure in the SAT of India, ICRISAT.

Food Legumes Make Cropping Systems Remunerative

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Food legumes are well known for their suitability for mixed, inter, and sequential crop systems in dry lands. Short-duration food legumes help in doubling cropping intensity in assured rainfall areas, particularly in peninsular and eastern India in rice fallows (Singh 1982).

In contrast, even in the irrigated areas of northern India, inclusion of urdbean (*Vigna mungo*) before mustard (*Brassica juncea*) proved most remunerative (Table 1).

TABLE 1. Seed yield and monetary returns mean — 1982-85.

Crop sequence Kharif-rabi	Total seed yield (kg/ha)	Net returns (Rs.)
Urdbean-mustard	3691	11906
Pearlmillet-chickpea	4663	10135
Mungbean-mustard	2925	8950
Pigeonpea-wheat	5389	8427
Clusterbean-wheat	5923	7040
Pearlmillet-wheat	7412	6977
Groundnut-wheat	4961	6646
Soybean-wheat	4872	5549

This sequence was followed by pearlmillet-chickpea, mungbean-mustard and pigeonpea var. UPAS-120-wheat. The existing cropping sequence of pearlmillet-wheat, though the highest yielding, gave lower monetary returns, because of higher investment on inputs (fertiliser and water) as compared to remunerative sequences involving other legume species. These legumes proved their worth and utility in rainy (*kharif*) as well as winter (*rabi*) seasons. Urdbean and mungbean varieties used were JU-77-41 and ML-62 respectively. Chickpea variety was JG-315 (WR). Urdbean as well as mungbean varieties were free from yellow mosaic virus and chickpea variety from *Fusarium* wilt under natural field conditions in all the three years. The new cropping systems may have wide application in irrigated areas.

Singh, R.P. 1982. Symp. Pulse Production in India by Hindustan Lever, 235-240.

Section 2

Management in Irrigated Farming Systems

Review of Contributed Papers

B.S. Dahiya *

THERE were 10 contributed papers in this section, representing seven countries, and diverse topics related to management of food legumes in irrigated farming systems. The review of these contributions indicated that there are major emphases on three aspects.

1. Intensive land use following cereal-cereal rotations, to produce more per unit area and time. This has been mainly due to the commitments of governments of these countries to achieve self-sufficiency in food grains.

2. The beneficial role of legumes (food/fodder) as short-duration crops or main season crops in cereal-based farming systems.

3. The efficient and economic use of available resources through management of individual crop components in a multiple cropping system.

Introduction of food legumes in irrigated areas implies intensive land use through multiple cropping. However, there is lack of information on multiple cropping involving food legumes which can be translated to the field.

The extent of multiple cropping — growing several crops on the same piece of land — varies widely among Asian countries, with the cropping index ranging from 108.5% in Pakistan to 184.3% in Taiwan. Multiple cropping is likely to gain more importance in Asian farming systems because:

1. The multiple cropping index is generally higher with smaller farm size. With the expected decrease in farm size, the intensity of land use is expected to increase.

2. Multiple cropping is a simple and inexpensive strategy for absorbing rapidly increasing availability of farm labour.

3. With already overpopulated areas and ever increasing rural populations, multiple cropping is an excellent alternative to capital-intensive industrialisation for increasing the income of the rural populations in Asian countries.

The contributors have emphasised the introduction of food legumes in multiple cropping under cereal-based farming systems — particularly rice. The management problems appear to have been envisaged, though not highlighted (McNeil and Eagleton; Gowda; Pandey).

With intensification of land use under sequential cropping pattern the interval between harvesting of one crop and planting the next is short. Thus the management of one crop will significantly influence the performance of the succeeding crops.

In the multiple cropping approach the level at which crop production strategy should be packaged and evaluated needs consideration. There are three levels — crop, cropping pattern and farm level.

The cropping pattern level, where the management program to enable all the crops in the cropping pattern to achieve maximum productivity in a given piece of land is specified, is the major concern. This level of testing production technology has been preferred because the biological interactions among crop components in a cropping pattern are expected to be large, due to the residual effect of the previous crop on the productivity of the current crop. This point has been emphasised considerably by different contributors (Veeranna; Singh; del Rosario and Santos; Sangakkara) that food legumes have a beneficial effect on the succeeding cereal crop. Legumes incorporated into the exhaustive cereal-cereal rotation have been found economical by giving productive returns and cutting down the expenditure substantially on fertilisers in the succeeding cereal crop. By developing high-yielding varieties of pigeonpea which fit in rotation with wheat, there is not only increased productivity but also a saving of 40 kg N/ha in the following wheat crop. This contribution by the author has made early pigeonpea a very successful crop in the wheat belt of north Indian states.

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To meet the requirements of a multiple cropping system, there is a need to tailor the cultivars of food legumes. There are three characteristics — short growth duration, stress tolerance and shade tolerance — which have been found useful in increasing the productivity and stability of intensive cropping patterns. Early maturity has several advantages, but it is generally associated with low yield because the limited time for vegetative growth is not enough to achieve maximum yield. However, early maturing varieties are comparable in terms of yield per day. The other character which needs consideration is resistance to temperature, as the fluctuations in temperature are sharp at the time of fruit development of spring-planted green gram/ black gram and post-rainy season food legumes like chickpea. Also, tolerance to brief phases of waterlogging will be a desirable varietal character in paddy-based farming systems. The present day varieties of food legumes suffer from temporary waterlogging in paddy fields.

Early maturity and high productivity in food legumes have been successfully utilised in cereal-based farming systems in Nigeria (Singh), Pakistan (Beg), Philippines (del Rosario and Santos) and Sri Lanka (Sangakkara). The detrimental effect of planting date on the succeeding cereal crop after a food legume has also been overcome by having early maturing varieties of pigeonpea, cowpea and green gram.

The success or failure of a multiple cropping system is largely determined by the choice of crop species and varieties within a species. The differences among environments are expected to be large. When the interaction is large enough to cause substantial changes in the ranking among varieties grown in different environments then the use of the high-cost multi-environment selection approach is justified. The studies on soybean (Sumarno) indicated that selection under two different environments showed wide variations. The selection for the specific environment in the farmer's field was successful.

The experience on breeding methodology and selection strategy with chickpeas has shown that bulk testing of F_2 and F_3 in different environments is useful in identifying potential crosses for further selections. The changing of environments by taking the selections from irrigated conditions to rainfed conditions in the next generation and vice-versa has also been found effective in selecting widely adapted varieties.

The resources of the majority of the Asian farmers are limited, therefore it is difficult to adopt high input technology which has a restricted scope. Thus any technology being developed, particularly for food legumes, should ensure low production cost, better area utility and high returns. The introduction of soybean in rice-based farming systems in the Philippines is high cost technology, so it has limited scope in spite of its potential.

The priority areas in food legume research should include both immediate remedial measures and long term measures.

Immediate Measures

1. The redirection of pricing and procurement policy away from cereals in favour of pulses.
2. Transfer of available technology to minimise the gap between yields at research stations and those obtained by farmers. The key components of this technology are: (i) seed; (ii) seed treatment; (iii) fertilisers; (iv) weed management; (v) pest management.
3. Quick spread of presently available moderately yielding but stable varieties.

Long Term Measures

1. Development of input-responsive, high-yielding varieties, modifying plant type and improving genetic potential for different farming systems. There is a need to have location-specific production technology.
2. Minimising the risk factor by incorporation of resistance to both biotic and abiotic factors. At present the pulses/food legumes are being shifted away from areas where irrigation facilities are being extended. To reverse this trend the tolerance of food legume varieties to salinity will be very helpful.
3. Seed dormancy will be useful in better incorporation of these crops in multiple cropping, cereal-based farming systems.
4. Procurement and pricing policy of the governments of these countries should be favourable for food legumes, as they have done in the cases of wheat and rice. The green revolution in wheat and rice has been possible, not only because of economically viable technology but because this technology has been backed up by appropriate packages of services and public policies. Whatever technology may be developed, it will not be adopted extensively unless it is backed up by a favourable procurement and pricing policy.

Performance of Soybean on Fallow Land in Pakistan after Main Crops of Wheat, Rice and Cotton

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PAKISTAN is short of edible oil. Consumption in 1984–85 was 900 000 t, of which 75% was imported. Of the indigenous production, 65% is from cotton seed which is not an oil crop.

Approximately 1.4 m ha of short-duration IRRI-type rice and 0.6 m ha of long-duration Basmati rice are grown annually in Pakistan. Short-term rice is harvested by October, and is grown in rotation with winter crops. Basmati rice is not harvested until December, too late for sowing of traditional winter crops. Cotton is grown on about 2.24 m ha, of which about 0.5 m ha remains fallow in spring. Wheat in rainfall areas is sown on 1.3 m ha. Half of this area remains fallow in the summer season.

Spring-sown soybean may be appropriate for rotations with Basmati rice and cotton, providing maturity occurs by June in time for the subsequent rice and cotton sowing. Results of trials grown in 1978 and 1981 (Judy et al. 1981; Jackobs et al. 1984) indicate that varieties of maturity groups between 00 and IV may be suitable (Table 1).

In rainfed fallow areas after wheat, varieties from groups II, III or IV have given an average yield ranging from 1.39 to 1.76 t/ha (Table 1).

The yield from soybean as the spring crop in cotton areas ranged from 1.17 to 2.0 t/ha. An average yield of 1.66 t/ha over an area of 107.4 ha was obtained.

Delayed sowing rapidly hastened time to maturity and reduced seed yield, which was most likely due to increasing temperatures in late spring and summer. Later varieties were higher yielding in early sowings but their advantage was dissipated with late sowing. Testing of sowing dates prior to February 17 is necessary.

TABLE 1. Performance of soybean after rice or after wheat as a summer crop.

Main Crop	Date of Planting M D Y	Group OO,O,I	Group II,III,IV	Mean Yield	Average Day, to Maturity
Rice	2/17/81	2.39 (4)*	2.91 (12)	2.78	108
	3/04/81	2.20 (4)	2.32 (12)	2.29	96
	3/20/78	1.62 (4)	2.05 (7)	1.90	95
	3/28/81	1.73 (6)	1.44 (10)	1.55	86
Wheat a. High rainfall	6/17/85	0.78 (2)	1.44 (22)	1.39	88
b. Low rainfall	7/22/85	0.85 (4)	1.95 (19)	1.76	81

* In parentheses are the number of entries.
Source: Judy et al. (1981); Jackobs et al. (1984).

Judy, W.H., Jackobs, J.A. and Engelbrecht-Wiggans, E.A. 1981. International Soybean Variety Experiment. Sixth Report of Results 1978. Intsoy 21, 198.

Jackobs, J.A., Smyth, C.A. and Erickson, D.R. 1984. International Soybean Variety Experiment. Eighth Report of Results 1980–1981. Intsoy, 26, 139–141.

Adaptability of Selected Legumes and Cereals to Post-rice Conditions

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ONE problem encountered in growing upland crops after rice is water availability. Usually there is excess water during crop establishment and water deficit during flowering and grain filling (Zandstra and Price 1977).

Adaptive responses to post-rice conditions of selected legumes (mungbean and cowpea) and cereals (corn and sorghum) were compared under field conditions from December 1984 to April 1985. Germination after rice was lower than in upland culture, possibly due to rapid drying of the soil surface and the resultant mechanical impedance to seedling emergence.

Gradual depletion of moisture in the paddy soil reduced plant growth, increased stomatal resistance, lowered leaf water potential, increased root-shoot ratio, increased free proline accumulation and changed leaf orientation. These parameters were significantly correlated with yield of the legumes but not of the cereals. In cereals, only the length of the root was correlated to their yielding ability in post-rice culture.

Earliness and the short pod-filling period in mungbean and cowpea served as a mechanism of escaping drought stress in the post-rice environment. A similar observation was made by Paje and del Rosario (1984) who showed that the earliness of bush sitao compared to pole sitao was an adaptive mechanism that allowed flowering before a detrimental level of drought occurred.

Yield was lower in paddy but the difference was only significant in sorghum cv. BTX622 and in corn. Flowering was also delayed but to a non-significant extent.

TABLE 1. Grain yield of eight varieties of legumes and cereals under post-rice and irrigated upland conditions; mean separation (according to parameter) by DMRT at 5%.

Species	Varieties	Grain yield (t/ha)		Days to flowering	
		Post-rice	Upland	Post-rice	Upland
Mungbean	Pag-asa 3	0.35f	0.89def	41fg	36g
	IPB M79 13-60	0.41f	0.88def	40g	37g
Cowpea	Vita 5	0.85def	0.95def	53cd	48d
	Vita 7	0.73def	1.00def	49de	45ef
Sorghum	Sg-5	1.14de	1.39d	50de	49d
	BTX 622	0.97def	2.07c	61ab	56bc
Corn	IPB Var 1	0.43f	4.64a	60ab	49d
	IPB 218	0.48ef	3.65b	56bc	52cd

Considering the yield potential and adaptive mechanism to post-rice condition, mungbean and cowpea were better adapted than corn and sorghum. There were no varietal differences in yield but measured morphological/physiological responses indicate the superiority of mungbean cv. IPB M79 13-60 to cv. Pag-asa 3, cowpea cv. Vita 5 to cv. Vita 7, sorghum cv. Sg-5 to cv. BTX 622 and corn cv. IPB 218 to IPB Var 1. These varietal differences suggest that selection for desirable traits may prove useful for developing crop varieties specifically for post-rice culture.

Paje, M.M. and del Rosario, D.A. 1984. J. Phil. Crop Sci., 9, 117-128.
Zandstra, H.G. and Price, E.C. 1977. IRRI Conf. on Cropping System Research.

The Potential of Chickpea after Rice

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CHICKPEA (*Cicer arietinum* L.) is a subtropical, cool season crop which grows well in a range of climates. In the tropics chickpea is usually planted as a monocrop in the cool, post-rainy season in a receding residual soil moisture situation (Saxena 1984). In many countries in the tropics, it is planted as a second crop after the main rainy season crop (usually rice). This is a common practice in Bangladesh, Burma, parts of India, Nepal and Pakistan (Sind province). In these situations chickpea can be planted either after tillage or as a relay crop with no tillage. The latter practice is more common.

As a relay crop, chickpea seeds are broadcast 10-15 days before the harvest of rice. However, it is possible to sow chickpeas in between paddy stubble either behind the plough or with appropriate seed drills with minimum disturbance to the stubble. It is recommend that 1.5-2 times the normal seed rate be used to compensate for poor germination and death due to collar rot (*Sclerotium rolfsii*).

Several factors are important in ensuring the success of chickpea in rice-based cropping systems:

1. The soil moisture levels at sowing and during the crop growth period are important determinants of crop establishment and yield. Cultivars vary in their ability to germinate under limiting soil moisture conditions, and this character can be bred into high yielding varieties (Saxena 1984). It is also essential to identify and incorporate drought tolerance.

2. Chickpea following rice has to be sown 30-40 days later than the optimal planting time. Thus, there is a need to identify and breed varieties adapted for late planting. ICRISAT has such a breeding program and a few lines have been identified that have performed well under late planting conditions.

3. Decaying paddy stubble may enhance the incidence of collar rot. Seed treatment with fungicides such as Thiram may reduce the pre-emergence mortality (M.P. Haware, ICRISAT, Patancheru, India, pers. comm.).

4. Pod borer (*Heliothis armigera*) resistance is essential in these situations because the podding period is expected to coincide with high pod borer activity.

5. It is necessary to determine whether *Rhizobium* inoculation is necessary for chickpea, as flooded paddy soils could be hostile for *Rhizobium* survival.

Thus, there seems to be a potential for growing chickpea after rice and a need for breeding varieties more suitable for this purpose.

Saxena, N.P. 1984. Chickpea. In: Goldsworthy, P.R. and Fisher, N.M., ed., The Physiology of Tropical Field Crops, John Wiley and Sons Ltd, 419–452.

Irrigated Food Legume Production in Northwestern Australia

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THE aim of the Ord River Irrigation Area (ORIA) in northwestern Australia (120°E–15°S) is to develop modern, mechanised, irrigated farming in Australia's semi-arid (annual monsoonal rainfall of 750 mm) tropics. The scheme is based on private farms on three soil types: clays (12 500 ha), river levees (300 ha), and irrigated sands (700 ha). Large areas are available for further development e.g. 65 000 ha of clay soils.

There are many difficulties in farming the area including: small local markets; remoteness from supplies, markets, population centres and services; poorly developed infrastructure; limited expertise and local experience; high freight charges and limited supply; plus the present low commodity prices. The area also has some advantages: it is close to Asian and small local markets and is the closest supplier of summer crops to West Australia; it has year round frost free production creating a high productivity environment; land prices are low and there is no limitation on water availability; many tropical crops can be grown here that are not suited to other Australian agricultural regions. Advantages of food and feed legumes in this situation include: usually high value per unit weight; good markets; little if any N fertiliser requirements; and in some cases, off-season production and perennial growth.

TABLE 1. Parameters associated with legume crops undergoing expansion.

Crop	Green vegetable bean	Peanut	Chickpea
Growth season	Dry	Wet/dry?	Dry
Past max area	20 ha	330 ha	225 ha
1985-86 area	20 ha	330 ha	225 ha
Av. commercial yield	4 t/ha	2.9 t/ha	1.4 t/ha
Trial yields	13 t/ha	7.0 t/ha	4.5 t/ha
Advantages			
a. Agronomic	Productive cultivars	Well adapted species. Good N fixer nutrient scavenger.	Well adapted cvs. Good N fixer and needs furrow irrigation.
b. Marketing	High value/weight Off season production	High value/wt. Captive local market.	Only Australian source of very large seeded types.
Limitations			
a. Agronomic	High insect pressures	Leaf diseases. Excessive top growth.	Root disease and watering methods.
b. Marketing	Distant from markets	Limited suitable soils.	May be grown elsewhere.
1st commercial prod.	1984	1981	1985
Present research	Commercial operation assessment	Leaf disease control. Improved quality cvs.	Water management. Disease management.

ORIA Effort from the Asian Perspective

1. Direct applicability e.g. the work on soybean establishment and varieties.
2. Future needs. With the population drift to the cities and further development in Asia it is important that mechanised, developed agricultural systems are available for the tropics as well as the temperate areas.
3. Synergistic effects. As tropical products become more available year round, new markets may open up and efficiencies of scale develop.
4. Competition. Competition between ORIA and Asian products may increase.

The problems faced and solutions sought in these climatically similar but culturally different areas demonstrate some similarities, but whether the areas will develop with mutual benefit is unknown.

Maximising Soybean Productivity after Lowland Rice through Optimising the Crop Management Practices

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SOYBEAN (*Glycine max* L.) has been grown for centuries in China and adjoining areas in East and Southeast Asia, but its productivity has remained low on rice land. The major cause of low yield, apart from poor seed longevity, poor nodulation, insects and diseases, is low levels of crop management in rainfed culture. Soybean productivity can be increased by optimum use of inputs and adopting improved productive practices (Cooper 1983; Dibb 1983).

Two field experiments were conducted to evaluate the maximum achievable yield of soybean with improved cultivars and management practices. The first experiment was conducted at Central Luzon State University from 15 December, 1984 to March 1985. The second experiment was sown at the research farm of the International Rice Research Institute, Los Baños on 10 March, 1985. Experiments were planted on well tilled plots following lowland rice, and were irrigated regularly and kept free of weeds and insects.

In the first experiment, the highest seed yield was recorded with inoculation and 30–60–60 kg/ha N–P_2O_5–K_2O (Table 1). Density was 50 plants/m^2 and the experiment was fully irrigated. The response to inoculation in the absence of N–P–K fertilisation was limited. The short-day condition hastened growth and development of the crop.

In the second experiment, the highest seed yield was obtained with 50 plants/m^2 and 25 cm row spacing (Table 2). The crop received 5 irrigations (40–50 cm) and 30–30–30 kg/ha N–P_2O_5–K_2O. The long day condition permitted better crop growth than in Experiment 1. Narrow rows increased radiation use, equalised root density through the planting area, increased water use and reduced weed growth.

Several management practices are important to obtain high seed yield in irrigated culture after lowland rice. These include *Rhizobium* inoculation, fertiliser application and optimum plant density. Optimum crop management practices will allow the use of soybean cultivars of different maturity (early, medium and full season) in different cropping systems.

TABLE 1. Effect of inoculation and fertiliser on seed yield of soybean.

Treatment	Yield (t/ha)
Control	1.04
Inoculated	1.65
Inoculated + 30–30–30	3.08
Inoculated + 30–30–60	3.61

TABLE 2. Effect of plant density and row spacing on seed yields of soybean (t/ha).

Cultivar	Density (plants/m^2)	Row spacing (cm)	
		25	50
G 2261	30	2.68	2.27
	50	2.63	2.61
UPLSY-2	30	3.19	2.74
	50	3.23	3.18
30290-11-11	30	3.53	2.92
	50	4.11	3.63

Cooper, R.L. 1983. Better crops with plant food, 67, 8–9.
Dibb, D.W. 1983. Agron. J. 75, 413–417.

Legumes for Intensification of Rice-based Farming Systems of Mid-country Sri Lanka

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THE mid-country of Sri Lanka contains approximately 1.3×10^5 ha of rice fields (Panabokke 1978), which are primarily cultivated two seasons per year with monsoonal rains. Thus these fields are left fallow for 4.5 months in a given cropping year (Domros 1970). Studies were therefore initiated in 1984 to evaluate the feasibility of growing short-term legumes and green manures to intensify land use and increase production, income levels and soil fertility.

Rice yields were monitored in a selected farmer's field during the 1984–85 'Maha' (October–February) season, and legumes established soon after the harvest. The selected legumes were mungbean (*Vigna radiata* L.), bush bean (*Phaseolus vulgaris* L.) and a green manure — Sunhemp (*Crotalaria juncea* L.). The crop residue of mungbean and bushbeans and the green manure crop was ploughed in and rice planted in the next season (May–September 1985). Due to the very short interseasonal period, no legume was planted in September 1985, and a rice crop was established in October 1985 to study the presence of any residual effect of the legumes planted before the previous rice crop.

All legumes had a beneficial effect on the succeeding rice crop (Table 1). Yields were increased significantly by the incorporation of green manure when compared with yields from plots with other legumes or left fallow as in traditional systems. This is attributed to the addition of a greater quantity of organic matter and nitrogen by sunhemp when compared with residues of crops from which a harvest is obtained (Pandey and Morris 1984).

TABLE 1. Rice and legume yields (kg/ha) during the experimental period.

Treatment	Rice yield Maha 84–85	Legume yield* 1985	Rice yield Yala 1985	Rice yield Maha 85–86
Fallow	3155		2951	3024
Mungbeans	3025	451	3205	2942
Bushbeans	2946	1814	3384	3094
Sunhemp	3145		4256	3199
LSD (P = 0.05)	164		114	124

* Mungbean — seed yield, bushbeans — fresh pods.

The legumes had no residual effect on the second rice crop due to the time interval involved.

Analysing the income generating potential, mungbean and bushbeans increased incomes due to their harvests, which fetched higher prices than rice. Thus, while the green manure increased the yield of the succeeding rice crop, this increase did not compensate for the incomes derived from the sale of legumes.

This study in its preliminary stages identified the value of short term legumes in increasing production and income levels of traditional rice farms in the mid-country of Sri Lanka. Further studies are being carried out to identify the agronomic traits associated with the above phenomenon.

Domros, M. 1970. Agroclimate of Ceylon. Steiner Verlag. 265p.
Panabokke, C.R. 1978. In: Soils and Rice, IRRI Publication 19–34.
Pandey, R.K. and Morris, R.A. 1984. In: Rice Farming Systems Programme, IRRI:13p.

'60-Day' Cowpea Varieties for Asian Farming Systems

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THE 'Green Revolution' in Asia has assured sufficient availability of food to the growing population for the last 15 years. However, with the limited scope for bringing extra land into cultivation and near 200% cropping intensity already practiced in several countries, the only way to keep food production in pace with the ever-increasing population is to further increase cropping intensity. Efforts are being made by several countries to grow an additional crop of mungbean or soybean but mungbean yields are very low and soybean takes over 90 days to mature. Cowpeas are also widely grown for green pods, dry seeds and fodder but the local varieties are late in maturity and often do not fit in the existing niches of rice-based or wheat-based cropping systems.

The International Institute of Tropical Agriculture (IITA) has recently developed extra-early cowpea varieties (Singh 1982) which require only 45 days of soil moisture and become ready for harvest within 60 days after planting. These have erect growth habit with near synchronous maturity. Several of these varieties have been evaluated in Burma, Korea, India, Pakistan, Nepal, Bangladesh, Thailand, Philippines, Indonesia and Sri Lanka and excellent results have been obtained (Singh and Pandey 1985). These varieties matured within 60 days and yielded between 1.2 and 3.1 t/ha. These can be grown as a catch crop between wheat and rice in South Asia and between two rice crops in Southeast Asia. The most promising varieties are IT82D–889, IT82D–789, IT82E–16, IT82E–18 and a vegetable type variety IT81D–1228–14. The crop can be grown on residual moisture in rice fallows or with supplementary irrigation in wheat fallows. A number of countries in Asia have irrigation facilities and other farm resources that will be more effectively used by introducing '60-day' cowpea varieties as a short-term crop to exploit the existing niches in their farming systems. This will not only ensure more nutritionally balanced food but will also provide additional fodder and enrich the soil for succeeding cereal crops.

Singh, B.B. 1982. Sixty-Day cowpea varieties. Agron. Abs. p.83.
Singh, B.B. and Pandey, R.K. 1985. Breeding cowpea varieties for rice-based cropping systems. A paper presented at the Workshop on Varietal Improvement for Rice-based Cropping Systems held at Pitsunaloke, Thailand. March 11–15, 1985.

Response of Soybean Genotypes to Land Preparation after Flooded Rice

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IN Indonesia soybean is traditionally grown after flooded rice with neither land preparation nor weeding. Although the local soybean strains appear adapted to this method, the yields generally are low. In a recent study there was no significant yield difference between tilled and untilled soybean plots planted after flooded rice in east Java, but weeding significantly increased the yield (Nakayama et al. 1983).

Soybean breeding at Bogor Research Institute for Food Crops utilises a good (tilled and weeded) environment for selection and yield testing. In an experiment, 15 genotypes (2 improved varieties and 13 promising lines) were grown after flooded rice, with and without land preparation. Crops on the prepared lands were weeded twice, and those on the unprepared ones were not weeded. The trial was conducted at four locations during the dry season of 1985.

The average yield of the 15 genotypes on the prepared and weeded plots was 1.03 t/ha, while that on the unprepared and unweeded plots was 0.78 t/ha. The yield difference between the two planting methods was significant. Among genotypes, the relative yield between the two planting methods ranged from 59 to 95%. Three lines (B-3347; B-3350; and B-3357) produced a relative yield of over 90% and were considered suitable for planting after rice without land preparation.

Nakayama, K., Sumadi, S., Abdulrachman, S., Adi Sarwanto and Okada, M. 1983. Contr. Centr. Res. Inst. for Food Crops Bogor 70, 1-21.

Productivity of Legume-based Cropping Systems in the Traditional Rice Monocrop Region of South India

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THE people of India, being mostly vegetarian, have to depend to a large extent on pulses for their protein requirement. Several studies have revealed that pulses can be successfully grown in rice fallows (Hukkeri et al. 1978; Mahadevappa et al. 1978). Gomez and Zandstra (1977) reported that optimum rates of P_2O_5 can be greater than 40 kg/ha for pulses.

Investigations were undertaken at the University Research Station, Sirugppa to determine the suitability and P requirement of pulses in the traditional monocrop area of the Tungabhadra command area during 1983. Subsequently the residual effect of pulses on rice was determined.

TABLE 1. Seed yield (t/ha) and cost-benefit ratio (CBR) of four rotations in 1983.

Crops	Pulse/rice yield (Winter)	CBR	Rice yield (Monsoon)	CBR
Chickpea	1.55	2.10	5.12	1.30
Mungbean	1.21	2.03	4.98	1.24
Cowpea	1.97	2.45	5.23	1.35
Rice	4.62	1.08	4.51	1.03

R B D P = 0.05 C.D. 0.47*

*Significant at P = 0.05

TABLE 2. Effect of rates or P_2O_5 on seed yield (t/ha) of three pulses.

P_2O_5 (kg/ha)	Winter/Summer		
	Chickpea	Mungbean	Cowpea
37.5	0.81	0.94	1.93
50.0	1.26	1.23	2.12
62.5	2.05	1.32	2.02
75.0	2.06	1.33	2.04
C.D.	0.106*	0.051*	0.122*

The highest pulse yield was that of cowpea followed by chickpea and mungbean (Table 1). By comparison, rice yielded 4.62 t/ha. In the succeeding monsoon season, the productivity of rice was highest when it followed cowpea although yield was similar following chickpea and mungbean. The rice-rice rotation recorded the lowest yield. This clearly indicates an advantage of introducing a pulse crop in the traditional rice monocrop areas.

Further, the chickpea and mungbean responded up to 62.5 kg/ha P_2O_5 (Table 2) while cowpea did not respond beyond 50 kg/ha P_2O_5. These responses reflect the low level of available P_2O_5 in the soil (12.3 kg/ha). The water requirement of these pulse crops was estimated to be around 800 mm/ha, compared to 4000 mm/ha for rice in the summer season. Thus the same quantity of water could support an area of pulses 4-5 times that of rice.

It is possible under this system of management that pulses could be grown successfully in the traditional rice monocrop areas of Tungabhadra command. This cropping system would assist in reducing the acute shortage of pulses and the fixed nitrogen contributed by the pulse crop would have a beneficial effect on the succeeding rice crop.

Gomez, A.A. and Zandstra, H.G. 1977. Proceedings Legume Rhizobium Workshop Univ. Philippines, 145, 81-85.
Hukkeri, S.B., Kulkarni, K.R. and Sharma, O.P. 1978. Agric. Situation in India, 289-291.
Mahadevappa, M., Gopal Reedy, T. and Shankare Gouda, B.T. 1978. Madras Agric. J., 63, 171-175.

Summer Mungbean in a Wheat-Rice Cropping System — Potential and Limitations

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TRADITIONALLY mungbean is a main-season crop (July–October). However, the wheat–rice rotation has become the predominant rotation in the Punjab State. In order to increase the production of pulses without sacrificing area and production of cereals, summer mungbean can be sandwiched between wheat and rice crops. Growing a legume crop in this cereal-based rotation has been found to increase the yield of succeeding crops and maintain soil fertility (Anon. 1981).

Mungbean Yellow Mosaic Virus is a serious hazard in the production of main-season mungbean. Fortunately, summer mungbean remains free from this disease because of high temperature and low humidity. Recently short duration (65–70 days) and higher yielding varieties of summer mungbean such as G 65, SML 32, K 851 and Pusa Baisakhi have been developed. However, to attain high yields, these varieties must be sown from 20th March to 10th April (Anon. 1979). This does not fit with the wheat–rice sequence as wheat in the Punjab is harvested in late April and mungbean cannot be sown later than April. Such a late-sown crop matures at the end of June and is generally caught up in early monsoon rains which result in reduced yields (Table 1), nonsynchronous maturity and poor grain quality (Anon. 1979).

TABLE 1. Seed yield of summer mungbean (kg/ha) as affected by date of sowing (Anon. 1979).

Date of sowing	SML 32	G 65	Average
March 20	1254	1170	1212
April 01	1309	1266	1287
April 10	1301	1224	1262
April 20	692	556	624

To increase the area of summer mungbean production by exploiting vast irrigated areas of wheat, the research program has been reoriented. Our approach is to develop extra-short-duration varieties (55–60 days) which when sown after the harvest of wheat mature by 15–20 June. Such varieties should tolerate low relative humidity (25–40%) and start flowering in 30–35 days in a highly determinate pattern, so as to limit the duration of pod maturation. Screening of breeding material has led to the identification of a promising line SML 99 (MG 46 × Shining Moong No. 1) which largely meets these criteria. It flowers in 35 days, compared with 44 days taken for check SML 32, and has bold, green, shining seeds. Suitable field management is being developed.

Anon. 1979. Annual Report, Department of Plant Breeding, PAU, Ludhiana.
Anon. 1981. Present Status and Future Strategies of Pulse Research in Punjab.

Section 3

Management in Rainfed Farming Systems

Review of Contributed Papers

Aran Patanothai *

THERE were 29 contributed papers in this section with diverse topics including country reports on production of food legumes, testing of various cropping systems involving food legumes, varietal improvement, adaptation, and various aspects of crop management.

Three papers were country reports — production of food legumes in the Himalayan range in Nepal by Khatiwada, pulse production in Fiji by Singh, and production of peanuts in Burma by Beech. These papers provide some insights into the current production situations in those countries, and also some of the factors associated with the productivity and adaptation of the crops. In most cases, the legumes are grown in association with other crops in some types of cropping systems — in mixed cropping with cereals in the Himalayan range, in intercropping with sugarcane in Fiji, in double cropping with peas, beans, and rice in Burma. Single cropping of legumes is also practiced but to a lesser extent. Ecological conditions largely determine the distribution of crop species or type of cultivar and methods of cultivation. In the Himalayan range, different species of legumes are grown in different elevations. In Fiji, pigeonpea is planted on fallow or sloping land while other pulses are mostly intercropped in sugarcane rows. In Burma, the rainfall pattern is the major factor determining the type of peanut grown, the date of sowing, and the cropping system. Social factors such as ethnicity and religion also play an important role in determining the species of crops grown and methods of cultivation employed in the Himalayan range.

Competition with other crops has some influence on the production of food legumes, as shown by reverse changes of planted areas of pulses and sugarcane in Fiji and of peanut and sesame in Burma. In addition to price responses, the attitude of the farmers to the crops also determines the management practices. In the Nepalese Himalayan region, legumes are considered a secondary traditional crop and insufficient attention is paid to cultural operations resulting in low crop yields. Major constraints to legume production in these countries include pests, diseases, low soil fertility, drought and excess of water, lack of good quality seed and organised marketing and price incentives.

The problem on lack of good quality seed is illustrated by a case study in Sri Lanka reported by Sangakkara. He found that mungbean growers generally keep their own seed because of the unavailability of good seed in government or private seed outlets when required. High moisture content and poor storage conditions cause a rapid loss in seed viability resulting in poor germination when planted. He also found that seed germinability could be retained by storing well dried seed in sealed polythene bags, a promising technique which could help alleviate the problem.

New cropping systems involving food legumes were reported in several contributed papers. In India, Chatterjee and Bhattacharyya described the potential for incorporating food legumes into various cropping systems in different areas. Improved management practices for some cropping systems have also been developed. Results of studies in Kerala brought out the economic feasibility of a cropping system involving rice followed by irrigated cassava intercropped with cowpea, green gram, black gram, or groundnut (Pillai et al.). Relay intercropping of pigeonpea in groundnut was found to have no detrimental effect on groundnut yield, and under favourable conditions yield of pigeonpea can be similar to normal planting situations (Yadavendra et al.). In Sri Lanka, studies are being carried out to examine various rainfed cropping systems involving food legumes. Preliminary results

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indicated increased yield of rice following interseasonal planting of short-duration legumes, better land and labour use patterns, and increased income of the farmers (Sangakkara). In south Thailand, intercropping of food legumes with young rubber has also shown good promise (Laosuwan et al.). These results indicate that there is a great potential for increasing the production of food legumes.

One of the main reasons for incorporation of legumes in farming systems is to improve soil fertility, and this is confirmed by the results of studies reported in some of the contributed papers. The use of *Mucuna* sp. in a crop rotation on an Oxisol soil has been studied in Indonesia. The results showed that yield of soybean grown after *Mucuna* sp. was significantly higher than that after groundnut or grass (Suwardjo and Sukmana). In north Thailand, trials on rotation of legumes and upland rice have demonstrated significant increases in yields of rice following the legumes (Aneckssamphant et al.). In northeast Thailand, ley farming of forage legumes doubled the yields of the succeeding upland crops compared to those obtained from the crops following cassava (Gibson). The author suggested that legume ley farming, especially if integrated with profitable animal production (particularly milk production), can overcome limitations to farm productivity currently imposed by soil fertility and by socioeconomic factors.

Actual practices by farmers of some potential cropping systems may be limited by lack of appropriate farm implements. Choudhary and Pandey pointed out that, although there is a great scope for growing food legumes in rainfed lowland rice lands, only a fraction is currently sown to the crops because of relative lack of tractive power and low capacity traditional seeding and tillage (manual and animal) methods. They reported the successful development of a multicrop seeder (inverted-T) which would extend the range of field conditions where seeding and optimum crop establishment could be achieved with minimum risk of failure. With increased cropping intensity, mechanisation becomes increasingly important, and the development of different types of low-cost farm equipment appropriate to small farmers is greatly needed.

In many areas, food legumes are grown in mixed cropping. In this type of cropping system, the crops compete with each other for light, moisture, and nutrients. Some crops are more competitive than the others, and selection of a suitable species combination is quite important. The study reported by Sangakkara comparing mixtures of three food legumes and three companion crops illustrated this well-known principle. Similar results were also obtained from the study reported by Rerkasem et al. in which 50:50 mixtures of legumes intercropped with cassava showed no advantage over monoculture, but corn and legume intercrops in the same proportion did. The advantage of corn intercrops was due to both the corn and legumes performing relatively better in intercrop than in monoculture. Detailed study of a corn-ricebean intercrop showed that nitrogen nutrition of both species in intercrop may be superior to that in monoculture. Progressive replacement of corn with beans showed a corresponding reduction of competition for soil nitrogen.

There is considerable evidence that suitable crop variety is a key factor contributing to the success of new cropping systems. Examples are shown in some of the contributed papers in this section.

Based on the initial cost benefit ratio, Yadavendra et al. found the benefit of relay intercropping of pigeonpea in groundnut only with some pigeonpea cultivars but not the others. In north India, wheat-rice rotation is a predominant crop rotation, and attempts have been made in insertion of food legumes between the two cereals. Short-duration mungbean cultivars (65–70 days) recently developed are still too late to fit into this crop rotation. Extra-short-duration cultivars (55–60 days) are required, and one such line has been identified through screening of breeding material. Dahiya reported the success of the breeding program at Haryana Agricultural University in developing early maturing cultivars of pigeonpea (AL-15) and chickpea (H82-2). After the release of these two cultivars, the adoption of pigeonpea-wheat rotation has increased, paddy-chickpea rotation has also been successful, and even three crops in succession (summer mung-pigeonpea-wheat, and paddy-chickpea-summer mung) were possible. In peninsular India, Chauhan et al. reported that three harvests were possible for early maturing pigeonpea cultivars and total yield of over 5 t/ha could be obtained. With appropriate agronomic practices, an early maturing cultivar in a multiple harvest system was found to be more productive than traditional longer duration cultivars.

With this body of evidence, increased attention is now being paid to breeding of crop cultivars suitable to cropping systems, and work is under way in breeding programs of several crops, including food legumes in various Asian countries. Only a few are reported in the contributed papers. In addition to those mentioned above, Gutteridge et al. reported the work at Khon Kaen University on the incorporation of food and forage legumes into farming systems in northeast Thailand. For food legumes, cowpea was selected as the main focus. A large collection has been evaluated and a number of promising lines have been identified which are non-photoperiod-sensitive and have synchronised flowering. Experiments on intercropping of cowpea with cassava and kenaf have given encouraging preliminary results. Also, in Thailand the Chainat Field Crops Research Center has developed new high-yielding mungbean cultivars, one of which is also early in maturity suitable for multiple cropping systems (Chinchest).

While early maturity is generally required for several cropping systems, later maturity may be preferred in other systems. Jain and Farris pointed out the potential of medium-duration pigeonpea in several conditions. They reported that medium-duration pigeonpea performed well in places where the rainy season is too short for long-duration types and is valuable where pigeonpea is wanted for an intercrop. In environments with mild winter temperatures it is also well adapted as a post-rainy season crop. This type of pigeonpea also has the potential to perform well in many parts of the world, and evidence was given for the trials in Thailand and the Philippines. Good yielding lines with resistance to *Fusarium* wilt and sterility mosaic and tolerance to pod borer have been developed at ICRISAT. In Fiji, Sivan et al. reported that the photoperiod-sensitive pigeonpea lines generally gave higher yields than the photoperiod-insensitive lines, and good yields of the ratoon crop were obtained from some lines in both groups.

As food legumes are generally grown in combination with other crops in different cropping systems, more attention should be paid to breeding of legume cultivars suitable to the different cropping systems. The required characteristics, however, have to be defined for the individual systems in the target areas.

Incorporation of food legumes into new farming systems or introduction of food legumes into new areas essentially place the crops in new environments. Thus, basic understanding of the species and cultivar adaptation is of prime importance. Information on the effects of environmental factors on growth and development of the crops is also useful in determining appropriate management practices.

Serial sowing date has been used to obtain this information, and two contributed papers reported such studies. From serial sowing date studies on peanuts in southeast Queensland, Bell et al. found that most yield and phenological traits of peanut varied with sowing date, and differences between cultivars were also observed. Relationships between some of the environmental factors and some crop characters have been established, but a lot more are yet to be investigated. Sukarin et al. reported the results of a serial sowing trial of 17 pigeonpea lines conducted at Khon Kaen, Thailand. In general, the lines fell into two groups with respect to phenological development: those sensitive and insensitive to daylength. Information on phenological development of these lines has enabled assessment of the potential of these two groups in the northeast Thailand environment. Analyses are being conducted to investigate the relationships of environmental parameters and some of the crop characters.

To facilitate the assessment of potential of a crop for a range of environments and management practices and the relative importance of environmental factors to crop performance, crop modelling has received a good deal of attention in recent years. Models have been developed for several crops, including some food legumes. Eksomtramage and Troedson reported an attempt to develop one for pigeonpea which would encompass more readily simulated variables such as plant density, water supply and temperature. Preliminary results indicate that variations in both density and water supply may have a substantial impact on development of pigeonpea seedlings.

Despite the complexity of cultivar adaptation and genotype x environment interaction, understanding of its nature is of prime importance.

The remaining papers dealt with certain aspects of crop management. Chatterjee et al. reported that presowing seed treatment with certain chemicals, and even with water, could increase yield of black gram, green gram, and groundnut, particularly under limited moisture supply. Ali studied crop-weed competition in pigeonpea intercropping. He found that in late pigeonpea–sorghum intercrop the initial 8–9 weeks period was the most critical, whereas in early pigeonpea–mungbean it extended only up to 6–7 weeks. His study on weed-suppressing abilities of short-growing legumes intercropped with early and medium-duration pigeonpea revealed that cowpea was most effective in suppressing weeds. The planting system also influenced weed flora and crop productivity. Karsono and Sumarno reported the results of a population density trial on five pigeonpea lines conducted in Indonesia in both the dry season and wet season. Although there was a tendency towards higher yields at higher densities, the differences were not statistically significant in all the lines. Studies on the responses of peanut to gypsum, lime, nitrogen, phosphorus, rhizobium, and several trace elements were reported by Beech. These papers indicated that drought, weeds, plant density, and nutrients are limiting factors to food legume production. Although these are general problems, solutions to these by management practices acceptable to farmers are location-specific and thus have to be determined for individual locations.

Weed Management in Pigeonpea-Based Intercropping

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PIGEONPEA is the second most widely grown food legume in India, next to chickpea. It occupies 3.17 million hectares and produces 2.24 million tonnes annually. The low yield (768 kg/ha) is due to various agroecological and management constraints (Chandra and Ali 1986). Systematic studies under the All India Co-ordinated Pulses Improvement Project (AICPIP) during 1982–85 showed that without efficient weed management the productivity of pigeonpea declined by 44% under sole cropping (Ali 1986).

Since over 90% of pigeonpea in India is grown mixed with cereals, oilseeds, cotton and short growing legumes, we sought to understand the nature and magnitude of crop-weed competition in pigeonpea-based intercrops and to evolve efficient weed management practices. Results of the AICPIP trials on crop-weed competition showed that in late pigeonpea-sorghum intercrop, the initial 8-9 weeks period was the most critical whereas in early pigeonpea-mungbean it extended only up to 6–7 weeks (Table 1).

TABLE 1. Effect of crop-weed competition on grain yield of pigeonpea (cv. Bahar)-sorghum (cv. SPV 221) intercrop under rainfed conditions.

Weed free period	Yield (kg/ha)		Weedy period	Yield (kg/ha)	
	Pigeonpea	Sorghum		Pigeonpea	Sorghum
Up to 20 days	2286	776	Up to 20 days	2394	846
Up to 40 days	2311	885	Up to 40 days	2236	756
Up to 60 days	2361	900	Up to 60 days	2094	743
Up to 80 days	2502	900	Up to 80 days	2036	718
Up to 100 days	2500	898	Up to 100 days	1944	716
Till maturity	2544	915	Till maturity	1914	545
LSD (P = 0.05)	204	49		204	49

The effect of short growing legumes (generally intercropped with early and medium-duration pigeonpea as a bonus crop) on weed suppression was also studied. Among various intercrops, cowpea with 38% weed suppressing ability was found to be the most effective. The system provided 2040 kg/ha and 445 kg/ha seed yield of pigeonpea and cowpea respectively, as against 2101 kg/ha pigeonpea seed under sole cropping. The weed suppressing ability of urdbean, soybean, mungbean and sorghum were 20–22%. Further, the planting system also influenced weed flora and crop productivity. Uniform row planting with additive population of intercrops proved distinctly superior to paired row planting.

Limited information on weed management in legume-cereal intercrop through herbicides revealed that S-triazine herbicides applied at 1–2 kg/ha (Shetty and Rao 1977) and alachlor applied at 2 kg/ha (Ali et al. 1982) as pre-emergence sprays are effective. These aspects are under investigation.

Ali, M. 1986. In: Proc. Nat. Seminar Maximising Pulses Production, DPR, Kanpur, India, Feb. 22–24, 1986.
Ali, M., Pandey, R.K. and Rawat, C.R. 1982. Madras Agric. J. 69, 474–78.
Chandra, S. and Ali, M. 1986. Tech. Bull. No. 1, DPR, Kanpur, India.
Shetty, S.V.R. and Rao, M.R. 1977. In: Proc. Sixth Asian Pacific Weed Sci. Conf., Jakarta, Indonesia.

Legumes in Rice-Based Upland Cropping Systems

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LEGUME rotation crops have become an integral part of upland rice-based farming systems. Legumes are essential to prevent soil degradation and the decline of rice yields (Buddee 1986).

Trials have demonstrated significant increases in rice yields, following legumes, and adequate yields of legumes (Table 1).

TABLE 1. Yield (t/ha) of legume crops and of subsequent upland rice crop.

Legume/Control	Legume yield		Subsequent rice crop	
	Grain	Stover	Yield	DMRT 5%*
Dolichos lab-lab	3.25	12.78	2.11	a
Cowpea (local cv. blackbean)	1.54	12.31	2.27	a
Peanut (Tainan-9)	2.75	4.05	1.72	abc
Cowpea (local cv. redbean)	2.18	2.63	1.70	abc
Mungbean (M58)	1.69	1.25	1.46	bc
Soybean (SJ4)	2.18	2.23	1.44	bc
Pigeonpea (local cv.)	0.51	18.62	1.26	bc
Upland rice control	1.27	—	1.11	c

*Duncan multiple range test.

The effects of sequential legume crops, corn–legume relays, and single legume crops on upland rice yield are summarised in Table 2.

TABLE 2. Yield (t/ha) of rotation crops and subsequent upland rice (average of four trials).

Legume/Control	Year 1 yields		Subsequent rice yield
	1st crop/s	2nd crop	
Rice-based control	1.54	—	1.30
Peanut (T9)/mung (M77)	2.09	0.51	1.96
Corn–mung intercrop/mung (M77)	1.92/0.53	0.36	2.11
Legume-based control (blackbean)	1.75	—	2.05

All three legume systems resulted in similar yields of the subsequent rice crop. The most financially and agronomically attractive are the systems in which a later maturing legume such as mungbean or pigeonpea makes use of residual soil moisture and provides ground cover and weed suppression for a longer period.

Further research should investigate the most profitable combination of rotation crops and the best adapted cultivars for local conditions; for example, the local pigeonpea cultivar flowers very late, seed filling is restricted, and the yield is low.

Buddee, W.F. (ed.) 1986. Thailand, Northern Upland Agriculture. DLD/ADAB Publication, Bangkok.

Production of Peanuts in Burma. 1. Background to Research

D.F. Beech, CSIRO, Division of Tropical Crops and Pastures, St Lucia 4067, Australia.

THE Arakan Yama Range creates a rain shadow in Central Burma called the 'Dry Zone' where the average annual rainfall is less than 900 mm, with 85–90% falling during the monsoon. Year-to-year variation can extend to 50% above or below the mean. Rainfall increases southwards, reaching 2500 mm at the Irrawaddy Delta. The rainfall pattern is the major factor determining the type of peanut grown, the date of sowing and the role of the peanut crop in the farming system.

Peanuts occupy the third largest cropped area after paddy rice and sesame, and are grown in two types of farming systems: (1) as a monsoon crop covering about 360 000 ha; (2) as a 'winter' crop of 290 000 ha. (Some Statistics in Agriculture, Burma, 1980). About 90% of the rain crop and 48% of the winter crop are grown in the Dry Zone divisions of Mandalay, Magwe and Sagaing. About 45% of the winter crop is grown in the Irrawaddy and Pegu divisions in Lower Burma. Average yields from the winter crop are some 68% more than the rain grown crop and are also less variable.

Between 1975 and 1980 the area under peanuts declined by 44%, but by 1984 there had been a recovery of about 15%. Associated with this decline was a large increase in peanut yield and in the area sown to sesame.

In Central Burma both spreading (Virgina) and erect (Spanish) types are grown during the monsoon season. Various peas and beans, and sometimes late sesame, are grown after erect types which mature in August-September. In Lower Burma, erect cultivars are grown, mainly on residual moisture, after short-duration cultivars of paddy rice, which usually mature in October and November. Alternative crops in this area are jute and late sesame.

The main problems of peanut cultivation in Burma are either a shortage or an excess of water. Drought frequently reduces yield of the winter crop and harvesting of the monsoon crop is often disrupted by heavy rainfall.

The lack of pure seed of good quality is also a major problem, especially in Lower Burma where maintenance of seed viability on farms is difficult. The quality of seed available in drier areas of Central Burma is much better, and this seed is often used for sowing in Lower Burma. Central storage facilities are being introduced to overcome this problem.

The crop is cultivated on a wide range of soils varying from very acid (pH 4.0) found in the Irrawaddy delta to very alkaline (pH 8.5) near Mandalay. Lack of effective nodulation has led to the official recommendation to apply nitrogenous fertiliser. Phosphate fertiliser is rarely used, due both to its very high cost and scarcity.

Production of Peanuts in Burma. 2. Research on Nutrition

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SIX experiments were conducted at Magwe, a major centre for peanut research, to develop practices to grow peanuts without nitrogen fertiliser. Two plant types used were an early erect cultivar, Magwe 10, (M10) and a longer duration spreading cultivar, Kyaung Gone, (KG) to evaluate optimum levels of N, P, lime, gypsum and trace elements (Table 1).

TABLE 1. Treatments applied to peanuts at Magwe Central Farm (kg/ha).

Year	Expt.	Lime	Gypsum	Nitrogen	Phosphorus	Rhizobium	Cultivar*
1979	1	—	0, 112	0, 33	0, 33, 66	0	M 10
1980	2	—	0, 112, 224	0, 33	0, 33, 66	0	M 10
1979	3	—	—	0, S, F**		± CB756	M 10
1980	4	—	224	0, S, F**		± CB756	M 10, KG
1980	5	0, 450, 900 1350, 1800, 2250	224	0		± CB756	M 10, KG
1979	6+			22	40		M 10

*Cultivars M 10 = Magwe 10, KG = Kyaung Gone.

**S,F. = 50 kg/ha N applied at sowing and commencement of flowering.

+ Trace elements, Ca, Mg, Zn, Cu, B, Fe, S, and Mo were evaluated in an incomplete 2^8 fractional factorial pot experiment with soil from Magwe Central Farm. Potassium was included in the basal fertiliser at 30 kg/ha.

Rainfall during the growing seasons of 1979 and 1980 was 310 mm and 490 mm, i.e. 44% and 70% of the long-term average, and the crops suffered severe drought during pod and kernel development. In 1979, application of 112 kg/ha gypsum to cv. Magwe 10 gave a small increase in seed yield by improving the shelling percentage by 2.2%. Also, N applied at sowing improved total dry matter but depressed pod yield. In 1980 gypsum at 112 kg/ha increased yields of dry matter, pods and seed, confirming the results of 1979. In the absence of inoculation N applied at 33 kg/ha increased dry matter, but depressed seed yield by 10%. Gypsum increased the shelling percentage and seed size in the absence of applied N but depressed it in its presence. There were no responses to phosphorus.

Experiments 3 and 4 were used to evaluate the commercial *Rhizobium*, strain CB756. A preliminary study conducted in 1979 on some 55 local isolates from 13 sites throughout lower and central Burma found that all except four were ineffective on peanuts (Bushby, pers. comm.). The severe drought conditions of the first year gave inconclusive data, but inoculation in the second year had no effect on dry matter production of either cultivar or the seed yield of cv. Kyaung Gone. However, there was a 16% yield increase for cv. Magwe 10 in the absence of applied N.

Application of lime at 2.25 t/ha raised the soil pH from 5.7 to 7.0. This led to a 20% increase in seed yield in both cultivars, but had no effect on the residual dry matter. In the pot experiment, sulfur alone increased pods per plant by 13% and seed yield by 14% (shelling percentage increased from 71 to 73%) but had no effect on total dry matter. Copper alone increased pod number by 18% and seed yield by 44% and again had no effect on total dry matter. Responses to copper and sulfur were additive. *Rhizobium* inoculation and the residual effect of lime and gypsum are being studied further.

The author wishes to acknowledge the assistance of his Burmese associates, U. Thoung and Daw Aye in conducting these experiments.

Serial Sowing Date Studies on Peanuts (*Arachis hypogaea* L.) in Southeast Queensland

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PEANUTS are grown worldwide from 40°S to 40°N latitude, so an understanding of the effects of environmental factors such as temperature, photoperiod and irradiance on crop growth and development have important implications for cultivar adaptation. Peanuts are botanically indeterminate, and until recently were thought to be day-neutral plants, with their phenology controlled primarily by temperature (Smith 1954). However, recent work has shown that reproductive efficiency may be affected considerably by photoperiod.

A preliminary field study was undertaken with supplementary irrigation in the 1983–84 summer season to examine effects of sowing date, in terms of environmental factors, on the growth and development of sixteen peanut genotypes. The latter were chosen from diverse geographical origins and sown at 14-day intervals from 28/9/83 to 15/2/84. Phenological observations were made at regular intervals and destructive samples were taken 35 (H1) and 65 (H2) days after first flower appearance.

Most yield and phenological traits varied with sowing date, and differences between cultivars were also observed. The duration of the time from emergence to flowering tended to fall with later sowings until late December, after which it remained relatively constant or increased slightly with the final sowings in February. Most yield traits increased to a maximum at sowing dates in late November–early December and then declined as sowing was delayed. Genotype groups derived by pattern analysis procedures on traits such as peg and pod number differed in responsiveness to changes in sowing date.

Regression techniques were used to assess which environmental variables (temperature, daylength or relative humidity) accounted for most of the variability observed across sowing dates. Average daily maximum temperature during the emergence to flowering period appeared to be the most important single factor affecting days to first flower. However, for a majority of genotypes, a temperature x daylength interaction was additionally important in accounting for variability in this trait.

Reproductive growth, particularly that present 35 days after flowering (H1), was strongly related to daylength during the emergence-to-flowering period. This observation was consistent across all genotypes for peg and pod numbers and pod weight, but was more variable for harvest index. Effects of environment during the emergence-to-flowering period on vegetative and reproductive components 65 days after flowering (H2) were still evident, although data were more variable and regressions were not significant for all genotypes.

Work is being undertaken to investigate interactions between genotype, sowing date and optimum plant density under irrigated conditions. Research is also planned to confirm the roles of photoperiod and temperature during the emergence-to-flowering period on subsequent reproductive development, and to investigate interactions between these photoperiod effects and patterns of subsequent yield accumulation under conditions of varied agronomic inputs.

Close collaboration is being maintained with CSIRO researchers in Canberra, who are investigating effects of temperature, photoperiod and irradiance on growth and development of peanuts under controlled environment conditions.

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Food Legumes under Intensive Cropping Systems in India

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IN India, cropping practice differs between areas with above 1150 mm, 1150–750 mm, and below 750 mm rainfall. Under rainfed conditions only one crop is grown in areas receiving less than 750 mm. Areas with 750–1150 mm rainfall provide scope to grow an intercrop along with other food crops like maize, sorghum or pearl millet. Where the rainfall is high (above 1150 mm) there is potential for a leguminous crop in sequence with food, fibre or fodder crops. In irrigated areas, which comprise only 30%, there is however, scope for growing food legumes as a sole or intercrop (Chatterjee and Bhattacharyya 1985).

In subtropical humid eastern India, rice is grown as the main crop during the rainy season (mid-June to mid-October). Non-photoperiod-sensitive rice varieties provide scope to grow food legumes such as green gram and black gram as pre-monsoon crops; cowpea, ricebean, horsegram, in addition to green and black grams as post-monsoon crops (August-October) and lentil, peas, chickpea, pigeonpea (rabi *Arhar*) as winter crops (October–March). Due to periodic water logging, growing of food legumes in the rainy season is limited to the uplands.

Work conducted during the last five years provided the following useful technological information:

- Intercropping black gram, soybean and pigeonpea, two weeks after direct-seeded upland rice provided a 50–75% increase in Land-Equivalent Ratio. Rice was sown in 20 cm drills with one skip row every two or three rice rows. Due to the high price of food legumes, production of 1–2 t/ha of food legumes along with 1.5–2.5 t/ha of rice appeared to be very remunerative (Sengupta et al. 1985).
- With the fall in the price of jute, growing of green gram and black gram after the harvest of wheat in rice–wheat–food legume sequence, from March to May, with presowing seed treatments and spraying of di-ammonium

phosphate at flowering, appeared to be profitable. It provided 1.5-2 t/ha of grain legumes, and this crop supplied 20 kg N/ha to the following rice crop.

- Establishment of pea, lentil and chickpea in the 75-100 cm space between paired (50-60 cm apart) rows of maize grown during mild, short winters (late October to early March), provided 1-1.5 t/ha of food legumes in addition to 5 t/ha of maize grain.

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Presowing Seed Treatments for Legumes

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Use of vigorous seeds in the case of short-duration crops and in limited moisture supply conditions is of great importance. Field experiments were conducted for several years with food legumes, viz: *Vigna mungo* L. cv. T_9, *Vigna radiata* L. (Welezer) cv. Panna, and *Arachis hypogaea* L. cv. AK 12-24 and MH 2 in Entisol soil with low organic-C, medium av. soil P, and low potassium. The seeds were directly sown in 15 m^2 plots, after soaking for 4 h either in distilled water or in solutions of disodium hydrogen orthophosphate (5×10^{-4}M) and of 4 polyethylene glycol (PEG-Mol.wt.6000 in 10^{-2}M) + disodium hydrogen orthophosphate (5×10^{-4}M), with recommended agronomic practices under rainfed conditions. The rainfall during the experiment was 20-50% below the evaporative demand and crop growth was mainly from profile stored soil moisture.

Shoot and root dry weights, water saturation deficit, rate of translocation from leaf to root, number and weight of nodules, nitrogenase activity and grain yield increased (Table 1) in plants raised from seeds pretreated with chemicals. Water-soaked seeds produced intermediate results.

TABLE 1. Growth (shoot and root), water saturation deficit, nodule growth (number and dry weight), nitrogenase activity and seed yield of different food legumes at different days after sowing (DAS).

Crops	Year sown	Control	Water	Na_2HPO_4	Na_2HPO_4 + PEG	LSD P = 0.05
A. *Dry weight of seedlings (g)*						
Black gram 26 DAS	1981 May	6.09	6.45	6.83	6.86	0.48
(days after sowing)	1981 Sept	4.48	5.03	5.29	5.60	0.29
Green gram 25 DAS	1984	3.14	4.50	—	4.88	—
B. *Dry weight of shoots g/m²*						
Black gram 65 DAS	1981 May	106.3	111.6	116.8	128.1	11.70
C. *Dry weight of roots in mg/dm³ soil volume up to 90 cm soil depth*						
Black gram 65 DAS	1981 May	129.90	143.72	165.58	176.63	8.54
	1981 Sept	104.52	132.48	147.99	172.86	8.89
Green gram 50 DAS	1984	137.19	145.98	—	166.33	—
D. *Water saturation deficit (%)*						
Black gram 45 DAS	1981 May	18.00	17.79	16.99	16.82	0.21
	1981 Sept	21.08	19.61	18.57	16.99	0.69
E. *Number and dry weight (within parentheses) in mg of nodule/plant*						
Black gram 33 DAS	1981 Sept	15(14)	15(16)	16(14)	13(13)	—
Groundnut 60 DAS	1983	139(109)	185(172)	217(269)	—	—
F. *Nitrogenase activity (n moles of ethylene formed/mg cell weight/hour)*						
Black gram 33 DAS	1981 Sept	6.34	6.91	13.92	9.13	—
Green gram 30 DAS	1984 Sept	7.78	8.12	—	8.18	—
G. *Seed yield (t/ha)*						
Black gram	1981 May	0.873	0.981	1.011	1.023	0.025
	1981 Sept	0.999	1.190	1.319	1.741	0.053
Green gram	1984	0.800	0.990	—	1.441	
Groundnut	1982	0.978	1.568	1.569	—	0.408
	1983	0.906	1.526	1.417	—	0.502

DAS = Days after sowing.

Thus, it was concluded that presowing seed treatment, which costs very little, can increase crop yield, particularly under limited moisture supply.

The Agronomy of Multiple Harvest Pigeonpea

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In tropical environments where winters are mild (e.g. minimum temperatures above 10°C), short-duration pigeonpea (about 120 days to first flush maturity) sown in the rainy season has the capacity to produce additional flushes of pods. In peninsular India, we have taken three harvests in about 220–250 days from a June sowing. The total yield from the three harvests was 5.2 t/ha in 1982–83 and 4.1 t/ha in 1984–85. Insect control was essential to protect yield of individual harvests and to secure multiple harvests.

In agronomic studies, sowing around the longest day (summer solstice) and a population density of about 25–30 plants/m^2 gave the best result. Delayed sowing not only lowered the yield of individual harvests but also increased the incidence of moisture stress on lighter soils.

Yield in the second and third harvests varied with genotype, although yield from the first harvest was similar (Table 1). ICPL 87 was found to be superior for multiple harvesting, probably due to its ability to retain green leaf area at the first flush maturity.

TABLE 1. Seed yield (t/ha) from three harvests of three early maturing pigeonpea genotypes at ICRISAT Centre, 1982–83.

	ICPL 4	ICPL 81	ICPL 87	SE
First harvest	2.15	2.51	2.21	±0.053
Second harvest	0.67	1.13	2.04	±0.050
Third harvest	0.23	0.24	0.97	±0.025
Total	3.05	3.88	5.22	—

The technique employed at first harvest influences subsequent performance. ICPL 87 gave a higher second harvest yield following hand-picking compared to ratooning the stems at two-thirds height. However, in environments closer to the equator, where photoperiods are not short enough to induce a second flush of flowers rapidly, plants harvested by ratooning were found to have more productive second and third flushes (Tayo 1985). In our studies, harvesting the first flush and the second flush together did not hamper formation of the second flush but reduced cost.

With appropriate agronomy, ICPL 87 in a multiple harvest system was found to be more productive on a per day and per ha basis than traditional, longer duration cultivars. This system is suitable for mechanised, higher input agriculture as well as for low-income farmers with the capacity for limited monetary inputs, such as for insecticide. Further, the system can be productive without irrigation, even though second and third cycle yields can be enhanced by irrigation.

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Mungbean in Cropping Systems in Thailand

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MUNGBEAN is one of the most important legume crops in Thailand where approximately 500 000 ha are planted. More than 60% of the production is exported, making Thailand number one exporter in the world. About 80% is planted in the late wet season (Aug–Sept) after harvesting the corn crop, and nearly 20% in the dry season (Dec–Jan) after harvesting rice. Only a few farmers plant in the early wet season (April–May), especially before cotton, and there is very little monocropping of mungbean.

The UT-1 mungbean variety (known as M7 A), which is the only one recommended, was released in 1976, and has achieved about 50% adoption, while the remaining area is occupied by local varieties. The local white pod variety is quite uniform but the local black pod varieties are variable.

Not all high yielding varieties named by AVRDC or other countries are high yielding in Thailand, but many gave higher yield than UT-1. As a result, in 1986 the Thailand Outreach Program at Kasetsart University released Kampaengsaen 1 and 2 as new varieties for Thai farmers. These two varieties are VC 1973 A and VC 2778 A, introduced from AVRDC. The Field Crops Research Institute will release 2 or 3 varieties in 1987. One is an early maturity type and the others have a high yield potential, having outyielded VC 1973 A and VC 2778 A. The Chainat Field Crops Research Centre has sole responsibility for mungbean research work in the Department of Agriculture. There is also wide cooperation with other organisations i.e. AVRDC, ACIAR, IAEA and IRRI. The Farming Systems Research Institute is directly responsible for cropping systems in Thailand. Most cropping systems include mungbean as one component — as an intercrop, a relay crop, or a sequence crop.

Extending Limits to Legume Crop Establishment in Rainfed Lowland Rice

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WITH soil and irrigation resources being stretched to their economic limit, there is an urgent need for crop intensification in less favourable soil and climatic conditions to keep up with food production targets in developing countries. Major priority areas appear to be in rainfed lowland rice lands.

Growth of food legumes on these rice soils is usually constrained by unpredictable rains and limited capacity of peasant farmers to establish a crop on limited soil water. Tillage and seeding limitations are more pronounced on soils with medium to high clay content and 2:1 layer lattice clay species. These are characteristics of large tracts of rice soils of Southeast Asia.

Relative lack of tractive power and low capacity traditional tillage (manual and animal) and seeding methods result in only a fraction of the available area being sown to upland legume crops.

A multicrop seeder (inverted-T) was developed to extend the range of these field conditions where seeding and optimum crop establishment could be achieved with minimum risk of failure. The seeder utilises an inverted-T opener which creates a seed micro-environment that lifts germination and plant establishment. A spring-loaded depth-cum-press wheel provides accurate seed depth control, improving seed-soil contact and seed cover.

Single and multi-row seeder units have been developed. These can be mounted on two-wheel tractor or pulled by animal(s). Complete units can be manufactured in developing countries, utilising local materials and expertise at a cost of approximately US$100.

A number of legume crops including soybean, mungbean, cowpea and peanut, were successfully established with this seeder. These results (1985–86) at the International Rice Research Institute indicated the great potential of this seeder, which is now in commercial production.

Selecting Food Legume Cultivars for Multiple Cropping Systems

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GROWING several crops on the same piece of land, or multiple cropping, is regarded as an excellent strategy for intensifying land use. Food legumes are an integral component of Asian farming systems, but many cultivars may not be suited to multiple cropping systems. There is a need to select food legume cultivars for multiple cropping systems.

Food legumes are known for their beneficial effects in maintaining soil productivity. The adoption of the paddy-wheat rotation in north India has caused imbalances in nutrient availability and the requirement for costly inputs, and the present study concerns the improvement of two major food legumes, pigeonpea and chickpea, for insertion into the current paddy–wheat rotation.

Some cultivars of pigeonpea and chickpea show large planting date effects, with the multiple cropping pattern requiring short-duration cultivars. The varietal improvement program has succeeded in developing early-maturing cultivars such as AL-15 (pigeonpea) and H82-2 (chickpea) suited to multiple cropping systems.

The area and production of pigeonpea in the north Indian states of Punjab and Haryana indicate that after the release of AL-15, the adoption of the pigeonpea-wheat rotation has increased. Early maturity also allowed the cultivation of three crops (summer mung + pigeonpea + wheat) in succession. In the pigeonpea-wheat rotation, the detrimental effect of a delayed planting date on the succeeding wheat crop (Saxena and Yadav 1975) was overcome by using an early maturing pigeonpea cultivar. Pigeonpea also has a residual effect on soil fertility and replaces the equivalent of 30–40 kg N/ha to the following wheat crop (Chandra and Ali 1986).

In a paddy-chickpea rotation, delayed planting date has a detrimental effect on yield of chickpea. With the availability of the chickpea cultivar H82-2, which is suitable for late planting and possesses field resistance to different diseases (Dahiya 1984), paddy-chickpea rotation has been successful. The Kabuli chickpea type, with its response to production inputs and resistance to stem rot and *Ascochyta*, has been identified for paddy-chickpea-summer mung farming systems.

These results indicate that through the selection of suitable cultivars, it has been possible to incorporate pigeonpea and chickpea into multiple cropping systems.

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Effects of Density and Water Supply on Growth of Pigeonpea Seedlings

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PROCESSES of growth in plant canopies may be effectively and efficiently modelled in terms of the radiation energy incident on the canopy, the proportion that is intercepted by the canopy, and the efficiency of conversion of radiation to chemical energy (Monteith 1977). Models based on these concepts are being used for predictive and analytical purposes in many agricultural crops.

The potential of pigeonpea as a pulse crop for a range of environments in Southeast Asia is currently being evaluated (Byth et al., Sukarin et al., these proceedings). The development of a model to predict pigeonpea performance across environments would greatly facilitate the evaluation process. There are major problems in developing accurate projections across environments, particularly with respect to edaphic limitations to growth. This is particularly the case with pigeonpea, which is likely to be cultivated on unamended, marginal soil types. Nevertheless, a first step will be to develop an accurate model encompassing more readily simulated variables such as plant density, water supply and temperature.

Basic data such as those in Table 1 have been collected to enable models developed for other species to be modified for pigeonpea. These data are being assessed on the basis of light and energy interception by the canopy, and effects of water deficit on the conversion of intercepted energy into biomass. Data in Table 1 indicate that variations in density and water supply may have a substantial impact on development of pigeonpea seedlings.

TABLE 1. Effects of density and irrigation on PAR interception, LAI and available soil water of pigeonpea seedlings.

Irrigation/Density (plants/m^2)	% PAR interception		LAI		%ASW[a]
	Day 31	Day 45	Day 31	Day 45	Day 24
Irrigated					
20	55	91	0.8	3.3	b
40	70	96	1.5	5.7	b
60	67	96	1.8	8.0	b
Dryland					
20	37	62	0.4	2.2	50
40	42	71	0.8	3.0	44
60	54	69	1.1	2.7	40

[a] % of available soil water remaining in profile.
[b] not recorded.

Monteith, J.L. 1977. Phil. Trans. R. Soc. Lond. B., 281, 277–294.

Legume Ley Farming — A Low-cost Method of Overcoming Soil Fertility Limitations in an Upland Agricultural System

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WITHIN the Third World, increasing population pressure is causing an increasing use of marginal infertile uplands. Such lands are 'fragile', i.e. easily irreversibly degraded by cultivation. Poor farmers will only increase productivity on these lands if relatively small cash input, small risk methods of improving and maintaining soil fertility are apparent to them (Infanger 1984). The following are some of the results of a research and pilot extension project conducted on infertile upland soils near Khon Kaen by the Faculty of Agriculture, Khon Kaen University and the Mekong Secretariat.

The herbage legumes siratro and verano stylo were sown with phosphorus, sulfur and potassium fertilisers and maintained for two or three years, and the land was then cultivated and sown to successive upland crops of roselle (*Hibiscus sabdariffa*) and cassava. The yields of the upland crops were approximately double those from comparable upland crop plots that had followed only cassava (Table 1). The legume leys were grazed by cattle. The beneficial effects of fertilised legume leys on crop yield were matched by increases in soil total nitrogen, potential mineralisable nitrogen and total carbon. One-year legumes (data not shown), unfertilised legume leys or weed fallow did not improve soil fertility as much as the fertilised two- and three-year legume leys, which differed little.

TABLE 1. Effect of legume leys on crop yields and soil fertility.

Ley treatment		Crop yld[2] after ley		Soil parameters[3] at the times:							
				Start experiment		End of leys			End of 2nd crop		
vegetation	fert[1]	1st	2nd	TN	TC	TN	NO	TC	TN	NO	TC
3yr cass	+	0.83	7.1	213	.37	213	44	.40	195	46	.40
3yr cass	0	0.76	7.0	195	—	—	—	—	186	—	—
3yr weeds	+	1.00	8.9	202	.38	233	59	.41	224	54	.43
3yr weeds	0	0.70	6.4	192	.35	214	53	.39	194	43	.39
2 & 3yr leg	+	1.54	12.9	206	.37	280	86	.48	268	68	.48
2 & 3yr leg	0	0.76	9.8	193	—	—	—	—	224	—	—

[1] + = P, K, S applied. 0 = no fertiliser applied.
[2] 1st crop = t OD coarse roselle fibre/ha. 2nd crop = t FW cassava tuber/ha.
[3] TN = total nitrogen (% × 10^4); TC = total carbon (%); NO = Potential mineral N (ppm); TN and TC of 0–15 cm depth. No of 0–5 cm depth.

The ley system was successfully integrated into the farming systems of 11 upland farms in a pilot extension project (Gibson 1984). The legume leys were grazed by milch cattle which also had access to on-farm crop residues and communal feed. In a comparative budget, net cash income (omitting labour costs) for a 1.3 ha upland farm per year were (in US$): traditional upland cropping ($260); beef cattle breeding on ley pastures ($319); milch cattle on ley pastures ($777).

It is suggested that legume ley farming, especially if integrated with profitable animal production (particularly milk production), can overcome limitations to farm productivity currently imposed by soil fertility and by socioeconomic factors.

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Incorporation of Legumes into Farming Systems in Northeast Thailand

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THIS project arose from the need to increase nitrogen accretion from both food and fodder legumes in the soil exhaustive farming practices now common over large areas of northeast Thailand. It is a joint research project based at Khon Kaen University, Thailand and at the University of Queensland, Australia and is funded by ACIAR.

The basic aims of the project are to facilitate the introduction of legumes into the farming systems of the region, to improve human and animal nutrition, and to help counteract the existing exploitive practices through nitrogen accretion and better management. The principal lines of work are: the incorporation or utilisation of leguminous crops in relay cropping or intercropping systems with rice and upland crops; the use of fodder legumes on waste lands, fallow lands and under-utilised areas such as paddy walls and roadsides; the use of fodder or green manure legumes in alley cropping and under-sowing systems with upland crops.

Cowpea has been selected as the main focus of interest in the food legumes. A large collection (approximately 480 lines) has been evaluated and a number of promising lines have been identified which are non-photoperiod-sensitive, and have synchronised flowering and long peduncles. Extensive studies have been conducted to overcome serious limitations imposed by pests and diseases.

Stylosanthes spp. and *Leucaena leucocephala* are the main fodder legumes under investigation. The stylos and other fodder legumes have been evaluated for use on heavily utilised communally grazed areas and for use in more managed backyard pasture situations. *Leucaena* and other shrub legumes are being evaluated principally as dry season forage sources.

Studies on the seed production of *Macroptilium atropurpureum*, *S. guianensis*, *Calopogonium caeruleum* and *Centrosema macrocarpum* have provided information which will assist in maximising seed yield from village-based enterprises.

Experimental programs examining various combinations of legume and field crop, such as alley cropping systems involving *Leucaena* and cassava and intercropping systems using cowpeas with cassava and kenaf, have given encouraging preliminary results.

The Potential of Medium-Duration Pigeonpea

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MEDIUM-DURATION pigeonpea performs well in places where the rainy season is too short for long-duration types and is particularly valuable where pigeonpea is wanted for an intercrop. In environments with mild winter temperatures it is also well adapted as a post-rainy season crop.

In southern India, medium-duration pigeonpea is sown at the start of the wet season. It flowers after the cessation of the rains and matures its seed before the winter, about 160–180 days after sowing. It is used as an intercrop with cereals such as sorghum, pearl millet, or groundnut. At ICRISAT when one row of this type of pigeonpea is sown with two rows of sorghum on the Vertisol soils or with five rows of groundnut on the Alfisols, it stabilises total production. This element of stability has led to farmers adopting the practice.

Three major diseases (*Fusarium* wilt, sterility mosaic (SM), and *Phytophthora* blight) and two insect pests (*Heliothis* and podfly) can cause substantial yield losses. However, good yielding lines with resistance to wilt and SM (Table 1) and tolerance to pod borer have been developed (Table 2).

TABLE 1. Yields (t/ha) of two wilt resistant, medium-duration pigeonpea lines and a susceptible control variety at ICRISAT Centre, rainy season 1984–85.

Entry	ICPL 84001	ICPL 8357	C 11 (control)	SE	CV%
1984	3.0	2.9	3.0	±0.16	12
1985	1.7	1.8	1.7	±0.08	9

Medium-duration pigeonpea has the potential to perform well in many parts of the world. In the Pigeonpea Observation Nursery at Suwan Farm, Thailand, the medium-duration entries were the best adapted of all maturity groups in 1982 and one entry, ICP 8863, yielded 5 t/ha compared to 2.1 t/ha for the local entry. In the 1984 Dry Season Trial at the International Rice Research Institute, in simulated rice-fallow conditions, the medium-duration entries outperformed the early entries and one of the *Heliothis* tolerant lines, ICPL 84060, yielded 3.2 t/ha (Table 2).

TABLE 2. Yields (t/ha) of medium-duration, *Heliothis*-tolerant pigeonpea lines from ICRISAT grown at IRRI, Los Baños, Philippines, 1984 dry season.

Entry	ICPL 84060	ICP 3009-EB-4-EB	ICPL 295 (control)	SE	CV%
Grain	3.2	2.7	2.5	±0.52	36
Fodder	18.1	23.8	16.3	±1.64	22

Besides disease and insect resistances, we have also bred and identified lines of this duration with many useful characters such as high protein, large-seeded vegetable, male sterile, dwarf and cleistogamous lines, and have identified many genetic markers.

Population Density in Pigeonpea in Indonesia

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THE planting density of pigeonpea (*Cajanus cajan*) has not been studied in Indonesia. The local pigeonpea strains are rarely planted in monoculture and usually intercropped with corn or other legumes. Maximum yields can only be achieved at the optimum plant density, which is conditioned by many factors such as plant type (determinate vs indeterminate, branching vs non-branching, short vs tall) and the environment (soil fertility, soil moisture etc.) (Sumarno et al., unpubl.).

A density study was conducted at Muneng Experiment Station (east Java) in the wet season (WS) of 1984–85 and dry season (DS) of 1985. Five pigeonpea lines (QPL–17, QPL–135, QPL–332, cv. Hunt and QPL–95) were tested at four plant densities. Results are presented in Tables 1 and 2.

TABLE 1. Seed yield of pigeonpea lines, averaged for plant populations, at Muneng wet season 1984–85 and dry season 1985.

Variety	Yield (kg/ha) WS	DS	Mean
QPL-17	1826a	1795a	1810
QPL-135	1552b	1530a	1541
QPL-332	779d	1309a	1044
Hunt	1166c	1477a	1322
QPL-95	1071c	1804a	1438

Values followed by a common letter are not significantly different at 5% LSD.

TABLE 2. Seed yield, averaged for five pigeonpea lines, at four plant populations.

Spacing	Density ($\times 10^4$)[1]	Yield (kg/ha) WS	DS	Mean
50 × 10 cm	40	1187a	1515a	1351
45 × 10 cm	44	1325a	1584a	1455
40 × 10 cm	50	1255a	1580a	1418
35 × 10 cm	57	1344a	1637a	1489

Values followed by a common letter are not significantly different at 5% HSD Tukey.
[1]Values $\times 10^4$ = plants/ha.

Yields differed between lines in the wet season, but not in the dry season. QPL-17 yielded consistently well in the both seasons averaging 1810 kg/ha (Table 1).

In each season, differences in plant populations for each line were not significant, although there was a tendency towards higher yields at higher densities (Table 2). In general, the yield of pigeonpea was higher in the dry season than in the wet season.

Sumarno, Karsono, S., Hamdani, M. and Widowati, S. 1986. Yield Performance of Introduced Pigeonpea Varieties in Indonesia (unpublished).

The Production of Food Legumes in the Himalayan Range

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THE production of protein to fulfil the nutritional requirement of human and animal populations is one of the most pressing problems of our time.

The Himalayan belt, with diversified agroecological conditions, is regarded as a repository for sources of plant protein of which leguminous crops are the most important. As traditional crops, beans and peas are grown to some extent in summer in the high Himalayan region (elevation above 4000 m) and in the high mountain region (elevation 2200–4500 m) along with maize. Legumes such as green gram, black gram, cowpea, ricebean, gardenpea, mothbean, soybean, horsebean, *Dolichos* spp. are concentrated in the middle Himalayan region (elevation 600–2400 m) and are grown as a single or mixed crop with other cereals. In the Siwalik Range (elevation 300–1200 m) and in the southern Gangetic Plain (elevation below 300 m) lentils, chickpea, grasspea, pigeonpea, fieldpea, mungbean are grown both traditionally and commercially.

The distribution of crops, and methods of cultivation vary depending on ecological conditions such as elevation, growing season, precipitation, slope, aspect and soil characteristics, as well as social factors such as ethnicity and religion.

In the Nepalese Himalayan region, about 216 000 ha of cropped area is occupied by legume crops. The average yield is very low — 0.38 t/ha because legumes are considered a secondary traditional crop and insufficient attention is paid to cultural operations. Inadequate technology, lack of knowledge of insects, pests and diseases and lack of organised marketing and price incentives constrain their increased production.

Though the yield of food legumes is very low, their value as food crops is quite significant. They are important sources of food and fodder and provide useful support for the restoration and maintenance of soil fertility on the steep terraces.

Potential of Food Legumes as Intercrops with Young Rubber

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INTERCROPPING of young rubber is widely practised by smallholders in southern Thailand. Previous reports have demonstrated that many annual and biennial crops are suitable for planting between rows of one- or two-year-old rubber (Anon. 1980; Templeton 1974; Wongsukon et al. 1974).

We conducted two experiments at different sites at Songkhla from 1981 to 1985 to observe the yield potential of intercrops such as food legumes and cereals and their effect on growth and yield of rubber.

In the first experiment the intercrops were sown in the same plot for 3–4 years between rows of rubber of differing ages. The results of this experiment are shown in Table 1. Most legumes gave low yield due mainly to diseases and soil variability.

TABLE 1. Yield (kg/ha) of mungbean, soybean, groundnut and corn planted each year for four years between rows of rubber.

	Age of rubber (months)							
	0–5 m[1]		10–16 m		22–28 m		34–40 m	
	NF[2]	F[2]	NF	F	NF	F	NF	F
Mungbean	—	—	444	668	310	510	255	443
Soybean	1250	—	975	1163	765	1261	944	1189
Groundnut	1193	—	944	1449	1090	1284	1032	1335
Corn	1802	2651	1523	2983	1088	2737	1076	3475

[1]Range of rubber ages from planting to harvest of all intercrops.
[2]F, NF = with and without fertiliser, respectively.

There was no obvious effect of shading by rubber on the yield of intercrops in successive years. Girth increments in the rubber intercropped with a legume cover and pineapple were good, with food legumes and with cereals they are moderate.

In the second experiment, five treatments including mungbean–groundnut, corn–upland rice, pigeonpea, legume cover and banana were planted between rows of rubber for two years. All intercrops performed well. Groundnut and mungbean yielded over 1.8 t/ha. Mungbean–groundnut and corn–upland rice intercrops resulted in largest girth increments. This was probably due to the high frequency of cultural practices as well as fertiliser application to intercrops. Other experiments at Hatyai using a pigeonpea intercrop indicate that short, indeterminate types are required.

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Wongsukon, P., Kongton, A. and Templeton, J.K. 1974. Rubber Research Centre, Tech. Bull. No. 56.

Intercropping Food Legumes with Cassava in a Rice-based Farming System

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CASSAVA (*Manihot esculanta*) is a secondary food crop of Kerala, usually raised as a monocrop under rainfed conditions. Shanmugavelu et al. (1973) have reported a significant yield response to irrigation. According to Prabhakar and Pillai (1983), the crop is suitable for intercropping with groundnut, cowpea and french beans because of late canopy closure. Precise information on the appropriate cropping system is lacking.

Investigations carried out in a sandy loam soil with cv. – M4 (duration of 10 to 11 months) under rainfed conditions revealed that 50 mm of irrigation when cumulative pan evaporation (CPE) reached 100 mm (IW/CPE = 0.5) (approximate interval of 24 days) was optimum (Table 1).

The irrigated crop at 9 months produced 30.8% more tuber yield than the rainfed crop at 11 months. Hastened development of cassava due to irrigation facilitated the cultivation of medium-duration (3 months) transplanted rice in the southwest monsoon season.

TABLE 1. Effect of irrigation on tuber yield of cassava cv. M-4.

	Irrigation treatment (IW/CPE ratios)					
	1.00	0.75	0.50	0.25	No irrigation	C.D. (0.05)
Mean yield of tuber (t/ha):						
9 months	40.5	36.6	36.9	28.7	22.9	6.7
11 months	47.6	43.3	41.6	33.9	28.2	6.7

Further studies revealed the possibility of intercropping cassava with cowpea, green gram, black gram or groundnut (maturing in 80-100 days) in the early stages without any adverse effect on the main crop (Table 2).

TABLE 2. Yield of cassava and intercrops as influenced by treatments.

	Cassava alone	Cassava + cowpea	Cassava + green gram	Cassava + black gram	Cassava + groundnut	C.D. (0.05)
Tuber yield of main crop (t/ha)	24.6	20.9	24.1	23.0	22.9	NS
Yield of intercrops (t/ha)	—	0.79	0.41	0.60	0.55	—
Profit index	10.0	11.0	12.7	12.8	11.9	—

Results of the studies brought out the economic feasibility of a cropping system involving rice in the southwest monsoon season (June-September) followed by irrigated cassava intercropped with cowpea, green gram, black gram or groundnut.

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Shanmugavelu, K.G., Thamburaj, S., Shanmugam, A. and Gopalaswamy, N. 1973. Indian J. Agric. Sci., 43(8), 789-791.

Legumes in Rainfed Farming Systems in Sri Lanka

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RICE occupies approximately 9.26×10^5 ha in Sri Lanka, and the production is 2.2 million t (FAO 1984). This crop is sown at the onset of the monsoonal rains, which occupy 7.5 months (Domros 1970). Estimated yields lie around 2375 kg/ha/yr based on two crops. This provides the traditional farmer with a low average annual income of SLR 8000 (1US$ = 28SLR) on a farm of 1 ha.

The rice farming systems of Sri Lanka are either totally rainfed or supplemented with irrigation. The rainfed systems, which occupy 3.32×10^5 ha (Central Bank 1984), generally have sufficient water for two rice crops. Measurement of soil moisture during the fallow periods (4.5 months of the cropping year) indicates sufficient moisture for arable cropping between rice crops. Such a crop could intensify land use, increase productivity and income levels and enrich the soil for the next rice crop by adding crop residue.

Legumes form a major component of tropical agriculture (Rachie 1977) and this holds true for Sri Lanka. Their short growth cycle, high protein content, income generating potential, and ability to enrich the soil make them ideal for insertion into the fallow period of rainfed farming systems. Crops such as mungbean (*Vigna radiata* — 60 days), bushbeans (*Phaseolus vulgaris* L. — 50 days) and vegetable cowpea (*Vigna unguiculata* L. — 50-60 days) could be easily fitted into rainfed farming systems. Under an irregular rainfall pattern, crops such as *Crotalaria juncea* L. could be broadcast at minimal cost to farmers. While not providing a supplementary income this green manure crop will help increase soil fertility during a hitherto unutilised period.

Studies are being carried out to examine this concept. Preliminary analyses indicate increased rice yield following interseasonal planting of short-term legumes. Increased income to farmers and better land and labour use patterns have been seen. Thus scientific evaluation of this system on a long-term basis may prove this intensification to be an ideal concept for increasing productivity of rainfed smallholder rice farming systems of Sri Lanka, as observed elsewhere in the Asian region.

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Some Problems Associated with Seed Sources in Grain Legumes — A Case Study

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FOOD legumes are widely cultivated in Sri Lanka and recent estimates indicate that an area of 85 000 ha is under cultivation with these species. The 5–6 species of legumes that are grown in this country are thus considered a very important subsidiary food crop (Gunasena 1974). Production level of these crops is below expectations (Agric. Implementation Plan 1985) and unpublished reports indicate that lack of good quality seed material is a major contributory factor. Thus a survey was carried out in a selected region of Sri Lanka to ascertain the availability of seed material.

A sample of farmers growing the most popular food legume mungbean (*Vigna radiata* L.) were interviewed on problems faced in obtaining seed material. The farmers cultivated this crop during the dry season, Yala (April-September). Sub-samples of their seed sources were obtained and tested for quality (measured in terms of germination) as per ISTA (1976) rules.

Results indicate that farmers generally keep their seed material from the previous crop. This was due to the unavilability of good seed in government or private seed outlets when required. Few farmers purchased their seeds from neighbouring farms or private stores. The seed material used by them had an average moisture content of 18% and a germination rate of 25%. This resulted in the use of very high seed rates of approximately 60 kg/ha.

Seed with 80–90% germination was supplied to farmers, who stored it in different containers for a period of 6 months. Jute bags were the most popular containers, followed by polythene bags, and storage conditions varied with ambient temperature and humidity. Evaluation of seed quality at the beginning and end of storage showed that well dried seed stored in sealed polythene bags retained germinability when compared with other storage containers which were jute, paper and cloth bags. Germinability of seeds in these containers was reduced by about 20% during the storage period.

The study illustrated the pressing need for good quality seed. Thus advice to farmers on good storage techniques and on the value of storing dried seed in proper containers will help to alleviate the problem.

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Gunasena, H.P.M. 1974. Field Crop Production, Lake House, Sri Lanka, 543p.
ISTA 1976. Seed Sciences & Technology, 1, 177p.

Yields of Legumes in Mixed Cropping Systems

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THE role of legumes in tropical farming systems was well reviewed by Norman et al. (1984) and many reasons are cited for their abundant use in such cropping patterns. Their possible contribution to intensification of production is considered the predominant feature that makes legumes acceptable into mixed farming systems (Gomez and Zanstra 1977).

A successful mixed cropping system depends upon the selection of species. The yielding ability of three legumes when grown together with three companion crops with differing growth forms was evaluated to identify their compatibility. The legumes selected were mungbean, cowpea and bushbeans, and the companion crops were cassava, corn and sweet potato. All combinations were grown at a similar density and the yields are presented in Table 1.

TABLE 1. Yields of legumes (kg/ha) under mixed crop conditions.

Companion crop (pods)	Mungbean (grain)	Cowpea (grain)	Bushbean (fresh beans)
Corn	640.8	413.9	2214.1
Cassava	747.3	484.0	2465.6
Sweet potato	783.4	546.1	2546.5
Monocrop of legume	846.5	643.2	2720.1
LSD (P = 0.05)	20.3	15.8	78.3

Yield of all legumes was affected by the companion crops. Corn reduces the yield of all legumes greatly, due to its ability to intercept more light by its thick tall canopy, thereby shading the shorter legumes. In contrast, legume yield was affected least by sweet potato, due to its short stature. The effect of cassava on legume yield was intermediate to corn and sweet potato, as this species was tall, showed a lesser capacity to intercept light than corn at the planted density, and was the crop with the longest duration of growth.

Bushbean, known for its adaptability to intercropping systems, was least affected by the companion crops. The other species require a greater quantity of light and thus are more susceptible to shade and hence to mixed crop conditions.

Reduction of competition between companion crops is a vital factor in increasing yields of mixed cropping systems (Willey 1979). Thus, best varieties for monocropping might not be the most suited for mixed cropping, due to the changes in the microclimate within crop mixtures, as indicated in the study. While legumes are an important species for tropical farming systems, their use in mixtures should be preceded by evaluations of their suitability. Use of tall companion crops, especially at high density, would not be suitable for incorporation with legumes. In contrast, species such as sweet potato or even cassava, which produce their economic yields from tubers, can be considered good companion crops to the legumes.

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Pulse Production in Fiji

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THE major pulses grown in Fiji are pigeonpea, cowpea, urd and mung. These were originally introduced to Fiji by the Indian population. Later introductions of improved genotypes were made from India, Nigeria and Australia (pigeonpea); Nigeria, USA and Australia (cowpea); India, Philippines and Taiwan (mung); India, Australia and Taiwan (urd).

Production is still below demand, and these together with other pulses are imported. Higher sugarcane prices some years ago encouraged farmers to plant more cane, and this was done at the expense of pulses. However, with the recent downturn in sugar prices, the area sown to pulses has increased.

Pigeonpea is the major pulse grown in Fiji, planted usually on fallow or sloping land. The other pulses are mostly intercropped in sugarcane rows, with some sole cropping in rotation with cane.

Areas planted are relatively small and the bulk of the production is for home consumption. Any surplus is sold in the municipal markets. The presence of processing plants has given farmers the ability to sell their produce in bulk, at a reduced price.

Major constraints to production of these pulses are pest control, especially in pigeonpea, and some nutritional problems. More recently pigeonpea stem disease, which could become a major problem, was identified. Yields of these pulses are low (Table 1).

In pigeonpea, research is directed towards improving yields through varietal introduction, pest and disease control and nutritional studies. In other pulses, improvement is through evaluation of high-yielding disease-resistant cultivars.

TABLE 1. Characteristics of released varieties cultivated in Fiji.

Crop/Varieties	1000 seed Wt. (g)	Seed colour	Maturity (days)	Av. trial yields (t/ha)
Pigeonpea				
Kamaal	100	Mottled brown	Plant: 170 Ratoon: 270	1.7
Kamica	206	Dark brown	Plant: 155 Ratoon: 260	1.5
Cowpea				
Vikash	—	Dark red	80–90	1.8
Ivory	176	White	80–90	1.5
Urd				
Station 8	36	Shiny green	64–75	1.2
Station 15	38	Dull green	64–75	1.0
Mung				
Station 25	59	Shiny green	75–80	1.0
Station 46	59	Dull green	75–80	1.3

Pigeonpea Genotype Evaluation in Fiji

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EVALUATION of pigeonpea lines in Fiji has been in progress for over a decade. In 1983 three photoperiod-sensitive varieties which averaged above 2 t/ha over the previous three years were released: Kamaal (Local Selection), Kamica (ICP 7035) and Royes (UQ 50). Since 1983, in collaboration with the ACIAR/UQ Pigeonpea Improvement Project, genotype evaluation and other aspects of research in pigeonpea have been expanded. In 1984, 44 genotypes and in 1985, 54 genotypes were evaluated in replicated yield trials at three sites, Legalega (Oxisol), Nasarawaqa (Oxisol) and Ba (Mollisol). Mean seed yields of promising lines are shown in Table 1.

The photoperiod-sensitive lines generally gave higher plant crop yields with some reaching over 2 t/ha under good growing conditions, but required longer growing periods (160–170 days). Where ratooning was possible with early planting, total yields of 3.0 t/ha at Legalega and 3.9 t/ha at Ba were obtained with variety Kamica.

Yields of photoperiod-insensitive early maturing lines (110–120 days) were generally lower at Legalega and Nasarawaqa. This was primarily due to poor soil conditions, disease and a flower drop problem, and the performance of these lines was much better at Ba on a more fertile soil site. At this site, QPL 116 gave the highest plant crop yield of 1.68 t/ha. Ratoon yields were also good, and at this site QPL 116 and QPL 44 produced total yields over 3 t/ha while four other lines (QPL 112, QPL 69, QPL 38 and ICPL 5) produced total yields over 2.5 t/ha. Ratoon yields were low or not obtained at other sites due to water stress and disease problems.

TABLE 1. Seed yield of pigeonpea lines at three sites in 1984 and 1985.

	Legalega		Nasarawaqa		Ba	
	1984	1985	1984	1985	1984	1985
	Photoperiod-sensitive lines					
Plant crop	1.52(5)	1.66(8)	1.08(4)	0.54(8)	1.87(8)	1.58(8)
Ratoon	—	1.24(2)	—	—	2.10(2)	—
	Photoperiod-insensitive lines					
Plant crop	0.60(8)	0.93(13)	1.20(8)	0.79(13)	—	1.35(13)
Ratoon	—	0.43(9)	—	—	—	1.19(13)

In parentheses: number of lines.

Effects of Time of Sowing on Phenology of Pigeonpea in Thailand

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PIGEONPEA is not a commercial crop in Thailand, but may have considerable potential in the poorer soils of the northeast. Potential markets include the large intensive animal production industry in Thailand, and export to nearby centres of human consumption.

A series of trials has been conducted in northeast Thailand since 1983 to evaluate the agronomic potential of pigeonpea in that environment. A serial sowing trial was conducted at Khon Kaen Field Crop Research Centre between August 1983 and August 1984. Single row plots of 17 lines were sown at two-week intervals and irrigated as necessary to prevent water deficit. As well as phenological data discussed here, data were collected on plant height and seed yield.

In general, the lines fell into two broad groups with respect to phenological development: sensitive and insensitive to daylength. Classification of individual lines was consistent with their performance in India and/or Australia.

In northeast Thailand, pigeonpea is most likely to be sown between April and September, with increasing reliance on stored water (post-monsoon growth) as sowing is delayed. For sowings throughout this period, daylength-insensitive lines flower substantially earlier than sensitive lines. Therefore the insensitive lines have greater potential in this environment because of reduced likelihood of water limitation and increased ability to fit into systems of multiple cropping.

Preliminary regression analyses have been conducted to investigate the causes of variation in time to flowering in cv. Quantum. Variates examined include means of daily temperatures (maximum, minimum and mean), total rainfall, and number of rain days, each for the period between sowing and 50% flowering. No significant correlations have been obtained between time to flowering and any of these variates. Analyses are continuing with other climatic variates and data from other lines.

The Use of *Mucuna* in Upland Farming Systems for Improving Soil Productivity

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Mucuna sp. is an edible legume crop grown as a home garden crop, especially in Yogyakarta, central Java. The seed is commonly used for making fermented cake (tempe) or mixed with cassava, which is used as a secondary staple food. It has a high nutritive value, as characterised by high protein (30%), carbohydrate (9.4%), fat (2.7%) and minerals. At IITA, Nigeria, *Mucuna* sp. has been studied for use as a cover crop.

In Indonesia, soil degradation is considered to be a serious problem in uplands under food crop cultivation. Soil erosion and depletion of organic matter may be severe, resulting in the drastic decline of soil productivity.

To overcome this problem, studies on the use of inedible legume cover crops such as *Crotalaria*, *Centrosema* and *Calopogonium* have been conducted by many researchers (Sastrosoedarjo 1984; Barus and Suwardo 1986). However, the development of these crops is difficult as the farmers do not perceive a direct advantage from them. The identification of alternative legume crops suitable for seed or other food production is therefore important.

The use of *Mucuna* sp. (that is considered as an edible legume crop) has been studied in a crop rotation on an Oxisol in a transmigration area of Jambi province. The results show that the yield of soybean grown after *Mucuna* sp. was significantly higher than that after either groundnut or grass (Table 1). This table also indicates that the effect of *Mucuna* is present on the yield of maize following soybean.

TABLE 1. Effect of *Mucuna*, groundnut and grass on the yields (t/ha) of soybean and maize.

Treatment	First crop (soybean)		Second crop (maize)	
	green matter	seed	green matter	seed
Mucuna, fresh crop residues removed	1.261a	1.150a	2.365b	1.461b
Mucuna, fresh crop residues returned	1.374a	1.259a	4.630a	2.251a
Groundnut (limed at 2 t/ha), all crop residues returned	0.992b	0.756b	2.022b	1.282b
Grass	0.722b	0.561c	1.626b	1.097b

Mulching of *Mucuna* also improved the soil condition (Table 2).

TABLE 2. Effect of *Mucuna* in combination with tillage treatment on the seed yield of soybean and maize.

Treatment	Soybean (t/ha)	Maize (t/ha)
Tilled, no fertiliser, *Mucuna* removed	0.693a	0.538a
No-tilled, fertiliser, *Mucuna* mulched	1.100b	2.209b
Tilled, fertilised, *Mucuna* incorporated	0.997c	1.811c

Numbers followed with a different letter are significantly different at P 0.01.

Mucuna is promising as an edible, fast growing (4–6 months), nitrogen rich legume, capable of improving soil productivity. It can be incorporated into a food crop rotation, or be a fallow crop in shifting cultivation.

Barus and Suwardjo, H. 1986. The effect of erosion and cover crop on the production of soybean and mungbean on Oxisol. Pemberitaan Penelitian Tanah dan Pupuk No. 6, 1986.

Sastrosoedarjo, S. 1984. Improvement of organic matter in upland farming systems. Proceeding Pertemuan Teknis Penelitian Pola Usahatani Menunjang Transmigrasi.

Relay Intercropping of Pigeonpea in Groundnut

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THE reluctance of farmers to adopt a mixed or intercropping system with groundnut caused a new relay intercropping system in groundnut to be tested without disturbing the traditional production system.

Virginia spreading groundnut was sown at 60 × 10 cm with the onset of monsoon (June-July) using bullock drawn implements. Intercultural operations continued up to 40-45 days after sowing (at pegging). Six pigeonpea cultivars (T 21, UPAS 120, S 5, ST 1, Tuian, T 15-15) were sown between the rows of groundnut at the last interculture operation. The groundnut crop matured by November and was harvested by traditional bullock drawn implements leaving the standing crop of pigeonpea. This matured on residual moisture as late as January depending upon the cultivar.

In the groundnut-pigeonpea relay intercropping, groundnut is the major component due to its importance as a cash crop. The groundnut yield levels were 854, 774 and 882 kg/ha in 1981, 1982 and 1983, respectively, which were equivalent to groundnut yields when relay intercropped with pigeonpea. This clearly suggested that relay intercropping of pigeonpea was not detrimental to groundnut production. The yield of pigeonpea was low, due to moisture stress in the delayed sowing (Singh et al. 1971; Saxena and Yadav 1975). However, under better conditions, pigeonpea yields under relay intercropping can be similar to normal planting situations (Ladola 1984). Cultivar T 15-15 gave the highest yield, followed by UPAS 120 in relay intercropping across environments.

While computing the initial cost benefit ratio (ICBR) of this cropping system, it was found that by spending a rupee in relay intercropping Rs. 2.80 were earned with pigeonpea cultivar T 15-15 and Rs. 2.00 with UPAS 120, while other cultivars were not found beneficial. With the recommendation of this cropping system by Gujarat Agricultural University, the minikit program by the Government of India for Gujarat has been widely adopted.

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Section 4

Environmental Factors

Review of Contributed Papers

A. Pookpakdi *

THE period of growth in food legumes is divided mainly into two phases: vegetative growth and reproductive growth. In vegetative growth, plants produce vegetative organs such as leaves, stems, branches and roots. Carbohydrate from photosynthesis is partly stored in primary roots and stem bases for further pod and seed development.

In the reproductive growth stage, plants produce flowers, pods and seeds, and translocate carbohydrate or dry matter into seeds. Seed development imposes strong sink demand for carbohydrate to be accumulated in seeds and the photosynthetic efficiency of leaves during the seed growth period increases. Pod numbers, seed numbers and seed size are the products of the different environmental and cultural factors which have affected the plants at different periods of growth, and the yield which is subsequently obtained varies according to these limits.

During the vegetative growth stage of crops, the production of high dry matter yield seems to be a good guarantee for subsequent high yield of crops. Dry matter of pigeonpea was low during the early vegetative growth stage but was found to increase linearly between 30-120 DAS (Govil et al.). In soybean, maximum dry matter yield has been produced at critical LAI of 3.4. In rice bean, the critical LAI was 3-4 when light interception of crop canopy exceeded 95% (Chatterjee et al.). Since 95% light interception point and maximum dry matter yield coincide in most of the field crops that exhibit the critical LAI fashion, it can be generally stated that the maximum dry matter yield of rice bean is produced when critical LAI is between 3-4 in the experiment reported.

Dry matter production, LAI and leaf area duration (LAD) can be influenced a great deal by environmental factors. In pigeonpea, (Govil et al.) high density and narrow row spacing increased LAI, LAD and LAD^1 (leaf area duration from pod initiation to harvest). Indeterminate varieties of pigeonpea generally produced more dry matter and LAI much faster than the determinate ones. In several experiments in legumes in the past (soybean, mungbean as well as pigeonpea), it was found that LAI, LAD and dry matter production positively correlated with seed yield.

Before considering the reproductive growth stage, it is necessary to emphasise that the vegetative and reproductive stages of legumes are partitioned by the flowering stage. Two growth habits in relation to flowering are found in legumes — the indeterminate and determinate growth habits. The former growth habit is found in legumes that produce vegetative growth during the period of pod and seed development. Usually, this type of growth habit gives rise to non-uniform maturity of products. The latter growth habit occurs in legumes which completely cease their vegetative growth before flowering, and growth after flowering is only for pod and seed development.

Flowering in legumes is mainly controlled by two important factors, photoperiod and temperature, which normally interact with each other with great intricacy. Legumes of the same species vary in response to photoperiod and temperature, so that there is considerable varietal variation of growth and flowering period.

In general, photoperiod exerts the major effect on flowering, and temperature the minor influence. In soybean, maturity classification is used to classify varietal response to different photoperiod and temperature, and maturity group classification is presently receiving serious consideration. In mungbeans it was found that some groups exhibit more short day flowering habits than others. Some groups flowered in 40 days, while others flowered in 60-70 days. Furthermore, some groups responded

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strongly to both photoperiod and temperature, and flowering response is difficult to understand and explain (Eagleton and Sandover).

Since photoperiod normally exerts the major effect on flowering, then legumes are classified as short day and long day plants. Examples of long day plants are peas, lentil, chickpea, horse bean and lupin, while short day plants are soybean, navy bean, black gram, mungbean and cowpea (Summerfield and Roberts). An attempt is being made to develop a technique to describe photothermal response of legumes, so that when planted under specific environments their vegetative and reproductive growth period will be well balanced and the crops will produce better yields. The flowering stage of the plant is vitally important and contributes greatly to yield response. If the crop flowers earlier, the vegetative phase is much shorter, so that plants do not have much time to produce vegetative organs and to store carbohydrate for subsequent pod and seed development. In contrast, much longer vegetative growth, due to the delay in flowering, will make it difficult for the plant to partition the carbohydrate to pod and seed. Low harvest index and yield are generally obtained in most cases.

Three studies in pigeonpea reported here (Thirathon et al.) showed evidence that the yield and yield components of legumes were dependent upon assimilates and dry matter produced earlier. By manipulating treatments, it was found that yield components which occurred earlier would utilise assimilate supplies for development at a rapid rate and with much higher priority than the components developed at the later stage. For example, the pod number increased tremendously as the result of assimilate supplied two weeks after flowering, while the seed size did not respond to assimilate supplied at this stage. If the assimilate was not limited, the pod number increased tremendously, and sometimes they were in excess of the capacity to fill at a later stage. In contrast, if assimilate was limited, the pod number decreased significantly.

Vegetative growth, LAI, and dry matter exert an important role in yield component development. In pigeonpea, LAI of 3.5–4.0 was found to be the focal point for maximum pod production. However, much higher LAI such as 5.4–6.7, although it produced maximum dry matter, tended to reduce pod number. This would suggest that slight mutual shading and flower abortion would be related in the pigeonpea canopy. Various studies in pigeonpeas (three studies in Australia and one study in India) suggested that the seed filling period in legumes is independent of the leaf photosynthesis at the seed development stage. The retention of leaf canopy to a certain extent would help plants to obtain high yield, due to an increase in seed size but not in pod number.

Compensation of each yield component in various legume species needs to be studied further. In soybean, environments and cultural practices seldom affect the number of seeds per pod and seed size, but they have significant effects on the pod number. In pigeonpea, increases in seed size of 9% and seed number per pod of 24% have been obtained when some pods were removed. It is worthwhile seeking greater understanding of change in yield components of other legumes such as black gram and rice bean, so that better cultural practices can be established for each particular legume in each environment.

Adaptation of legumes to environment, particularly in different farming systems, is vitally important. In Nepal, the placement of legumes in each cropping pattern has been considered through the adaptation of each species to drought and temperature resistance (Wagley). Most of the winter legumes such as grass pea, lentils and chickpea are planted after rice because of low-temperature tolerance and drought resistance. Mungbean is planted in spring in the areas in which drought may occur. From the farming systems viewpoint, we need to develop varieties of legume tolerant or resistant to drought, low temperature and waterlogging. Studies have been conducted to measure carbon isotope composition as a means of determining water use efficiency in legumes (Farquhar and Hubick). This area of research will be an important consideration in dealing with legume species planted in the areas where drought is the major environmental limitation.

Growth Analysis of Rice Bean

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RICE bean, *Vigna umbellata*, produced seed yields of 2.5–3.4 t/ha, when sown July–August and harvested late November–mid-December on the subtropical (23°N) Gangetic plains (mild winter conditions with minimum temperature in November–December from 12 to 18°C). This was much higher than the other two conventional beans, *Vigna mungo* and *Vigna radiata*, which usually yield 0.8–1.5 t/ha. Moreover the storability of the grains of rice bean was much superior to the other two food legumes.

The duration of a number of genotypes, when sown at monthly intervals, ranged from 100–462 days. September-sown crops were earliest to mature; October-sown crops took the maximum time. Experiments under controlled conditions showed that rice bean is photoperiod-sensitive, a short-day crop, with variable sensitivity among genotypes. Plant height, branching, and number of nodes per plant were higher in July- and August-sown crops than in September-sown crops, which were more determinate and erect in habit. The first raceme in July- and August-sown crops developed at the 8th to 10th node from the base of the main stem, compared to the 2nd node in the September-sown crop. The percentages of flowers setting pods were higher in September-sown (33–37%) than in July- and August sown (28–30%) crops and pod maturity was more synchronous in the late sown crop.

Nodulation started early (15 days after sowing). July- and August-sown crops showed higher number of nodules than the September-sown crop, but the nodules senesced before the onset of flowering in the early sown crops.

The critical leaf area index appeared to be 3–4 when light interception in the crop canopy exceeded 95%. Crop growth rates of early sown crops recorded two peaks with a lag phase in between, while September-sown crop did not show this lag phase. The two years mean seed yield of July-, August- and September-sown crops were 3.09, 3.34 and 3.33 t/ha, when established in rows 30 cm apart and plants 10 cm apart (Table 1). The seed yield was closely and significantly correlated with number of pods/unit area and leaf area duration between flowering and maturity.

TABLE 1. Effect of sowing dates, varieties and row spacings on seed yield (kg/ha) of rice bean.

		Dates of Planting (D)					
	Row	25 July		25 August		25 September	
Variety (V)	Spacing (S)	1983	1984	1983	1984	1983	1984
S 9	30	3112	3486	3386	3735	3486	3836
	60	2850	3125	3121	3395	2175	2362
S 8	30	2697	3114	2956	3370	3110	3395
	60	2547	2830	2830	3112	1985	2127
Dangar-Rani	30	2865	3237	3120	3467	2900	3246
	60	2646	2900	2898	3150	1826	2014
LSD P = 0.05*		D		S		D × S	
1983		337.7		193.6		335.7	
1984		398.4		220.7		382.2	

*Significant at P = 0.05.

The Phenology of Mungbeans in Northwestern Australia

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ONE limitation to mechanised mungbean cropping is that the phenology of the best cultivars is often poorly matched to the constraints imposed by the environment. In northwest Australia for example, commercial cultivars must be planted in February in the peak of the monsoon, when it is difficult to operate planting machinery.

In 1983 a trial was undertaken in the Ord River Irrigation Area (16°S), to examine the range of phenological responses in the mungbean with a view to developing cultivars suited to practical planting date options. The methodology followed similar studies by Lawn (1979) and Shamsad Begum et al. (1983). Fifteen accessions were planted under irrigated conditions every second Wednesday for 27 plantings between January 1983 and January 1984. Mean monthly temperatures ranged from 21.6°C in July 1983 to 32.9°C in November, and daylength from 11.1 h in June to 12.9 h in December.

Pattern analysis of the time to first flower delineated three categories of accession: group A with a mean of 40 days and a range less than 30; group C with a mean of 60-70 days and a range of 100; and a more heterogeneous group B which was intermediate between A and C lines. These groups differed in the degree to which they responded to mean daily photoperiod and mean daily minimum or mean temperature (Table 1). In none of the 15 accessions was mean daily maximum temperature significant in determining variation in the time to first flower. There was only a small correlation (0.55) between the minimum time taken for an accession to reach first flower and its range across planting dates.

TABLE 1. Equations of best fit for three typical mungbean accessions, of the regression over planting date of rate of development (r = 100 × inverse of days to first flower), on mean daily photoperiod (p) and mean daily mean temperature (Tm) or mean daily minimum temperature (t) from planting to first open flower.

Mungbean accession	Group	Regression equation of best fit: Equation	Adjusted R^2	Significance
CPI 29231	A	$r = -0.14 + 0.09Tm$	0.69	$p<0.01$
CPI 30757	B	$r = 7.3 + 0.13t - 0.63p$	0.38	$p<0.01$
CPI 60823	C	$r = 12.6 - 0.92p$	0.77	$p<0.01$

Despite the differences between accessions in the time to first flower, there was negligible difference between accessions in the mean duration of the interval between first flower and first mature pod, and in the responsiveness of this interval to difference in planting date. The mean time from first flower to first pod across all accessions was only 22 days.

These results pose a dilemma, for while there is considerable scope for manipulating the preflowering phase of mungbeans, the duration of pod growth and maturity is constrained by the fact that seed size must not exceed a predetermined market expectation. Attempts to extend the time from planting to maturity in cultivars destined for mechanised cropping will need to be matched by emphasis on a more synchronous and plentiful pod set per unit area, if the extra duration is not to result in indeterminate and unmanageable vegetative growth.

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Measurement of Carbon Isotope Composition to Seek, and Exploit, Variation in Water-Use Efficiency

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THE greatest limitation to world agricultural productivity is water availability (McWilliam 1986). This is obviously the case in arid areas, but is also a problem for crops grown in tropical monsoonal climates on residual water after the main wet season crop. Peanut intercropped with rice is an example.

Selection of genotypes with greater efficiency of water use (W) (ratio of biomass production to water transpired), using classical field techniques, is difficult. Recently, Farquhar and Richards (1984) showed, in pot experiments, that variation in the physiological component of W in wheat genotypes was correlated with the isotopic composition of carbon in the plant material. Plants with greater W showed less discrimination (Δ) against the naturally occurring stable isotope, ^{13}C. Hubick et al. (1986) have shown that this was also the case in a pot study involving nine peanut genotypes. Both sets of results are in accord with a theory of carbon isotope discrimination developed earlier (Farquhar et al. 1982). These topics have recently been reviewed (Farquhar et al. 1986).

In a survey of tropical legumes we also found considerable variation among mungbean, black gram, cowpea, and pigeonpea genotypes. Variation in Δ and in W has also been measured in cotton and barley.

The results are promising in that Δ may be measured quickly in small samples of plant material and with minimal problems of storage and handling. However, the technique gives no information about absolute yield, and only indirectly gives information about the ratio of total yield to water transpired. It needs to be tested at the crop level. Mass spectrometers are used to measure and these require considerable capital investment, technical expertise, and maintenance. Nevertheless, they can be operated at centralised locations, with dried samples being sent by mail.

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Growth Analysis in Relation to Pigeonpea Improvement

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INFORMATION on the physiological parameters related to growth, development and yield in early pigeonpea is scanty. Studies conducted in India by Bahal et al. (1979) indicated that total dry matter production in traditional varieties of pigeonpea is as high as that of major cereals. The objective of this study was to assess possible constraints to higher production, with respect to partitioning of total dry matter to reproductive sinks. Growth, dry matter accumulation and yield components were determined in four genotypes of early pigeonpea under four dates of sowing and different plant densities. Data on growth characteristics, dry matter accumulation (vegetative and reproductive) were obtained for three sowings, while the data on yield components were obtained for two dates of sowing. Growth analysis showed that the total dry matter was low up to 30 days after sowing and increased linearly up to 120 days. There were significant differences between genotypes with regard to growth characteristics such as leaf area index (LAI), leaf area duration (LAD) for total crop duration and from pod initiation to harvest (LAD′). The mean LAI of genotypes did not vary much at the initial stages. However, during the later stages of growth, the LAI and LAD increased at a much faster rate. The higher biological and seed yields were attributable to high LAD and LAD′, during the later stages of growth. Indeterminate varieties under high plant density and narrow row spacing (50 cm) developed a large leaf area and were presumably able to make better use of light. The varieties also showed higher seed yield under these conditions. This was because of linear increase in total dry matter without a significant reduction in harvest index (HI). HI was the maximum with increased plant population in all sowings. However, it was inversely proportional to biological yield (Singh et al. 1984). The seed yield and pods per plant were reduced 25 and 45%, respectively, in later sowings. Moreover, with equal space (1500 cm^2) provided to each plant, the geometry of 50 × 30 cm gave greater seed yield than 75 × 20 cm. Growth and branching of individual plants were reduced at the higher plant population, but on per unit area basis more dry matter was produced. It is suggested that selection and breeding should be concentrated on improving LAD and LAD', total dry matter per plant, more effective branches, more pods per plant and longer raceme length.

TABLE 1. Performance of genotypes in relation to growth and biological yield in pigeonpea.

	LAI/LAD Date of Sowing				Biological yield (g/plant) Date of Sowing			
	10th June		25th July		10th June		25th July	
Stage	NDT	DT	NDT	DT	NDT	DT	NDT	DT
30 (LAI)	0.453	0.388	0.459	0.414	3.63	3.09	2.65	2.26
30 to pod initiation	12.57	9.48	10.67	6.56	25.65	11.33	11.05	6.80
Pod initiation to harvest	16.71	11.60	11.18	5.33	127.0	94.06	76.06	50.35

NDT = Indeterminate varieties; DT = Determinate varieties.

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Photothermal Regulation of Flowering in Food Legumes and Implications for Screening Germplasm

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TIMES to flowering (f) in the grain legumes vary appreciably between genotypes, locations, seasons and dates of planting. As in most annual crops, timely flowering is important in crop adaptation.

Relative responsiveness to three factors — vernalisation (v), post-vernalisation mean temperature ($\bar{t}$) and photoperiod (p) — modulates rates of progress towards flowering ($1/f$) in those species of food legume responding to photoperiod as quantitative long-day plants (e.g. in *Pisum sativum*, *Vicia faba*, *Lens culinaris*, *Cicer arietinum* and *Lupinus* spp.). Species classified as quantitative short-day plants (e.g. *Glycine max*, *Phaseolus lunatus*, *Phaseolus vulgaris*, *Vigna mungo*, *Vigna radiata* and *Vigna unguiculata*) do not respond to vernalisation but are often acutely sensitive to both photoperiod and mean temperature.

Recent data on diverse genotypes of each of *Vicia faba*, *Lens culinaris* and *Cicer arietinum*, representing the first group, and on *Glycine max*, *Vigna unguiculata* and *Phaseolus vulgaris*, representing the second group, show that simple linear models which relate $1/f$ to v, $\bar{t}$ and p can accurately describe photothermal response surfaces for flowering. The principal features of these response surfaces can be calculated from data collected in just three or four field environments; base temperatures (i.e. the values of $\bar{t}$ when $1/f = o$, or $f = \alpha$) and thermal sums (day degrees above the base temperatures) for flowering can also be easily calculated. It is suggested that these models can lead to a rational selection of field sites for screening germplasm for photoperiod and temperature sensitivity with respect to flowering. The approach advocated, which analyses responses in terms of $1/f$ (instead of the traditional approach, which uses f), removes interactions between temperature and photoperiod and provides a sound basis for the separate genetical analysis of each response.

Effect on Sink Development of Changes in Assimilate Supply During Different Growth Stages of Short-Season Pigeonpea

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PIGEONPEA is an important subsistence crop in the tropics and subtropics of India, Africa, Southeast Asia and the Caribbean. Despite its long history of cultivation and its international importance, there has been relatively little sustained scientific study of pigeonpea production and improvement, and there is little scientific knowledge of the factors influencing seed yield accumulation. The primary objective of this study was to investigate some physiological factors influencing development of seed yield in high density canopies of short-season pigeonpea genotypes.

Three field experiments were carried out at Redland Bay, southeast Queensland (27°S) during three summer seasons between January 1982 and May 1984. These studies used shading (44% transmission) and various modifications of plant exposure (by a number of techniques including the use of reflectors, removal of neighbours and temporary restraining of neighbouring plants) to vary radiation and hence assimilate supply at different growth stages. Plant population was 400 000 pl./ha for the first experiment and 500 000 pl./ha for the second and third experiments. These studies were carried out under optimum inputs of fertiliser, water supply and pest control.

The results indicated that seed yield was independent of changes in dry matter production during the vegetative period, but was related to assimilate supply during either the four weeks following flowering (due to change in seed number) or the later period of reproductive growth (4–8 weeks) (due to changes in seed size). Assimilate supply (S) during the first two weeks following flowering influenced maximum pod number formed (MP) ($MP = -86.28 + 20.85S - 1.03S^2$, $r^2 = 0.86^{**}$). During the second half (2–4 weeks), S influenced the number of earlier formed pods which were retained at maturity $PL = 60.43 - 360.22S + 1101.91S^2$, $r^2 = 0.42^*$, where PL = per cent pod loss). Of these, the period of 2–4 weeks following flowering was more critical for sink development, since in the control crop the number of pods (seeds) produced was in excess of the capacity to fill them at a later stage. This critical period for dry matter production and sink development coincided with the initiation of linear dry weight increase in the earlier formed pods.

The dependence of yield on the number of seed retained at maturity, which also depended on dry matter production during the rapid pod-filling stage, suggested that yield was limited by source supply during this growth period. It would appear, then, that improvement of yield might best be sought by way of improving this supply. It was therefore necessary to develop an understanding of the sources of assimilate which may be available for sink development. Aspects of this work will be discussed in the following paper.

Relationship between Leaf Area, Radiation Interception and Dry Matter Production after Flowering in Short-Season Pigeonpea

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RESULTS described in the previous paper by Thirathon et al. in these proceedings indicated that development of yield in short-season pigeonpea depended on the capacity of the canopy to supply assimilate during the initial rapid pod-filling stage. The study described here aimed to examine, in some detail, the plant and environmental factors which influenced the source production of the canopy during the period between flowering and maturity. Two experiments were carried out in the field at 27°S during January 1983–May 1984.

In the first experiment, removal of leaves from various parts of the canopy indicated that for two genotypes (69–1 and cv. Hunt) maximum crop growth rates (CGR) of 20 and 14 g/m/d during the initial four weeks following flowering were associated with leaf area indices (LAI) of 4.0 and 6.0 respectively, compared to actual LAI in untreated plants of

5.4 for 69-1 and 6.7 for cv. Hunt. Maximum sink production (pod number) was attained with LAI of approximately 3.5–4.0 during the early reproductive period. The overinvestment of dry matter in leaf at this stage, which probably reduced maximum pod number, was associated with greater leaf area duration during the seed filling period. Regardless of LAI at flowering, there was considerable loss of leaf area in the later stage of reproductive growth. While CGR for the control treatment was reduced to 10 g/m/d, the rate in the partially defoliated treatments (46% leaf removal) averaged 27% lower.

The photosynthetic output of the canopy (Ph) and the contribution by various plant parts and layers in line 69-1 were further measured by exposing the canopy to $^{14}CO_2$ of known specific activity during the early (0–4 weeks) and late (4–8 weeks) reproductive periods. A maximum (midday) canopy photosynthesis rate of 1.75 mg $CO_2/m^2/s$ was measured in the 0–4 weeks following flowering, and this fell to 0.86 mg $CO_2/m^2/s$ during weeks 4–8. The reduction in Ph and CGR with time was attributed mainly to reduction in Ph capacity of leaves with age. The maximum leaf Ph rates were 0.53 and 0.31 mg $CO_2/m^2/s$ for the earlier and later stages of growth, respectively.

The accumulation of Ph from the top of the canopy downwards was linearly related to PAR intercepted during both growth periods, but the slope and therefore the Ph efficiency of PAR conversion (4.31×10^{-3} and 3.36×10^{-3} mg CO_2/J, respectively) decreased with age. The similar efficiency of Ph conversion of radiation in all layers of the canopy was associated with light extinction coefficients (K) of 0.35 and 0.84 in the top and low canopies, respectively. The efficiency of dry weight increase per unit of PAR intercepted was 1.62 and 1.18 g/MJ, respectively, for the early and late reproductive periods.

Compensatory Ability of Pigeonpea to a Reduction in Sink Capacity

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PREVIOUS studies described by Thirathon et al. in these proceedings showed that pod number was influenced to a large extent by current assimilate supply, both in the maximum number of pods produced and their survival. Final pod number per plant appeared to adjust to assimilate supply during the four weeks following flowering, such that there was little change in individual seed weight at maturity. This experiment investigated the effect of pod removal at various stages on seed yield and its components.

Two lines, 69-1 and cv. Hunt, were used in this study. Four pod retention treatments (5, 10, 15 and 20 pods per plant) were established at two weeks after flowering, and were maintained by further pod removal for either two or four weeks after the initial treatments.

Manipulation of pod number (sink size) by removal resulted in up to 9% increase in seed size and 24% increase in seeds per pod in the pods remaining. While these findings can be used as evidence of some excess in sink capacity (by way of seed number per pod and seed size) in the control plant, evidence is also provided for a large increase ($y = 0.37 + 0.29x$, $r^2 = 0.99^{**}$) in seed yield with an increase in pod number (increased sink capacity).

The influence of pod number on seed yield occurs not only through the effects on the sink for storage, but also through an influence of the sink as it affects the demand for assimilates. Total above-ground dry matter was linearly related to the number of pods and this suggests that sink demand through pod number may have influenced the photosynthetic capacity of the canopy.

Although it has been suggested, because of its perenniality, that pigeonpea has the capability to continue to produce pods, this capacity has been found to be influenced by the development of the earlier formed pods. The maximum number of green pods obtained was 12 pods for 69-1 in the treatment in which five pods were retained for two weeks. Even if these pods had been allowed to develop to maturity, the increase in final pod number would not have compensated for the initial reduction.

Environmental Stress on Pulse (Legume) Productivity

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AGRICULTURE in Nepal is complex, owing to the diversity of environments. The soils are highly variable, derived mainly from young parental materials of the Himalayan massif. The climate is monsoonal, and water is precarious from November to April where irrigation is not available. The approach is to adopt management practices to conserve moisture and develop varieties tolerant of drought. The latter involves both 'escape', usually through earliness, and plant tolerance of moisture stress. Tolerance is often dependent on a vigorous root system and the ability to go dormant during unfavourable periods. The opposite problem, waterlogging, can also occur, particularly in low-lying areas in summer (Rachie and Bharati 1985).

Most Nepalese soils are comparatively fertile without pH extremes. However, many soils in contrast and delta areas are coarse-textured and naturally droughty, while other areas, especially lowland, are high in clay and subject to waterlogging. The winter legumes, especially grasspea, lentils and chickpea are more or less resistant to drought. Among the summer species, the most drought resistant is pigeonpea by virtue of its deep root system, followed by cowpea and horsegram. The most tolerant to waterlogging are soybean, ricebean, and some variants of cowpea.

The pulses are predominantly grown as associated and relay crops with cereals and oilseeds. Most typical cropping patterns are:

Terai

1. Rice — grasspea + lentil + mustard + linseed
2. Rice — chickpea + lentil + mustard + linseed
3. Maize — chickpea + grasspea + lentil + mustard
4. Rice — rice + mungbean
5. Rice — wheat — mungbean
6. Pigeonpea — fallow
7. Rice + pigeonpea (on bunds)

Hills/Valleys

1. Maize + soybean — mustard
2. Maize + cowpea — mustard
3. Maize/black gram — mustard
4. Rice + soybeans (on bunds)

Symbols denote system

(—) = sequence
(+) = association or intercropping
(/) = relay cropping

Constraints and Status of Improvement

1. Climate/weather: In Nepal much of the influence of climate is related to elevation (topography) and region. Winters are normally cool and dry, while summers (monsoon) are humid. Extremes of rainfall range from about 1.1 to 5.0 m; but the 'norm' is usually 1.4 to 2.0 m. In some areas, hailstorms are devastating to established crops in certain seasons.

2. Soils and topography: Soils of the hills and upland regions are largely derived from young parent materials and classed as inceptisols or alfisols; while the valleys and the terai are mainly sedimentary — sandy or clayey loams. Except where highly leached, eroded or heavily cropped without nutrient replenishment, the soils are productive and range from about pH 5 to 6. Sloping lands are more fragile than level areas and require much greater care in use and management. Major soil-related constraints are droughtiness, or coarse texture, extremes of pH and specific plant nutrient deficiencies, like P, K, Ca or Mo.

3. Biotic constraints: The most important biotic constraints to legume production are plant diseases (including nematodes) and insect pests.

Rachie, K.O. and Bharati, M.P. 1985. A Consultancy Report on Pulses Improvement in Nepal. Integrated Cereal Project, Department of Agriculture.

Section 5

Edaphic Factors

Review of Contributed Papers

Pirmpoon Keerati-Kasikorn *

NUTRITION can be one of the various constraints that limit legume production. There were 15 contributed papers outlining various forms of nutrition constraint. The content could be divided into four areas, viz.:

1. plant responses;
2. factors affecting the responses to nutrients;
3. methods to assess the limits in nutrition;
4. nutrient cycling in a farming system.

Plant Responses

Omission trials have often been used to identify nutrient deficiencies in soils. Keerati-Kasikorn et al. employed this method in northeastern Thai farmers' fields, using peanut as a test crop. Potassium, copper and boron were deficient in Grey Podzolic soil. Potassium and copper deficiencies caused yield reductions of about 50 and 20%, respectively. Boron deficiency did not affect peanut yield but did produce disorder kernels called 'hollow heart'. Similar response of peanut to boron application was reported in Rerkasem et al. A survey of farmers' peanut seeds in Chiang Mai Province (Netsangtip et al.) and Khon Kaen Province (Keerati-Kasikorn et al.) in north and northeast Thailand has confirmed the existence of boron deficiency. More data of this kind are required in terms of sample number in each land form, in each season and throughout the region before any conclusion can be made on the extent of boron deficiency. Yield reduction due to boron deficiency was also found in mungbean and black gram grown in northern Thailand (Rerkasem et al.).

Responses were also reported in soils with unfavourable conditions. Ratanarat et al. found iron deficiency in calcareous soil. Peanut grown in tin-tailing soils responded to organic and inorganic fertilisers (Lim).

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Sensitivity of some species to salt and acidity were investigated in two other papers. Nitrogen fixation in Faba bean was not affected by adding salt at 30 and 60 μg/l (Knobel). Pigeonpea cv. Hunt did not respond to liming, which was applied as high as 4.8 kg/ha (Cowie et al.).

Plant Responses to Nutrients

Species and Cultivars

Species and cultivars have an important role in determining plant response. Mungbean and black gram were more sensitive to boron deficiency than soybean and peanut. Nearly 50% yield reduction was found in the first two species (Rerkasem et al.). Ratanarat et al. compared a number of peanut cultivars grown in a calcareous soil. Tainan 9 was more sensitive to Fe deficiency than Robut 33–1, RCM 387, Natal Common, KAC 253 and KAC 320. Different cultivars of pigeonpea respond differently to Al saturation. Royes was more sensitive than Hunt (Cowie et al.). There was no explanation for these differences. More investigations are required in order to understand this type of interaction.

Microorganisms

Most chemical reactions in soil systems involve microorganisms to some extent. Rhizobia and mycorrhizae play especially important roles in plant nutrition. Ismail reported that applied nitrogen at 60 kg N/ha increased nodule dry weight of mungbean but not the yield. This result indicated that mungbean received an adequate amount of nitrogen through nitrogen fixation.

The role of mycorrhizae in nutrition has been increasingly acknowledged. Jalali reported that phosphorus uptake by chickpea and mungbean from less soluble phosphorus sources was increased in the presence of mycorrhiza. In addition mycorrhiza suppressed the infection of legume pathogens, viz. *Fusarium* and *Rhizoctonia*.

Assessing Limits in Nutrition

Since nutrient deficiencies vary widely with soils and crops, accurate methods for assessing the nutrient status of soils are essential to successful crop growth. Assessment of actual and potential nutrient limitations can be carried out in two ways, viz.

1. diagnosis by plant tissue test;
2. prediction by soil test.

Diagnosis by Plant Tissue Test

PLANT SYMPTOMS

Plant symptoms are the simple indications of any disorder of the plant. Diagnosis of deficiencies by symptoms should be used with caution, because not only can deficiency symptoms be confused with those caused by diseases, but they also vary with plant species and environmental conditions. However, the hollow heart symptom which is specific to boron deficiency, was used to identify the boron-deficient area in the north (Netsangtip et al.; Rerkasem et al.) and northeast (Keerati-Kasikorn) regions of Thailand. The survey undertaken in this way will be correlated with the soil properties from which the samples were taken in an effort to be able to use a soil test to predict potentially boron-deficient soils.

CRITICAL CONCENTRATION

Concentration of nutrients in plant tissue is the most widely used method for identifying nutrient constraint. The critical concentration value is the minimum level of a nutrient element below which deficiency would occur. The critical value varies with various factors such as plant species, plant age and plant parts, and kind of nutrients. Data on the requirements for individual plant species were not presented in the contributed papers to this season. The paper by Bell et al. discusses some problems encountered in the use of critical values. They reported that critical concentration of potassium in peanut and soybean decreased with increasing plant age; the critical zinc concentration for the youngest open leaf of soybean was twice as high as that of the youngest fully expanded leaf (YFEL). Despite these problems, Bell et al. consider that analyses of the YFEL can give a good guide to deficiency diagnosis in food legume crops. Plant part sampled also varies with different nutrients. Youngest folded leaf (YFL) of peanut and youngest opened leaf (YOL) of soybean were the more sensitive for copper (Bell et al.) and boron (Kirk et al.). Youngest fully expanded leaf of peanut and soybean was recommended for establishing values of phosphorus, potassium, sulfur and zinc (Bell et al.).

ENZYME ACTIVITY

Mahmood et al. have attempted to determine the copper status of peanut by measuring the metallo-enzyme, ascorbate oxidase (AO). AO activity measured by O_2 electrode was related to level of copper application. The simple test using a strip containing ascorbic acid was reported to be able to differentiate the copper-adequate plant from the inadequate one. Further work is needed to establish that the response is specific to copper deficiency.

Prediction by Soil Test

Soil tests offer a powerful procedure for predicting the likely occurrence of nutrient deficiencies in crops. However, they must be carefully calibrated with crop production under field conditions. Moreover, appropriate procedures must be devised for each nutrient element and for a given soil. Hiranburana and Chawachati measured the boron content of the northern Thai soils by extracting soluble boron from the soil with hot water. Boron content ranged from 0.13–0.25 μg/g. The sorption characteristics of boron in the soils were determined. To obtain 0.1 μg B/ml in equilibrium soil solution required 0.9–1.8 kg B/ha from external sources. These figures need to be calibrated to plant responses.

Since critical soil test values available in published papers for a given nutrient element vary with various factors such as determination method, plant species and soil type, as well as other factors governing plant growth, a value then is more or less specific for each circumstance. Much more work with soil tests needs to be done in Asian countries to ensure that they can be used with confidence.

Laboratory Analyses

The necessary equipment for plant analysis, as well as for short methods of element determination, has been outlined in Plaskett's paper. It is a very helpful guideline, particularly to the new researcher. This type of information should be extended to the soil test laboratory.

Nutrient Cycling

Hsu and Chin measured the nutrient inputs and outputs of the cropping systems in the Tai Lake region of east China. The net inputs of the nutrients to soil were nitrogen and phosphorus at the rate of 50–200 kg N/ha/yr and 20–65 kg P/ha/yr, respectively.

The net losses through drainage, leaching and crop removal were potassium, calcium and magnesium at 30–140 kg K/ha/yr, 120–280 kg Ca/ha/yr and 50–100 kg Mg/ha/yr respectively; details of the sources and amount of nutrient inputs and losses are not given. However the questions asked in this paper are important to the development of sound agricultural practices in farming systems involving food legumes. In such systems, the long-term fertility is a key component to the stability of the system.

Conclusion

Nutritional constraints do exist in this region. Their magnitude varies with legume species and cultivars grown and with microorganism activities in the soil system. To overcome these constraints and improve legume productivity, reliable methods of diagnosis and prediction using chemical and biological soil tests and plant tissue tests must be employed prior to recommended nutrient application.

Stabilising and sustaining farming systems by maintaining soil fertility can only be made by manipulating the nutrient inputs and outputs, and this depends on detailed data from nutrient cycling studies.

Diagnosis of Nutrient Deficiencies in Peanut and Soybean

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PLANT analysis is widely used for both the diagnosis and prediction of nutrient deficiencies. In this study, standards have been developed for the diagnosis of deficiencies of phosphorus, potassium, sulfur, zinc and copper at defined growth stages in peanut cv. White Spanish and soybean cv. Buchanan.

Peanut and soybean were grown under glasshouse conditions with graded levels of the element under study. Various leaf, petiole and stem tissues were sampled at defined stages of growth; concentration of the element under study was related to shoot dry weight to obtain a critical concentration.

For most elements, the youngest fully expanded leaf blade (YFEL) was satisfactory for deficiency diagnosis, thereby simplifying sampling procedures. However, for reliable diagnosis the following points need to be considered:

a. For particular elements, such as copper and boron (Kirk and Loneragan, these proceedings) younger leaf tissues (youngest open leaf in soybean and youngest folded leaf in peanut) were preferable for deficiency diagnosis.

b. Petioles generally had different nutrient concentrations to leaf blades and should be excluded from tissues sampled.

c. Critical concentrations can vary between successive leaves. In soybean, critical zinc concentrations varied twofold between the YFEL (6 μg/g on day 35) and the next youngest leaf (12 μg/g). Critical concentrations of phosphorus and potassium also exhibited substantial variation with leaf age. Variation in critical concentrations between the YFEL and the next oldest leaf was less of a problem for sampling, but in the field these older leaves are less valuable as they are more likely to suffer insect damage. Thus, careful sampling according to defined leaf age is necessary.

d. For potassium, a marked decline in critical concentrations in the YFEL was obtained for both peanut and soybean with increasing plant age. In soybean, the decline in critical potassium concentration (2.0–2.2% at day 26 to 0.35–0.4% at day 55) was not related to stage of development, as it occurred in plants which flowered and set pods as well as in plants which remained vegetative throughout the experiment.

Standards developed for deficiency diagnosis are now being evaluated in field grown peanut and soybean in Thailand.

Responses of Pigeonpea to Lime on an Oxisol in Fiji

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NUTRITIONAL problems associated with soil acidity are common in the highly weathered soils of the tropics. The low productivity of the 'Talasiga' soils of Fiji (acidic Oxisols) is possibly due to Al toxicity associated with low pH (Rayment and Wallis 1981). Although pigeonpea is reputed to have low fertility requirements, its tolerance of Al was unknown (Whiteman et al. 1985).

Five different lime rates up to 4.8 t/ha $CaCO_3$, were incorporated to 10, 20 and 30 cm three months prior to sowing pigeonpea cv. Hunt, an early-maturing photoperiod-insensitive line. At sowing, 40 kg P/ha as triple superphosphate was broadcast and 20 kg P, 10 kg Mg, 2 kg Zn, 250 g B and 100 g Mo/ha was banded beside the seed. Six weeks after sowing, 50 kg K/ha was broadcast.

The soil had an initial pH (1:5 soil/HO_2O) of 5.1, an effective cation exchange capacity (ECEC) below 30 mmol (p^+)/kg, and Al saturation of about 45% of the ECEC at the surface, rising to 60% at 30 cm. The highest lime rate increased pH to 5.8 and reduced the Al saturation in the top 20 cm to about 5%.

Vegetative yields at flowering were increased slightly by liming (Table 1). Excessive flower drop during abnormally prolonged flowering period resulted in widely varied seed yields within each treatment, from which no meaningful assessment of the seed response to lime was possible. Vegetative yields at maturity were not affected by lime and exceeded 6 t/ha in all treatments.

Root systems were normal, with tap root penetration to at least 20 cm and primary laterals penetrating past 40 cm in all treatments. In contrast, an earlier trial using cv. 'Royes' (Cowie unpublished) showed a strong inverse relationship between root penetration and Al saturation; many plants had truncated root systems and no tap root development. In nearby commercial fields, 58% of Royes and 95% of Hunt showed normal tap root development.

Thus, the pigeonpea Hunt is particularly tolerant of Al, producing good vegetative growth at Al saturations in excess of 45% of the ECEC. Other observations have indicated that cv. Royes is less tolerant. On acid soils high in Al, cv. Hunt may be less susceptible than cv. Royes to moisture and nutrient stresses, because of more extensive root exploration.

TABLE 1. Effect of lime on vegetative yields at flowering (g/m dry matter).

Incorporation Depth (cm)	Lime rate (t/ha) 0	0.4	0.8	1.6	3.2	4.8	$\bar{x}$
10	330 (49)[A]	339 (25)	334 (25)	349 (35)	364 (4)	338 (1)	350
20	311 (40)	402	379	398	412	381 (7)	380
30	314 (47)	334 (33)	317 (39)	367 (21)	369 (15)	367 (5)	345
$\bar{x}$	318	358	343	371	381	377	
Depth 5% LSD = 23			Rate 5% LSD = 43			Depth × Rate N.S.	

[A] Aluminium saturations (% of ECEC 0-10cm) at sowing, where available.

Rayment, G.E. and Wallis, E.S. 1981. A report to the Native Land Development Corp., Aug. 1981, p.62.
Whiteman, P.C., Byth, D.E. and Wallis, E.S. 1985. In: Summerfield, R.S., and Roberts, E.H., ed., Grain Legume Crops, London, Collins, Chapter 15.

Boron Status and Sorption Characteristics of Selected Soils in Northern Thailand

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According to an international study by the FAO (Sillanpaa 1982), boron status of soils in Thailand appears to be low. We have found further evidence of low boron levels in soils of northern Thailand. The present study examined hot water soluble boron (HWSB) levels and boron sorption characteristics of ten selected soil series of importance in the lowlands and uplands of northern Thailand. Soils were chosen to give a wide range of characteristics which might affect boron status such as texture, minerology, soil pH and organic matter.

HWSB and boron sorption isotherms were determined using the methods of Dible and Berger (1952) and Sims and Bingham (1967), respectively. An alternative method was developed for estimating boron sorption capacity and boron fertiliser requirements. Graded amounts of added boron were incubated with soil at field capacity for up to 30 days. Then a hot water extract was measured for boron. Characteristic curves relating amounts of added boron to levels of HWSB were constructed for each soil.

HWSB levels in ten soil series from northern Thailand were all low (0.13 to 0.25 μg/g in surface soil). Boron levels in this range may limit plant growth especially in sensitive crops. Boron sorption studies suggest a minimum fertiliser boron requirement of 0.9–1.8 kg/ha to raise equilibrium soil solution boron concentration to 0.1 μg/ml. From incubation studies, lower boron requirements were estimated (0.35–1.02 kg/ha of element boron to raise hot water extractable boron levels to 0.3 μg/g). These estimates of plant boron requirements are now being tested in field experiments with legumes.

Further studies should investigate effects of soil texture, soil pH, organic matter, clay content, soluble salts and cations (Ca, Mn, Fe, Al) on boron availability in these soils.

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Sillanpaa, M. 1982. FAO Soils Bulletin 48.
Sims, J.R. and Bingham, F.T. 1967. Soil Sci. Soc. Amer. Proc., 31, 728–32.

Nutrient Balance of Important Cropping Systems in the Tai Lake Region, China

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In the Tai Lake region of east China, important cropping systems are the double cropping of wheat followed by rice and the triple cropping of barley (or naked barley) followed by two crops of rice. They have long been widely adopted in this region, but nutrient cycling in these cropping systems is not known. In order to obtain nutrient balance sheets, we measured nutrient inputs from precipitation, irrigation, seeding or transplanting and fertilisation, and nutrient losses from drainage, leaching and crop removal. Samples were analysed for nitrogen, phosphorus, potassium, calcium, magnesium and sulfur. Field experiments were carried out on three paddy soils (permeable, stagnating, and waterlogged) with each of the two cropping systems beginning in 1982.

It was found that the balances of N, P, K and Mg were quite different from those of Ca and S, which were predominantly influenced by the hydrologic cycling. And the balances for the double cropping system were similar to those for the triple although the input and output of nutrients in the two systems were different in magnitude. The net inputs to the soil nutrient pool were 50–200 kg N/ha/year and 20–65 kg P/ha/year, and the net losses were 30–140 kg K/ha/year, 120–280 kg Ca/ha/year and 50–100 kg Mg/ha/year. There was little net change in the soil sulfur pool except for losses in the most permeable of the paddy soils.

Relevance of V-A Mycorrhizal System in Increasing Crop Productivity in Legume Crops

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Increased nutrient uptake (particulary phosphorus) by mycorrhizal fungi in symbiotic associations with the roots of most legume crops has potential for increasing crop productivity of low fertility soils. Our studies on the uptake of P from low-solubility sources by mycorrhizal plants have been carried out in the hope that mycorrhizal infection may render such sources of P readily available to the host plants. While testing the ability of chickpea and mungbean to utilise different sources of less-available P, it was observed that plants grown in nutrient-deficient soils (particularly P-deficient) responded significantly to rock-phosphate + VA mycorrhizal treatments, in terms of total dry matter production and P-uptake. This could be attributed largely to the greater physical contact between P-particles and hyphae than between host roots and P-particles; it was less attributable to the fungal endophyte directly dissolving the particles.

TABLE 1. The effects of soil type, mycorrhizal inoculation and rock-phosphate on root and shoot dry weights (mg/plant) in chickpea.

	Root dry weight				Shoot dry weight			
Soil type	S1	S2	S3	Mean	S1	S2	S3	Mean
Treatment								
MYC + RP	184	222	130	176	1986	1774	1298	1686
RP	141	219	56	139	1336	1765	892	1331
Nil	118	179	57	118	873	1454	1117	1147
S.E.				2.78				126.07
Mean	148	207	81		1480	1664	1021	
S.E.		1.31		1.31		72.78		72.78

S1 & S2 — sterilised and unsterilised P-deficient soils respectively;
S3 — unsterilised P-rich soil; MYC — mycorrhizal inoculation;
RP — rock phosphate.

Mycorrhizal plants were found to remain functional longer than non-mycorrhizal ones, and less susceptible to certain types of pathogenic infections. Our studies demonstrated that mycorrhizal inoculations resulted in significant reductions in the host infection by *Fusarium* and *Rhizoctonia*. Drastic growth suppression of *F. oxysporum* f.sp. *ciceri* occurred in chickpea plants inoculated with the V-A mycorrhizal fungus, *Glomus* sp. Similar response was found with *Rhizoctonia solani* when chickpea was seed-pelleted with sporocarps of the mycorrhizal endophyte. The ability of the mycorrhizal plant to develop in the absence of available soil phosphate was directly related to the suppression of infection by the pathogenic fungi.

Selection of the efficient strains of endophyte is critical to the development of mycorrhizal fungi for use in agricultural technology.

Nutrient Deficiencies Affecting Peanut Production in Soils of Northeast Thailand

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PEANUT is widely grown in the rainy season on upland soils (mostly Paleustults) in northeast Thailand. The nutrient status of these soils for peanut production has not been adequately assessed. Response to phosphorus, potassium, sulfur, and copper on a range of soil types of this region have been obtained in pot trials using pasture legumes (Wilaipon 1976). The present experiments were set up to identify nutrient deficiencies which could limit yield and kernel quality of peanut on an Oxic Paleustult (Khorat series).

Four omission design field trials were conducted in Khon Kaen province on three farmers' fields. At site 1, peanut was planted on the same plot in two successive years. Young folded and youngest fully expanded leaves were sampled at around day 30 and day 50 after emergence for nutrient analysis. Pod, kernel, and shoot dry matter yield as well as yield components were recorded at maturity. The percentage of kernels with hollow heart symptoms was also determined.

In the first year of planting, no yield responses were obtained at any of the three sites. Replanting at site 1 in year two without added potassium resulted in a 48% yield reduction. Yield of the unfertilised peanuts in year two was similar to those grown without added potassium. Yield reductions of 20% were found when plants were grown without added copper, however significant reductions ($P = 0.05$) were obtained at one site only. Leaf analyses showed that copper concentrations in young leaves were suppressed in the presence of basal fertilisers. This could be corrected by copper foliar sprays. Peanuts grown without added molybdenum appeared yellowish in foliage colour and had low leaf and shoot nitrogen concentrations.

Without added boron, hollow heart was found at site 1, in 9 and 34% of kernels in years one and two, respectively. Peanut kernels sampled from farmers' fields in the rainy season also exhibited hollow heart in 315 samples obtained from six villages in Khon Kaen province (hollow heart incidence ranged from 1 to 75%). Severe hollow heart incidence (>5% of kernels affected) was found at only 12 of those sites.

Based on two years experiments, it is concluded that potassium, copper, boron and molybdenum deficiencies may limit peanut production in an Oxic Paleustult in northeastern Thailand. More detailed surveys of farmers' peanut crops are needed to determine the distribution and severity of these deficiencies.

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Boron Deficiency in Soybean and Peanut

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PEANUTS grown in the Chiang Mai region of Thailand produce kernels with a high incidence of hollow heart (Netsangtip et al., these proceedings), a disorder corrected by applications of boron. Soils in this region have very low levels of hot water soluble boron (Hiranburana and Chawachati, these proceedings). Hollow heart has also been reported from the Khon Kaen region and it appears likely that boron deficiency may limit the production of peanuts in extensive areas of northern Thailand. This work aims to develop plant analysis standards for the diagnosis of boron deficiency in peanut and soybean, two potentially important food legumes in Thailand.

Boron concentrations in leaves of both species vary with leaf age. In marginally deficient plants, older leaves may contain twice the boron concentration of young leaves (Table 1). Consequently for diagnostic purposes it is important to sample leaves at a defined stage of leaf development.

The most sensitive leaf for boron deficiency diagnosis is the youngest open leaf (YOL) in soybean and the young folded leaf (YFL) in peanut. In the varieties used in this work, vegetative growth was depressed when boron concentration in these tissues fell below 7–8 $\mu g/g$ dry wt. and 3–5 $\mu g/g$ dry wt., respectively. However, specific plant functions such as leaf elongation in soybean are impaired at much higher leaf boron concentrations. Investigations are proceeding to define a functional boron concentration for peanut and soybean.

TABLE 1. Effect of leaf age on B concentration ($\mu g/g$) in leaves of marginally deficient and B adequate soybeans and peanuts. Soybean cv. Buchanan 28 days old. Peanut cv. White Spanish 30 days old.

	Soybean		Peanut	
	YOL	YOL + 2[A]	YFL	YFL + 2[B]
B deficient (80% max dry wt.)	4.9	8.1	1.8	4.7
B adequate	31.3	37.5	35.1	30.3

[A] YOL + 2: leaf which is 2 leaves more mature than YOL.
[B] YFL + 2: leaf which is 2 leaves more mature than YFL.

Influence of Salt Stress on the Development of Nodules of Food Legumes

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UNDER saline conditions, bean plant growth yield is decreased and nodulation is reduced causing a restricted nitrogen fixation (Bernstein and Ogata 1966; Wilson 1970; Balasubramanian and Shinha 1976), although there may be differences in the effect of *Rhizobium* strains on nodulation under different levels of salinity (Islam and Ghoulam 1981).

To investigate the effect of different levels of salt concentrations, a pot trial was set up with two varieties of *Vicia faba major* (Trio, Con Amore) and one variety of *V.f. minor* (Kleine Skladia) in two soils differing in organic matter content.

The salt — NaCl — was applied in three levels (0-30-60 meq/l) after emergence. The nodule development was determined over six harvests which were made at intervals of two weeks. At every harvest the dry weights of different plant organs and the number of nodules were recorded. The dates for plant DM, nodule number, nodule weight and plant N concentration are shown for the last harvest in Table 1.

TABLE 1. Effect of different salt levels of three *Vicia faba* varieties in two soils differing in organic matter content.

	Kleine Skadia			Trio			Con Amore		
Salt levels:	0	30	60	0	30	60	0	30	60
				High organic matter soil					
Plant DM (g)	39[A]	38	33	42	37	34	33	35	38
Nodule Number	384	207	165	194	228	280	111	189	215
Nodule Weight (g/plant)	.65	.55	.77	.68	.56	.61	.57	.45	.57
Plant N concn (%)	3.1	3.1	3.2	2.8	3.0	3.0	3.0	3.1	3.0
				Low organic material soil					
Plant DM (g)	42	34	24	38	33	28	27	28	23
Nodule Number	91	142	91	82	172	119	24	171	61
Nodule Weight (g/plant)	.74	.63	.78	.40	.28	.45	.19	.44	.30
Plant N concn (%)	2.8	3.0	3.1	3.1	3.0	3.1	3.0	3.0	3.1

[A]: LSD (P = 0.05): Plant DM 10; Nodule number 144; Nodule weight 0.31.

The number of nodules increased until the beginning of the pod-filling phase, regardless of salt treatments and soil types. A reduction in the number of nodules due to salt treatment was apparent only in the first harvests. At the final harvest both the number of nodules and their dry weight were higher in salt treated plants than in the control. The number of nodules but not their dry weight was found to be affected by different soils. At the final harvest, salt levels reduced plant DM of Kleine Skladia and Trio on both soils with a more pronounced effect on the low organic matter soil. Con Amore yields were unaffected by salt levels on both soils.

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Production of Groundnuts on Tin-tailing Soils in Malaysia

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An estimated 200 000 hectares of wasteland has resulted from tin mining operations in Malaysia. These tin-tailing soils are mainly of sand texture and have very poor physical characteristics and nutritional status. The rehabilitation of such soils would provide additional area for crop production.

The productivity of the sand tailing was investigated for the cropping of groundnuts. Supplements in the form of fertilisers (12 N:12 P_2O_5:17 K_2O: 2 Mg 0 + trace elements) at 400 kg/ha and chicken manure at 10 t/ha were applied. Comparisons were made between the untreated tin-tailings and tailings supplemented with inorganic fertiliser or chicken manure or both, and with loam soil supplemented with inorganic fertiliser.

TABLE 1. Effect of fertiliser and chicken manure on the growth and yield of groundnut on tin-tailing soil and a loam soil.

Treatment to tin-tailing soil	Height cm	Branches per plant	Dry matter g/plant	Pod no. per plant	Pod yield g/plant	Shelling per cent
Untreated tin-tailing (TT)	11.6	0.45	1.4	2.0	1.2	67.0
(TT) + fertiliser (F)	27.2	3.2	12.8	11.3	10.3	76.2
(TT) + chicken manure (CM)	33.4	4.3	20.9	20.6	20.6	76.6
(TT) + (F) + (CM)	38.9	4.55	21.1	22.9	23.4	74.9
Loam soil + fertiliser	30.8	4.95	33.8	33.0	33.3	78.1
LSD P-0.05	4.9	0.65	4.8	5.3	4.6	2.7

The growth and yield of groundnuts improved significantly with the use of inorganic or organic supplements. The improvement was seen in the increased size of plants (height, number of branches and dry matter) which resulted in higher production of pods (number, weight and shelling percentage). The untreated tin-tailing soil was unsuitable for growing groundnuts and the plants only managed to survive. Inorganic fertiliser was not as effective as chicken manure. The beneficial effect of chicken manure was such that no further growth and yield response was obtained with further supplement of the inorganic fertiliser. However, in spite of the improvements achieved with the addition of chicken manure, the growth and productivity of the groundnut plants were still poorer than that of loam soil. Further investigations are necessary in order that groundnut yields on tin-tailing soils can be brought to the level of normal soils.

Ascorbate Oxidase Activity in Peanut: Relation to Copper and Growth

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The copper metallo-enzyme, ascorbate oxidase (AO), has been used as an indicator of plant copper status in citrus (Bar-Akiva et al. 1969) and subterranean clover (Loneragan et al. 1982). In the present study, the activity of AO in peanut cv. White Spanish was examined in relation to copper supply, plant growth and tissue copper concentration.

AO activity was measured on crude leaf homogenates (extracted in 67 mM KH_2PO_4; 3 mM Na_2EDTA) using an O_2 electrode. A simplified semi-quantitative procedure for measuring AO activity was also developed using a test strip to determine the concentration of ascorbic acid remaining in the assay mixture after a 20 min. incubation period. For AO assays, the youngest folded leaf (YFL) was sampled when blade length was 50–100% of the length of the enclosing stipules.

AO activity increased substantially with increasing copper supply in peanut (Table 1). Increases in AO activity were closely related to increases in shoot yield and in pod number per plant. Reduced growth in peanut was associated with < 1.7 $\mu g/g$ copper in the youngest open leaf, the critical concentration reported by Robson et al. (1980). AO was more responsive to increasing copper supply than copper concentration in the youngest open leaf. The strip test for AO activity was effective in differentiating between copper-deficient and copper-adequate peanuts. Further studies are required to determine the specificity of AO activity for copper supply.

TABLE 1. Effect of copper supply on growth, leaf copper concentration and leaf AO activity in peanut.

Cu supply (mg/pot)	Shoot yield (g/pot)	Pod no./ plant	Cu conc. (μg/g)	AO activity in YFL	
				O_2 uptake (nmol/leaf/min)	Strip test (μg/ml)
0	13.7	3.8	1.3	47	900
300	13.2	3.6	1.6	33	850
1000	17.3	4.7	2.0	134	250
3000	17.5	5.8	3.8	360	150
SE	0.4	0.3	0.3	27	150

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A Field Survey of Boron Deficiency in Peanuts Grown in the Chiang Mai Valley

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HOLLOW heart is a boron-specific disorder of peanut kernels (Cox and Reid 1964) which renders the crop especially sensitive to boron deficiency. Using the incidence of hollow heart as an indicator of boron deficiency, a survey of farmers' peanut crops in the Chiang Mai valley was conducted in the dry season 1985. Sites were widely distributed in the Chiang Mai valley and surrounding uplands, including 88 locations in seven districts. The percentage of kernels with hollow heart was determined by visual assessment and samples were rated according to severity of the disorder, as follows:

Nil — zero kernels with hollow heart;
Mild — 0.1-5.0%;
Severe — 5.1-20%;
Very severe — >20%

Hollow heart was found in peanut kernels from half the sites and rated as severe at 32% of sites surveyed (Table 1). A high incidence of hollow heart was found in Hang Dong (80%), Doi Saket (38%) and San Kamphaeng (31%), the districts where most intensive sampling took place. Upland sites had a higher incidence of hollow heart (85% of sites) than the lowland sites (40%). Kernels with hollow heart contained <13 μg/g boron.

These results, together with studies on the boron status of major soil series in northern Thailand (Hiranburana and Chawachati, these proceedings), suggest that boron deficiency may be widespread in northern Thailand. Further research should now define soil and environmental factors associated with boron deficiency in peanut and other crops and develop fertiliser practices for correction of the deficiency.

TABLE 1. Number of sites in the Chiang Mai valley at which hollow heart disorder was observed in peanut kernels from farmers' fields. (Lowland sites <350 m elevation).

	Severity of hollow heart			
	Nil	Mild	Severe	V. Severe
Lowlands	41	11	13	3
Uplands	3	5	10	2
All Sites	44	16	23	5

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Effects of Applied Nitrogen and Detopping on Seed Yield of Mungbean

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In soybean and chickpea, nitrogen fixation declines rapidly during pod-filling stage of plant growth (Lawn and Brun 1974; Evans 1982). In pigeonpea, removal of plant apices promotes branching (Tayo 1982), and this in turn is expected to increase the sites of flower bud formation. It is often assumed that nitrogen application at early flowering stage and detopping increase seed yields of food legumes, but there is little experimental evidence to test this claim.

Our experiment with mungbean (*Vigna radiata* (L) cv. CES 28) indicated that nitrogen application (60 kg N/ha) at the vegetative, flowering or pod-filling stage had little effect on seed yields and pod number/plant. However, applied nitrogen generally increased nodule dry weight/plant, in uncut and detopped crops, compared with the unfertilised control (0 kg N/ha). Detopping (50% defoliation) at 1.5 months after planting caused a 35% reduction in seed yield compared with the uncut control, but it had no effect on nodule dry weight (Table 1).

TABLE 1. Seed yields, number of pods per plant and nodule dry weight of mungbean following nitrogen application (kg N/ha) and detopping.

Data Collection	Time of N application (plant growth stage)	Control (Uncut)		Detopped	
		0 kg N	60 kg N	0 kg N	60 kg N
Seed yield (kg/ha)	Vegetative	586	529	272	277
	Flowering	476	470	306	305
	Pod-filling	414	470	463	354
No. of pods/ plant	Vegetative	20.1	12.2	7.8	12.4
	Flowering	12.7	9.3	8.5	7.7
	Pod-filling	11.8	12.3	11.8	7.7
Nodule dry weight (mg/plant)	Vegetative	22.8	21.5	24.5	17.8
	Flowering	19.8	27.0	17.3	24.0
	Pod-filling	20.8	28.5	16.5	23.3

Treatments	LSD's (P = 0.05)		
	Seed yields	No. of pods	Nodule D.Wt
Rates of N	104	9.7	6.2
Time of N application	99	17.6	10.4
Detopping	152	35.6	13.7

It appears that inorganic nitrogen, irrespective of time of application, contributes very little to pod production and final seed yields. Whether mungbeans (or other food legumes) are dependent on symbiotic nitrogen during pod-filling and for seed production needs further investigation.

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Analytical Techniques for Elemental Analysis in Plant Tissues

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A scheme is shown for routine analysis of plant material in a laboratory with a minimum of analytical instrumentation for N, S, Ca, Mg, K, B, Fe, Cu, Mn, Zn, Mo, Co. The basic requirements are:

a. Aluminum block digestor for nitrogen
b. Aluminium frypans for wet ashing procedures
c. Muffle furnace for dry ashing
d. Erlenmeyer flasks with Schoniger stopper for sulfur combustion

e. UV/VIS spectrophotometer for colorimetric and turbimetric analysis
f. Atomic absorption spectrophotometer (AAS) with graphite furnace attachment and background corrector
g. A top loading balance (capable of weighing 1 mg)
h. A microcomputer is an additional option for data handling and manipulation.

A Kjeldahl digestion is used for colorimetric N analysis. B and P also use colorimetric analysis following a dry ashing procedure which can subsequently be used for K, Ca, Mg, Fe, Mn, Cu and Zn analysis by flame AAS.

Separate wet ashing digests are necessary for Co and Mo, which are then solvent-extracted for graphite furnace AAS. Turbimetric sulfate analysis follows a combustion method using a Schoniger oxygen flask assembly.

This laboratory has interfaced a microcomputer to both the AAS and the UV/VIS spectrophotometer. The instruments are operated manually, and data files that have been stored on floppy disc are automatically called and processed with calibrations and reagent blank corrections. On completion of a sample run, the results can be printed out or stored on floppy disc for further statistical analysis.

Hence, by careful selection of analytical techniques all elements shown can be analysed on a sample size of 1600 mg.

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Iron Deficiency in Peanut on Black Calcareous Soils

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BLACK calcareous soils of Thailand (Rendzinas or Calciustolls) occupy 500 000 ha and are located mostly on the highlands of central and northern areas of the country. These soils are considered quite fertile, but leaf chlorosis resembling iron deficiency occurs quite commonly in peanuts, although patchy in distribution.

We have examined the response of peanut cv. Tainan 9 to soil and foliar iron applications on a Takli series soil (pH 7.9, clay 47%, organic matter 2.9%, exchangeable Ca 150 meq/100 g soil, DPTA extractable Fe 2.4 μg/g). At the same field site, 17 peanut cultivars were screened for iron efficiency in relation to three local cultivars (Tainan 9, Sukothai 38 and Lampang).

Peanut cv. Tainan 9 exhibited severe chlorosis when grown without added iron, and kernel yields were reduced from 930 to 680 kg/ha. The degree of iron deficiency was uneven in this experiment with a decrease in severity along a gradient from replicate 1 to 4. Mean kernel yield increased along this gradient from 750 to 1169 kg/ha.

Foliar iron sprays (0.5% $FeSO_4$ in 0.25% Tween 80), applied every 7 days from 10 days after emergence, increased top yields of peanut cv. Tainan 9 from 975 to 4660 kg/ha and pod yields from 162 to 975 kg/ha. Shelling percentage increased from 30% in unsprayed plants to 49% in plants sprayed every 7 days.

Iron chlorosis was evident in all 20 peanut cultivars examined, although the degree of chlorosis varied. Cultivars with low chlorosis scores tended to produce higher kernel yields. Three Thai peanut cultivars exhibited high chlorosis scores and low kernel yield relative to most other cultivars. Five cultivars (Robut 33-1, RCM 387, Natal Common, KAC 253, KAC 320) were significantly more iron-efficient than Tainan 9 and produced two to three times higher kernel yields.

Iron deficiency on black calcareous soils of the central and northern highlands severely restricts growth and yield of peanut cultivars recommended for use in Thailand. Foliar application of $FeSO_4$ (0.5% w/v with 0.25% Tween 80) at 7-15 day intervals from 10 days after emergence was partially effective in correcting iron deficiency. Some introduced peanut cultivars of Virginia and Valencia types seem to be more adaptable to iron-deficient soils than the recommended Valencia peanut cultivars. Further introduction of iron-efficient peanut germplasm should be undertaken.

Boron Deficiency in Grain Legumes

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Low levels of hot water soluble boron (Hiranburana and Chawachati, these proceedings) have been found in many series of the major soils of northern Thailand. Boron deficiency has been identified in farmers' peanut crops throughout the Chiang Mai Valley (Netsangtip et al., these proceedings). However, the four major food legumes of northern Thailand — green gram, black gram, soybean and peanut — have been found to differ significantly in their response to boron deficiency.

In a soil of San Sai series (coarse-loamy, mixed, isohyperthermic, Typic Tropaqualf) in which sunflower yield was markedly reduced by boron deficiency (Rerkasem, in press) the yields of black gram and green gram were also reduced; but no yield response has been observed in soybean and peanuts (Table 1).

TABLE 1. Effects of boron application on the yield and some yield attributes of four legumes.

a. Black gram, soybean and peanuts.

Borax (kg/ha)	Grain yield (g/m^2)			% Hollow heart in peanut	Boron in peanut kernels ($\mu g/g$)
	Soybean	Peanut	Black gram		
0	166	120	78	34	13.2
10	182	138	145	0	23.3
20	149	147	130	0	25.0
40	149	116	130	0	24.4
LSD (P = 0.05)	58	58	58	—	2.2

b. Green gram.

Dry matter and yield components	Borax applied (kg/ha)		Significant difference
	0	10	
Dry matter (g/m^2)	169	311	*
Pod bearing (nodes/plant)	4.5	8.0	*
Pods/plant	7.1	13.1	*
Pod size (seeds/pod)	8.8	13.0	*

Deficiency symptoms in green gram and black gram included chlorosis of leaf margins, shortened internodes and inhibited reproductive development. Although peanut showed no yield response, without added boron a large proportion of the kernels exhibited the hollow heart, a disorder specific to boron deficiency. The incidence of hollow heart correlated very closely with boron concentration in the kernels.

Section 6

Nitrogen Fixation

Review of Contributed Papers

R.J. Roughley *

NINETEEN papers dealing with N_2 fixation were contributed to the working group. They could be classified into eight broad groups dealing with: determining the need to inoculate, strain selection, host x strain interactions, seed inoculation technology, population dynamics of rhizobia in soil, environmental effects on nodulation and nodule physiology, methods of measuring nitrogen fixation, and the contribution of legumes to the nitrogen economy of soils.

This arrangement of the papers demonstrated that within this region, research in an integrated program of N_2 fixation and utilisation ranges from the very first steps to the final stages of measuring the contribution of the legume to the agro-ecosystem. It is surprising that no papers were submitted dealing with inoculant manufacture, as Asia has no source of the high quality inoculants crucial to the success of, for example, introducing soybeans in new areas.

Is Inoculation Necessary?

Sundram et al. answer this, the first necessary question to ask, with evidence from studies with groundnuts in Malaysia. In new areas inoculation was necessary, but where groundnut had been grown previously there was no response.

Strain Selection and Host x Strain Interactions

Six papers were submitted, five of which dealt with soybeans. Paterno et al. followed the natural progression of first establishing the need for inoculation at some sites in the Philippines and then reporting on experiments at two sites to select effective, competitive strains. They obtained yield increases between 18-50% and a nodule occupancy between 67-99% with four strains; one was less competitive (36-40% nodule occupancy). Faizah also reported that in a comparison of 10 strains at three sites, inoculation increased yield.

A warning about host specificity within the genus *Glycine* is given by Brockwell and Gault. They inoculated two cultivars of *G. max* and three of *G. soja* with four soybean rhizobia (three *Bradyrhizobium japonicum* and one *Rhizobium fredii*) and one cowpea strain. Reactions on *G. max* differed from those on the three *G. soja* cultivars, which all differed from one another. No two strains of rhizobia behaved alike. The authors point out that this diversity is available for breeders to exploit.

Breeders at IITA displayed in their conference poster how they have in fact used this diversity to exploit the promiscuity of local soybean lines compared with specific lines from the USA, and successfully avoided the need to inoculate soybeans. To determine whether this option was a possibility in northern Thailand, Thompson et al. sowed trap hosts of cowpeas, *G. soja*, and local and U.S. lines of *G. max* and cowpea at 25 sites. All isolates made from the resulting nodules would nodulate all hosts, but they need further testing to determine their relative effectiveness. There may be a price to pay for this option, as Lumyong and Thongtoa found traditional Thailand cultivars fixed more nitrogen with rhizobia selected by the developed lines SJ4 and SJ5 than with local cowpea-type rhizobia.

I believe that the opposing strategies, viz. whether to breed for specificity or promiscuity for soybeans in Thailand, are still open to question. The answer must consider local conditions for the manufacture and distribution of inoculants and the level of farming sophistication. Further work is still needed.

The host x strain interactions found with soybeans were also demonstrated in pigeonpea by Kimani. He tested 12 genotypes with four strains of rhizobia, finding inoculation not only increased yield but also reduced time to flowering and maturity.

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Technology of Seed Inoculation

Seed inoculation is the most common means of introducing rhizobia into soil. Its effectiveness is affected by the amount of peat which adheres to the seed and the number of rhizobia surviving the period between inoculation and the development of a seedling rhizosphere. Boonkerd et al. compared six adhesives, including water. Synthetic glue and gum arabic, two widely used adhesives, were both excellent adhesives and protectants of rhizobia. Water, likely to be the most common adhesive used, was the poorest of all.

Coating materials such as lime have been widely used to encapsulate rhizobia on seed, thus separating them from acid soils and providing extra protection when aerially sowing or broadcasting pasture seed. Lu Shang-Ling et al. pelleted seed of *Astragalus sinicus* and groundnut with calcium carbonate or calcium magnesium sulfate and 1–3% ammonium molybdate. Survival of rhizobia, plant establishment, nodulation and yield were increased by seed pelleting.

Groundnut and other food legumes are not usually pelleted because of likely seed damage and further, groundnut seed in many countries is often treated with toxic agrochemicals.

Ecology of *Bradyrhizobium japonicum* in Soil

Competition between the inoculum and the rhizobia already in the soil is a major constraint to establishing elite strains of rhizobia in many soils. We still have only a rudimentary understanding of what makes a strain competitive. The inoculum potential is important, but few studies have followed the fate of inoculant strains in the period between sowing and nodulation in field soils.

Roughley et al. followed changes in numbers of soybean rhizobia in soils either free of these rhizobia and/or where a resident population was established. In the absence of rhizobia, numbers initially declined but later increased in the rhizosphere, and following nodule breakdown reached $\log_{10}$ 14.39/ha 12 months after sowing.

Where rhizobia were already present in soil they dominated the developing rhizosphere, but the proportion of nodules formed by the inoculum was greater than its rhizosphere representation. Perhaps strategic placement of inoculant may give the introduced strains an early advantage.

Environmental Effects

Of all constraints on nitrogen fixation, environmental effects have perhaps been most widely studied, particularly the effect of temperature and the phosphorus status of soil. The physical effects of daylength and flooding are relatively neglected, and in the tropics ephemeral flooding may be particularly significant.

Physical Effects

Sangakkara reports on the effect of flooding on nodulation and nodule function of *Phaseolus*, cowpea, mungbean and *Crotalaria juncea*.

Nodulation of *Phaseolus* and *Crotalaria*, although reduced by flooding, was least affected; mungbeans were particularly sensitive. Follow-up studies to increase our understanding of the causes of these effects are required.

Wesselmann found early nodulation of *Lathyrus* varied directly with daylength but the nodules senesced earlier. Long days increased N_2 fixation and yield, but as the effect is host-determined, no generalities can be drawn.

Nutrition

Information on the effect of nutrient deficiencies on legumes is usually directed at the plant. O'Hara et al. reported on the sulfur nutrition of vegetative and bacteroid forms of rhizobia. While sulfur limited *Bradyrhizobium japonicum* and *B.* sp. from groundnut in culture, bacteroids isolated from nodules on roots and sulfur-deficient plants were not deficient, indicating adequate sulfur supply in these nodules.

The interaction between soil N, fertiliser N and fixed N is the subject of an ever-growing number of papers. As Sangakkara and Cho point out, the interaction varies with the species and its environment. However as Herridge's results show, the interaction is even more specific, varying widely between introductions of soybeans. Thus, while Sangakkara and Cho draw attention to differences between soybeans and lentils of unknown cultivars, these differences between hosts may in fact not be general.

Herridge describes two strategies to increase nitrogen fixation in soils high in N. Soil preparation of a no-tillage fallow reduced soil N mineralisation by 13.5%, cf. a cultivated fallow with increased N_2 fixation of 59%. This timely demonstration of the significant gains that may accrue by changing agronomic practice was the only example submitted to the Workshop.

The second strategy was to select NO_3 tolerance from within a large number of genotypes; the success rate was 6%. Lines from Korea formed 17 times the nodule mass of cultivar Bragg, with a resulting conservation in soil N.

This approach has identified highly significant breeding material from which the appropriate genes may be incorporated into agronomically desirable soybean cultivars.

Legumes and the N Economy of Soils

The paper by Ofori et al. serves as a reminder that food legumes in the tropics are often not sown in a monocrop but in combination with a companion crop such as maize, cassava, rubber or oil palm, and also that the bulk of the N_2 fixed by a food legume is harvested in the seed. Their data, obtained by both natural abundance and by labelling soil with ^{15}N fertiliser, indicated that intercropping cowpea with maize did not affect symbiotic fixation but there was no transfer of N to the maize.

Nitrogen balance calculations showed depletions of 57 kg N/ha after the intercrop and an N gain of 6 kg/ha after a monocrop of cowpeas.

Senaratne and Hardarson measured the soil N after crops of faba bean, pea and barley. Although each crop reduced soil nitrogen there was an N-sparing effect of 29 kg N/ha by faba bean and 24 kg N/ha by pea compared with barley, and this effect was reflected in the growth of subsequent crops.

Measurement of Nitrogen Fixation

Measurement of nitrogen fixation is not straightforward. Some of the methods already proposed may be suitable to some but not all systems, while others may provide difficulties in interpretation. The widely used C_2H_2 reduction assay is a case in point. The technique is simple to use, can be interpreted relatively easily when used to detect the presence of N_2-ase activity, but is subject to major problems, particularly with nodulated legumes. As is often the case, the method is not calibrated with ^{15}N.

Peoples et al. describe the use of natural abundance methods, which depend on discrimination between soil and atmospheric-derived N by the small difference in the proportion of ^{15}N they contain. Whilst it requires scrupulous analytical procedures, it avoids the problems of suitable reference plants for measurement of soil N uptake, used when the difference in ^{15}N between atmospheric N and soil N is increased by adding enriched N fertiliser to the soil.

Methods using ^{15}N depend on access to a mass spectrometer. An alternative is to analyse the products of fixation transported in the xylem. Many tropical legumes export the ureides allantoin and allantoic acid, whilst most temperate legumes export amides. When ureide-exporting plants are fed NO_3 this is largely transported to the shoot where it is reduced, and ureide N is all but absent. Hence a calculation of the proportion of the total N transported as ureide gives a measure of the plants' dependence on nitrogen fixation.

Measuring N_2 fixation by sap analysis of amide-transporting plants is less straightforward. Peoples, together with colleagues at RRI Malaysia, describe progress in developing a method using groundnut. Results are promising, but not all the variables that could affect the method have been tested.

Effect of Adhesives on Inoculant Adhesions, Rhizobial Survival and Nodulation

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SUCCESSFUL inoculation of legume seed depends on the introduction of an adequate number of effective rhizobia to the seed. The capacity of seed to hold enough rhizobia depends on a suitable adhesive. The objective of this study was to evaluate the suitability of locally available adhesives for delivering rhizobia into soil through seed coating.

Six chosen adhesives were synthetic glue 100%, gum arabic 40%, vegetable cooking oil 100%, tapioca starch 5%, sucrose 30%, and water. An equal amount (15 ml) of each adhesive was added to 500g of SJ5 soybean seeds. Peat inoculant of 40g containing USDA 110 rhizobia strain was added to each 500g seed treated. Sieving was performed immediately after inoculation and every two hours for the first six hours. The amount of inoculant on seed, number of rhizobia on seeds, and nodulation were determined for each sieving treatment. Nodulation was achieved by growing plants in Leonard jars supplemented with N-depleted plant nutrient solution.

Synthetic glue and gum arabic were excellent adhesives in binding and providing higher number of rhizobia per seed. Vegetable oil and starch also provided high binding capacity of inoculant on seed but lower numbers of rhizobia per seed were obtained. Although sucrose was not a good adhesive it provided high viability of rhizobia per seed. Water was the poorest adhesive. However, all adhesives provided from 1.15×10^4 to 8.4×10^5 rhizobia per seed. These numbers were adequate for nodulation in the greenhouse tests, and no differences in nodulation were obtained.

Symbiotic Relationships Between *Glycine* spp. and Rhizobia

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RECENT reports illustrate the complexity of the symbiotic interactions that occur in associations between species of *Glycine* and strains of *Rhizobium*. Bromfield and Roughley (1980) found that 'tropical' soybean cv. Malayan nodulated and fixed N_2 equally well with both *R. japonicum* and *Rhizobium* sp. isolates from cowpea, but that the *Rhizobium* sp. failed to nodulate 'American' soybeans. Keyser et al. (1982) located fast-growing strains of rhizobia that were symbiotically ineffective (or poorly effective) with 'American' cultivars but effective for black-seeded Peking. Keyser (pers. comm., 1983) also reported interactions in nitrogen fixation between associations of different lines of *Glycine soja* with fast- and slow-growing strains of *R. japonicum*.

We have demonstrated that these host/bacteria interactions are even more complex than previously believed (Table 1). An experiment was conducted in pots of washed river sand and vermiculite (1:1/v:v) (Bergersen and Turner 1970) in a glasshouse. Two lines of soybean and three lines of *G. soja* were inoculated with five strains of rhizobia. The strains were CB1809 — highly effective for most 'American' soybeans; USDA192 — from China; CC1603b — isolated from *G. tomentella* and effective for most Australian native *Glycine* spp.; CB756 — archetypal, broad host range, cowpea type; QA878 — also from *G. tomentella*. USDA192 was the only fast grower.

TABLE 1. Nodulation and N_2 fixation of associations between five lines of *Glycine* spp. and five strains of rhizobia of diverse origins.

	G. max		*G. soja*		
	Malayan 1618	Lincoln	Q10847	CPI101128	CPI101129
CB1809	+ E	+ E	+ E	+ E	+ i
USDA192	– –	– –	– –	+ e	+ E
CC1603b	– –	– –	+ i	– –	+ i
CB756	– –	– –	+ i	– –	+ E
QA878	+ i	+ i	+ i	+ i	+ i

+ = nodules, – = no nodules, E = effective, e = partly effective, i = ineffective.

With these strains, nodulation and N_2 fixation of the two soybean cultivars were similar, which was unexpected, but soybean differed from the *G. soja* lines and each line was substantially different from the others. No two strains of rhizobia behaved alike. Had other plant lines (e.g. *Glycine* spp. from Australia) or other rhizobia (e.g. cowpea strains effective also for soybean) been considered, undoubtedly still more complex relationships would have emerged.

This diversity of symbiotic interaction has important implications for soybean breeding programs, especially those that involve hybridisation between *G. max* and *G. soja* or, in Australia, between *G. max* and native *Glycine* spp. In particular, it widens the options for soybean breeders concerned with the development of cultivars suited to the tropics.

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Response of Soybean to Inoculation with Selected Strains of *Rhizobium japonicum*

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DUE to the high production cost and low yield of soybean, the crop is not popular with local farmers despite its potential as a major food crop in Malaysia.

For soybean cultivation to be economically viable, the productivity of the plant would need to be doubled from 1.5 to 3.0 t/ha. To achieve this aim, an integrated approach in soybean research including breeding and selection, disease and pest control, mechanisation as well as biological nitrogen fixation (BNF) aspects would be needed.

Improvement of soybean yield through optimisation of BNF activities in the plant has occurred in many countries and could be a useful contribution in increasing soybean productivity in this country. It is therefore the objective of this study to determine whether locally adapted soybean can benefit through rhizobial inoculation under Malaysian field conditions.

Three trials were conducted to evaluate the response to rhizobial inoculation of a locally adapted soybean variety, Palmetto, under Malaysian field conditions.

Ten effective strains of *Rhizobium japonicum* were tested both in the presence and absence of applied fertiliser N.

The effect of various levels of N and Ca and the techniques of inoculant application on the growth and yield of soybean were also examined.

Plants were evaluated for nodulation, growth and seed yield.

Both rhizobial inoculation as well as applied mineral N increased dry matter yield and nitrogen content of plants. Mineral N however, inhibited nodulation when applied at 150 kg/ha. While rhizobial inoculation increased seed yield significantly, application of mineral N did not.

It is therefore demonstrated that inoculation with effective *Rhizobium* strains can improve soybean yield and at the same time lower production costs in Malaysia.

Strategies to Improve N Fixation by Food Legumes

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INCREASING the dependence of food legumes on N fixation and, at the same time, decreasing their reliance on soil N remains a major challenge in research efforts to stabilise the N cycles in both tropical and temperate agriculture. At the NSW Department of Agriculture Research Centre, Tamworth, two major research projects have provided a focus for these objectives. In the first, we have sought to enhance N fixation by a range of legumes through soil management, in particular soil nitrate management. In the second program, we have searched the available germplasm of soybean for genotypes with improved N fixation ability.

Effect of soil management of N fixation: The experiments involved three sites, four legumes (soybean, pigeonpea, mungbean, cowpea) and three tillage treatments. Results for 'Forrest' soybean, sown in December 1983 at the medium fertiliser site, are presented in Table 1.

TABLE 1. Effect of soil nitrate management, soybean growth and N fixation.

Soil Management	Soil nitrate at sowing[1] (kg/ha)	Crop N (kg/ha)	% crop N from N fixation[2] (P)	N fixed (kg/ha)
Cultivated fallow	214	252	52	132
No-tillage fallow	185	355	66	236
No-tillage, double fallow	132	238	71	168

[1]0 to 120 cm depth. [2]Using the ureide method (Herridge 1984).
Data from D.F. Herridge and J.F. Holland, unpublished.

Higher levels of P and total N fixed were achieved in the no-tillage plots relative to the cultivated treatment, due to the combination of reduced available nitrate (column 1) and improved crop growth (column 2). P was further increased in the no-tillage, double crop plots but total N fixed was restricted by limited moisture.

Selection of superior N fixing genotypes of soybean: A program was commenced in 1980 to screen almost 500 genotypes of soybean for improved N fixation activity in the presence of nitrate. Two years of screening under glasshouse conditions reduced the original germplasm to 32 elite lines which were inoculated with *R. japonicum* CB1809 and sown into a fertile field soil (260 kg NO_3^--N/ha, 0–120 cm depth) in November 1984. The superior lines from the field trial were all of Korean origin and showed up to 17 fold increases in nodulation, 20 fold increases in N fixation and equivalent growth relative to Bragg. Residual soil nitrate levels in the plots containing the superior lines were up to 34 kg N/ha higher than Bragg.

TABLE 2. Measurements of nodulation, N fixation and growth of the selected lines and commercial Bragg and Hardee.

	Nodule mass (mg/plant)	Nodule no/plant	% plants nodulates	N fix index[1]	Shoot g/plant	Residual Soil NO_3^- (kg/ha)
Korean 466	376	34.5	98	36	45.9	57
468	254	16.8	95	27	43.3	75
Bragg	24	2.0	43	11	39.7	42
Hardee	0	0.0	0	12	67.1	24

[1]Using the ureide method: value of 12 equals zero fixation: value of 70 equals 100% fixation. Data from Herridge and Betts (1985).

Herridge, D.F. 1984. Crop Sci. 25, 173–179.
Herridge, D.F. and Betts, J.H. 1985. In: Evans, H.J., Bottomley, P.J. and Newton, W.E., ed., Nitrogen Fixation Research Progress, Martinus Nijhoff, p.32.

Response of Pigeonpea Genotypes to Inoculation with Rhizobia and Phosphate Fertiliser Application

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PIGEONPEA (*Cajanus cajan* (L.) Millsp) is an important pulse crop grown in the semi-arid tropics because of its tolerance to drought, wide adaptability and as a protein source. Low grain yields in farmers' fields have been attributed partly to low soil fertility and cost of chemical fertilisers (Onim 1984). *Rhizobium* inoculation with phosphate fertilisation has been suggested as an alternative, since P is known to limit N fixation (Keya 1984). Little has been done to determine the role of symbiotic nitrogen fixation in meeting nitrogen demand of local pigeonpea in eastern Africa. Pigeonpea grain yield increases of 7–51% over non-inoculated controls have been reported in India (Rewari et al. 1980). Thompson et al. (1980) estimated that in India pigeonpea could fix up to 69 kg/ha per season, accounting for 52% of the total N intake.

A study was conducted to determine if there are genotypic differences in nitrogen fixing ability by local and exotic pigeonpea genotypes and to evaluate the response of these genotypes to inoculation with *Rhizobium* strains. Twelve genotypes of different maturity groups were inoculated with four *Rhizobium* strains and grown in soils with and without phosphate fertiliser application (40 kg P_2O_5/ha) at two locations in 1984 and 1985.

The results showed that inoculation increased the number of primary branches; one season reduced time to flowering and maturity and increased nodulation and grain yield. Inoculation increased plant height in the late maturity group but reduced it in early and medium maturity genotypes. Significant genotype x *Rhizobium* interactions were detected for number of primary branches, nodules per plant, and 100-seed weight. The results also indicated that response to *Rhizobium* strains was genotype-specific. Cultivars NPP670 and NPP671/1 showed improved performance when inoculated with strain P724 while NPP673/3 performed better with strain P791.

Although P addition and rhizobia inoculation separately increased grain yield, their combined effect was more pronounced. A mixture of *Rhizobium* strains (3100 plus 3185) plus phosphate fertiliser application gave the highest yield increases.

TABLE 1. Effect of P, maturity group and rhizobia strain on grain yield g/plant.

Genotype/maturity group	Control	+P	Rh_1 −P	Rh_1 +P	Rh_2 −P	Rh_2 +P	Rh_3 −P	Rh_3 +P	Rh_4 −P	Rh_4 +P
1. Early (5 genotypes)	67.5	74.4	70.1	71.9	75.9	70.5	60.6	78.9	80.4	94.4
2. Medium/late (6 genotypes)	65.5	82.4	76.8	83.9	61.5	76.3	67.6	93.6	77.5	83.9
Mean	66.5	78.4	73.5	77.9	68.7	73.4	64.1	86.3	78.9	89.4

Key: Rh_1 = P724; Rh_2 = strain 3100; Rh_3 = 3195; Rh_4 = mixture of 3100 + 3195.

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Cross Inoculation Between SJ4, SJ5 and Two Traditional Thai Soybean Cultivars

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VARIETIES SJ4 and SJ5 are recommended soybeans for growing in many parts of Thailand, especially in the dry season. The high yield can be improved by inoculating with specific rhizobia. But in the northern areas of Sukothai, Pisanulocke and Chiang Mai Provinces the farmers still grow traditional soybean varieties (Dok-kaw and Dam-Tiar) without inoculation. Studies of specific rhizobia for these varieties have not been reported.

Dok-kaw gave the highest dry weight of nodules and plants when grown in poorly drained alluvial soils, but the others gave the highest dry weight when grown in Pimai series. Uninoculated soybean gave a larger size and smaller amount of nodules than that of the inoculated group. These strains slightly differed from the *Rhizobium* which the Agricultural Extension Department recommended for SJ4 and SJ5 and could be grown on YMA + 2% NaCl utilising mannitol and fructose. They were capable of nodulating *Vigna unguiculata* and *Macroptilium atropurpurea* c.v. siratro, but failed to nodulate *Vicia faba*, *Pisum sativum* and *Medicago sativa*.

Using modified Leonard jars tests showed that the *Rhizobium* isolated from SJ varieties (R_{SJ}) produced more nodules, dry weight of nodules and dry weight of plant in traditional varieties than the isolates from traditional varieties (R_{DK}, R_{DT}). It was also found that the total percentage of nitrogen of Dok-kaw and Dam-Tiar ranged between 2.66 and 3.17 when inoculated with R_{SJ4} and R_{SJ5}.

It is concluded that the yield of traditional soybean may be improved by use of specific rhizobia for SJ4 and SJ5. This should be confirmed by further field experiments in 1987.

Evaluation of N_2 Fixation in a Maize/Cowpea Intercrop System Using ^{15}N Methods

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THE stable isotype of nitrogen, ^{15}N, offers reliable and direct methods of measuring N_2 fixation by legumes in intercropping systems. The principle of the method is a comparison of the degree of dilution of ^{15}N taken up from the soil by a non-fixing crop with that shown by a legume fixing atmospheric N_2. The percentage (P) of crop N fixed from atmospheric N_2 is estimated from differences in isotopic composition of the sources of N available for plant growth. These differences may arise from (a) variations in natural abundance of ^{15}N in soil N (the basis of the ^{15}N natural abundance (NA) method) and (b) artificial labelling of the soil with ^{15}N enriched fertiliser (the basis of the ^{15}N-labelled fertiliser (NL) method) (Ledgard et al. 1985). P is determined as:

$$P = 100x\,(\text{atom \% }^{15}\text{N cereal} - \text{atom \% }^{15}\text{N legume}) / (\text{atom \% }^{15}\text{N cereal} - \text{atom \% }^{15}\text{N for legume depending on } N_2)$$

Either method can be used for estimating P and thus evaluating the N economy of intercropping systems. The ^{15}N natural abundance method is particularly appropriate to areas such as Southeast Asia and Africa where intercropping is extensively practiced but where normally little or no N fertiliser is applied.

A field experiment was conducted between November 1984 and April 1985, at Waroona (33°S, 116°E) in Western Australia, to measure the P values of cowpea as a sole crop or as an intercrop with maize, and to determine its contribution of fixed N to the intercrop system. Sole crops and intercrop mixtures were in a randomised block design. The plants were sown in rows, on beds separated by irrigation furrows, maize at a density of 60 000 plants/ha and cowpea at 150 000 plants/ha; the densities in the intercropping mixture were the same as the sole crops. Unconfined microplots were marked out in the centre of each plot and isotopically labelled ^{15}N-urea (1.37 atom % excess) was applied as a solution to the N plots. At maturity, ten plants of each crop were harvested from the microplots for determinations of dry matter, nitrogen yields, and ^{15}N content of plant biomass. The ^{15}N concentrations and $\delta\,^{15}N$ of the samples were determined by a triple collector mass spectrometer.

The estimates of N_2-fixed (kg/ha) and their percentage of the total plant N were as follows:

	P_{NA}	P_{NL}
Sole crop	87 (69%)	76 (48%)
Intercrop	57 (64%)	73 (68%)

The data using the two methods suggested that intercropping did not significantly affect cowpea's dependence on atmospheric N_2, in comparison with the sole cowpea. The lesser estimates of the amount of N_2 fixed by ^{15}N natural abundance compared to ^{15}N-labelled fertiliser, were largely the result of reduced dry matter and N yields.

Concentrations of ^{15}N and $\delta\,^{15}N$ values of the sole and the intercrop maize were similar, suggesting that there was no transfer of nitrogen from the intercrop cowpea to the maize. The lower P value of the sole cowpea in the ^{15}N-labelled fertiliser data compared to that of the ^{15}N natural abundance might have reflected a reduction in N_2 fixation caused by fertiliser N.

Estimates of N benefit to the cropping systems, using the ^{15}N natural abundance, showed soil N depletions of about 57 kg/ha after sole maize, and 49 kg/ha after the intercrop, but a marginal grain of 6 kg/ha after sole cowpea. These results indicate that residual N benefit from cowpea to the soil of an intercrop system was negligible, largely because the quantity of fixed N_2 was harvested in the cowpea seed.

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Sulfur Nutrition of Free Living and Symbiotic *Bradyrhizobium japonicum* and *Bradyrhizobium* sp. (*Arachis*)

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In legumes, the diagnosis of nutrient deficiencies is complicated by the symbiotic nitrogen fixing system. Apart from effects on host plant growth, nutrient deficiencies may specifically limit growth and survival of rhizobia in the soil, nodulation and nitrogen fixation. To diagnose and correct nutrient problems affecting symbiotic legumes it is important to know which phase of the symbiosis is most sensitive to each essential nutrient since this will determine the sensitivity of the overall process.

Although sulfur deficiency primarily affects legume nitrogen fixation by reducing plant growth and limiting protein synthesis (Wooding et al. 1970) there is some evidence of a specific effect of sulfur deficiency on N_2 fixation (Jones et al. 1971). Sulfur-deficient legumes maintain high concentrations of sulfur within their root nodules. The aim of this study was to assess whether this sulfur is available to the bacteroids of sulfur-deficient legumes.

The approach we used was to establish parameters associated with sulfur excess or deficiency in free-living rhizobia and then determine how bacteroids from sulfur-deficient and sulfur-adequate legumes behave for these characteristics.

Bradyrhizobium japonicum strains USDA 110 and USDA 122 and *Bradyrhizobium* sp. (*Arachis*) strain Nc 92 grown in chemostat culture (D = 0.02h) were used to study ^{35}S-sulfate uptake under sulfate-limiting (10 μM) or sulfate excess (1 mM) conditions. With an excess of sulfate, the maximum uptake rate was 0.1 nmol sulfate/min/mg protein; however, this increased at least 20-fold in the sulfate-limited cultures. Sulfate-limited cells of all three strains derepressed the enzyme alkaline sulfatase, in parallel with the depression of the sulfate transport system. Bacteroids isolated from nodules of sulfur-adequate and sulfur-deficient soybean and peanut, capable of transporting (^{14}C) succinate, showed very limited sulfate uptake and no alkaline sulfatase activity, characteristics of sulfate-excess cells.

These results indicate that although legumes may be markedly sulfate-deficient in terms of growth, bacteroids present within root nodules have access to adequate sulfur to meet their requirements.

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Wooding, F.J., Paulsen, G.M. and Murphy, L.S. 1970. Agron. J. 62, 277–280.

Response of Soybean to Inoculation with *Bradyrhizobium japonicum*

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PREVIOUS field trials have shown that the response of soybean to inoculation tends to be site-specific (Paterno et al. 1984). Most of these experiments were simple inoculation trials involving single strain or multiple strain inoculants.

Recently, field experiments were conducted in two locations to evaluate five *Bradyrhizobium japonicum* strains, namely BGm 9, BGm 11, CB 1809, TAL 377 and USDA 110. Increases in yield due to inoculation with either strain BGm 9, CB 1809, TAL 377 or USDA 110 ranged from 18 to 50% (Table 1). These strains had nodule occupancy of 67–99%. In contrast BGm 11 which formed only 36–40% of the nodules increased yield by only 9–10%. The application of 16 kg N/ha increased yield by only 15% in Laguna, and 30% in Zamboanga del Sur.

TABLE 1.

B. japonicum strain	Grain Yield (t/ha)		Nodule Occupancy (%)	
Treatment	Zamboanga del Sur	Laguna	Zamboanga del Sur	Laguna
Uninoculated	1.60 BC	1.00 C	-	-
16 kg N/ha	2.08 AB	1.15 ABC	-	-
BGm 9	2.15 A	1.50 A	75 B	99 A
BGm 11	1.74 ABC	1.10 ABC	36 C	40 B
CB 1809	2.07 AB	1.36 AB	67 B	99 A
TAL 377	1.89 AB	1.50 A	94 AB	99 A
USDA 110	2.20 A	1.41 AB	98 A	99 A

Paterno, E.S., B.G. Magtagnob, N.T. Armones, V.Z. Perdido and M.L.Q. Sison, 1984. PCARRD Project Terminal Report.

Quantification of Biological Nitrogen Fixation in Food Legumes

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THE assessment of the role of nodulated legumes in agricultural systems depends not only on N contents of plant products, but also on the distinction between soil and atmospheric sources of crop N. Two techniques being used to evaluate the N_2-fixing status of food legumes are described herein.

Techniques involving ^{15}N: The stable isotope of nitrogen, ^{15}N, occurs naturally in soil organic and mineral N and in the atmosphere, where its abundance is universally 0.3663 atoms %. In soils, the natural abundance of ^{15}N is frequently slightly higher. When the isotopic abundances are different in two sources of N used for plant growth, the proportions of plant nitrogen derived from each source can be calculated from measurements of the isotopic abundances in the N of nodulated legumes and of non-N-fixing reference plants in the same soil. Often the very small differences in natural abundance of ^{15}N between soil N and N_2 can be used, if a suitable mass spectrometer is available. This technique has been successfully used for food legumes in several countries (e.g. Bergersen et al. 1985). It requires scrupulous analytical procedures and is very sensitive to contamination of plant material from extraneous sources of ^{15}N. More usually, the difference between soil N and N_2 is extended by incorporation in the soil of small amounts of fertiliser-N highly enriched with ^{15}N. With this technique major errors may arise from differences between the growth patterns of legume and reference plant, combined with uneven distribution of the added ^{15}N in the soil and time-dependent changes in ^{15}N abundance. These lead to differences in the proportions of indigenous soil N and ^{15}N-enriched N assimilated by legume and reference plant. Although such errors can be minimised, they are less serious in the natural abundance method because ^{15}N abundances are more uniform with depth and change less with time.

Analysis of xylem sap: The products of N_2 fixation are exported from nodules of legumes to the shoot in the transpiration stream and analyses of xylem sap will identify transported forms of N. Symbiotic legumes are often classed as being either amide-exporting or ureide-exporting species. 'Ureide' species are principally of tropical origin, and when effectively nodulated transport most N as the ureides, allantoin and allantoic acid. However, scarcely any ureide-N is found in xylem sap when plants are fed nitrate with much of the absorbed nitrate passing to the shoot, since these plants reduce little nitrate in their roots. Such differences in sap composition have been correlated with the extent of the legume's reliance upon N_2 fixation and an analytical system has been developed for soybean based on relative ureide contents (Herridge 1984). Although many 'amide'-producers have an active root nitrate reductase, some nitrate may escape the reductase system and pass to the shoot in the xylem as free nitrate. Thus the proportion of nitrate in the sap tends to increase and relative content of amino acids decrease as there is an increased plant reliance on soil mineral N. Recent work by the authors indicates that comparisons of the concentrations of asparagine and/or glutamine and sap nitrate content may possibly be used to estimate symbiotic dependence in groundnut, chickpea, lentil and pea.

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Herridge, D.F. 1984. Crop Sci., 25, 173–179.

Use of Xylem Sap Analysis to Evaluate the Nitrogen Fixing Status of Field-grown Groundnut (*Arachis hypogaea* L.)

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THE principal forms of amino-N transported in xylem have been studied in nodulated Virginia- and Spanish-type groundnut varieties. Asparagine (Asn) was found to be a major component of xylem exudate collected from all parts of nodulated roots, although its relative abundance in sap changed with the point of collection. Xylem samples from the lower root (below nodulated zone), presumed to contain only cycled N, recorded 44% of total sap N as Asn compared with 70% for sap from the top of the whole root. The increased proportion of Asn in upper root xylem was assumed to be due to an Asn-dominated contribution from the nodules, and indeed 80% of N of nodule bleeding sap was shown to be in the form of this amide.

Glasshouse experiments were initiated to examine the change in the Asn content of root-bleeding exudate in the presence of inorganic-N (nitrate). Nodulated plants were grown in N-free rooting medium but received a range of levels of ^{15}N-nitrate of known enrichment. The proportions of accumulated plant N derived from N_2 or nitrate were determined by ^{15}N dilution. The treatments showed a substantial decline in the relative Asn content and a compensatory increase in sap nitrate with increased nitrate supply. 'Standard curves' were prepared relating the abundance of Asn in xylem sap and the ratio of nitrate: total amino acid to plant reliance on N_2 fixation. These curves were used to evaluate xylem exudate samples collected from field-grown groundnut in Malaysia (Table 1).

TABLE 1. Analyses of root-bleeding xylem saps collected from groundnut at various field sites in Malaysia. Estimates of the proportional dependence of symbiosis are shown in parentheses.

Identity	Total amino acids (mgN/ml)[a]	Nitrate (mgN/ml)[b]	Asn as a % amino acid N[c]	Ratio NO_3: total amino N (N/N)	**Ratio** Asn: total sap N[d] (N/N)
Sungei Buloh:					
Site 1 uninoculated	0.68	0.11	61	0.16 (65)	0.53 (57)
Site 2 inoculated	0.80	0.01	67	0.01 (95)	0.66 (88)
Site 3 + N fertiliser	0.47	0.20	59	0.43 (40)	0.41 (33)
Changkat Larang:					
Site 1 uninoculated	0.31	0.03	57	0.11 (73)	0.57 (67)
Site 2 inoculated	0.49	0.01	71	0.03 (90)	0.71 (96)
Changkat Ibul:					
Field sample	0.19	0.09	61	0.51 (35)	0.40 (30)

[a]Determined by ninhydrin with Asn as the standard (mg N/ml = m molar concentration × 1.75 × 14).
[b]By a salicylic acid method (mg N/ml = m molar concentration × 1 × 14).
[c]Determined by HPLC analysis.
[d]Total amino N + nitrate-N.

Studies comparing xylem composition of groundnut inoculated with *Rhizobium* CB756 or with any one of a number of field isolated strains from Thailand (provided by ACIAR project No. 8329) suggest that there was little influence of *Rhizobium* strain on patterns of N transport in the presence of nitrate. There was some indication that there may be varietal differences between Virginia- and Spanish-type groundnut in relative xylem composition in young seedlings, but not in mature plants. Other variables likely to complicate xylem sap assays, such as the site and mode of collection, are currently under investigation.

Nitrogen Nutrition in Legume/Non-Legume Intercrops

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INTERCROPS of corn and cassava with traditional legumes, namely, ricebean, winged bean and lablab were evaluated in relation to the monocultures. De Wit's design of replacement experiments was used (de Wit 1960). Monocultures of corn and of cassava at their respective asymtotic densities were compared with intercrops in which a proportion of the corn or cassava plants was replaced by an equivalent number of legume plants.

Measured as the sum of yield of each species in intercrop relative to their monoculture yield:

Relative Yield Total = Relative Yield, non-legume + Relative Yield, legume
(where Relative Yield species x_i = Intercrop Yield, X_{ij}/Monocrop Yield, X_{ii})

there is an advantage in intercropping over monoculture when Relative Yield Total (RYT) > 1.

In 50:50 mixtures, there was no advantage of legume intercrops in cassava, as the legumes performed more poorly than in monoculture. The relative yield of legumes in cassava was found to be lower than their respective proportion of plants in the intercrop mixtures. At 50:50 corn:legume, corn intercrops had RYT > 1 for all the legumes. In absolute terms, up to 70 kg/ha of additional N was removed by the intercrops than the best monocultures, with slight or no reduction in total dry matter and grain yield.

The advantage of corn intercrops was due to both the corn and legumes performing relatively better in intercrop than in monoculture. Detailed study of a corn–ricebean intercrop has shown that nitrogen nutrition of both species in intercrop may be superior to that in monoculture.

Analysis of natural enriched ^{15}N in the plant materials, using corn as reference, showed that intercropped ricebean derived a much larger proportion of its nitrogen from fixation than when it was grown in monoculture (Peoples et al., these proceedings). In one experiment with 50:50 mixture of corn:ricebean we found that at corn maturity, nitrogen fixation was contributing to 75% of the nitrogen taken up in the tops of intercropped ricebean, whereas only 32% of the nitrogen in mono-ricebean could be accounted for by fixation.

Progressive replacement of corn with beans shows a corresponding reduction of competition for soil nitrogen. An experiment that examined effects of corn:ricebean proportions at 100:0, 75:25, 50:50, 25:75 and 0:100 showed that nitrogen concentration in the corn increased as the proportion of corn decreased.

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Population Dynamics of Soybean Inoculants in the Field

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THE development of populations of soybean inoculant was studied in two environments which were ecologically distinct: (i) where previously the soil had been free of *Rhizobium japonicum*; (ii) where the soil already contained established populations of (resident) *R. japonicum*. The experiments were conducted with irrigated crops of Bragg soybean on a vertisol at Breeza, New South Wales.

The representative data in Table 1 illustrate the development of rhizobial populations following inoculation of soybeans sown into soil previously free of *R. japonicum*. Features include the degree of inoculant mortality between the time of inoculation and the formation of a rhizosphere, and the substantial increase in populations in the soil after harvest which was probably due mainly to the release of rhizobia from disintegrating nodules.

TABLE 1. Fluctuations in populations of inoculant rhizobia during and after a crop of soybeans grown in soil previously free of *R. japonicum*.

Source	Size ($\log_{10}$ rhizobia/ha)
In soil before sowing	nil
At inoculation of seed bed	12.04
In seed bed 24 h after sowing	10.71
In rhizosphere (day 14)	8.00
In rhizosphere (day 28)	8.55
In rhizosphere (day 42)	10.33
In soil 6 months after sowing (= 1 month after harvest)	12.09
In soil 10 months after sowing	14.36
In soil 12 months after sowing	14.39

The results of this and other experiments showed that, in soil previously free of rhizobia, the extent of nodulation depends on the rate of application of inoculant, its distribution through the soil profile, its survival, and the nitrate content of the soil. These same factors remain influential in the presence of established rhizobia but the size of that resident population assumes major importance in determining the extent of inoculant-induced nodulation (Table 2). Although resident rhizobia soon dominate inoculant strains in colonisation of the rhizosphere, the proportion of nodules formed by the inoculant is greater than its rhizosphere representation. This may be due to an advantage of strategic placement.

TABLE 2. Influence of size of population of resident *R. japonicum* on rhizosphere colonisation and nodulation of Bragg soybeans by inoculant strain.

Exp. no.[a]	Rhizobia at sowing ($\log_{10}$ soil)		Rhizobia in rhizosphere ($\log_{10}$ plant/ha)		Nodule occupancy (%)	
	Resident	Inoculant	Resident	Inoculant	Resident	Inoculant
1	10.7	nil	2.7	nil	100	0
1	10.7	12.5	5.6	4.1	51	49
1	10.7	14.6	7.3	4.3	24	76
2	9.8	14.1	3.9	3.3	11	89
2	14.2	14.1	6.6	2.4	97	3

[a]Experiment 1 — low rate of inoculant mortality; exp. 2 — high rate.

Some of the findings that emerge from this work on the population dynamics of inoculant strains and their rhizobial competitors are relevant to inonculation strategy, not only for soybeans but for legumes generally.

Nodulation Patterns of Selected Legumes in Two Rice Soils of Sri Lanka

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NITROGEN is a major component of soil fertility, and maintenance of soil N levels allows continuous and productive agriculture (Greenland 1977). This can be achieved by the incorporation of legumes into farming systems, especially in the tropics, where N losses are great (Agboola and Fayemi 1972).

The establishment of legumes during interseasonal periods in rainfed rice farming systems may have beneficial effects on the succeeding rice crop. The beneficial effects of the legume depends on its successful growth and nodulation. This in turn is affected by many factors, among which the moisture status of the soil becomes important as the fields are primarily meant for lowland rice culture. As excessive soil moisture levels, which are a feature of rice soils affect nodulation and N fixation, nodulation characters of four common legumes were studied in two rice soils found in the midcountry of Sri Lanka. The legumes were bushbean, cowpea, mungbean and a green manure sunhemp (*Crotalaria juncea*). The soils were maintained at saturated and unsaturated conditions to resemble field conditions found in these soils during interseasonal periods.

TABLE 1. Effect of soil moisture on nodulation characters of selected legumes (observed at flowering).

	Nodules/plant		Nodule wt. (g/plant)		% active nodules/plant	
	**A	B	A	B	A	B
Unsaturated Soil						
Bushbean	34	29	0.35	0.41	85	72
Cowpea	26	24	0.26	0.30	81	68
Mungbean	35	38	0.31	0.27	75	82
Sunhemp	50	44	0.52	0.49	73	64
LSD (P = 0.05)	9	10	0.08	0.11	-	-
Saturated Soil						
Bushbean	24	21	0.24	0.26	31	43
Cowpea	10	12	0.11	0.14	12	15
Mungbean	14	18	0.09	0.11	10	16
Sunhemp	36	38	0.46	0.43	54	49
LSD (P = 0.05)	7	12	0.10	0.14	-	-

** A = low humic grey soil, B = imperfectly drained reddish brown latosol.

High moisture levels reduced nodulation characters of all legumes (Table 1). This is considered a direct effect of the lack of sufficient oxygen for effective nodulation, as rhizobia are active under aerobic conditions (Minchin and Pate 1975). However, reduction of nodulation due to saturated conditions was less in sunhemp and beans than in the other crops. Hence, legumes suited to drier conditions are not suitable for fields that have high water contents during the interseasonal period. Under such conditions, legumes such as bushbeans or sunhemp can be used. If drier conditions prevail, most short-term legumes can be established successfully. Thus, farmers selecting legumes for intensification of rice systems should consider soil moisture levels in order to obtain successful crop growth and yields and to enrich the rice soils.

Agboola, A. and Fayemi, A.A.A. 1972. Agron. J., 64, 409.
Greenland, D.J. 1977. In: Biological N fixation in Farming Systems of the Tropics. John Wiley and Sons, 13–26.
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Relationship Between Fertiliser N and N Fixation in Lentils and Soybeans

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NITROGEN fixation in agricultural land is rarely hindered by the lack of highly active N fixing micro-organisms (Alexander 1982) but often by the multitude of factors of the environment, crop and microbes. There is commonly an inverse relationship between added fertiliser N and N fixation in legumes (e.g. Mengel and Kirkby 1982). This relationship, however, varies with species and with environmental and soil conditions. Thus, a growth chamber experiment was carried out using ^{15}N labelled NH_4NO_3 to quantify the effect of added N on N fixation in soybeans (*Glycine max*) and lentils (*Lens esculenta*). Plants fertilised with N at rates of 25, 50, 75 and 100 kg/ha were harvested at 30 and 55 days after germination to achieve the desired objective.

The effect of added N on N fixation varied with the time of harvest and the crop. The rate of decrease in N fixation of soybeans and lentils due to fertiliser N at 30 days was indicated by the regression equations $y = -0.258x + 0.733$ ($r = 0.969$) and $y = -0.246x + 0.897$ ($r = 0.975$) respectively. This shows that increasing quantities of fertiliser N had similar effects on both crops. In contrast, reductions in N fixation at the second harvest showed significant differences. Rate of reduction in N fixation of soybeans was indicated by $y = -1.544x + 0.054$ ($r = 0.970$), which was significantly greater than that of lentils ($y = -1.012x + 0.034$ ($r = 0.984$)).

TABLE 1. Effect of N fertiliser (kg N/ha) on N fixation (mg/pot).

N fertiliser application (kg/ha)		25	50	75	100
Harvest 1	Lentils	70	64	43	25
	Soybeans	52	47	26	14
Harvest 2	Lentils	283	230	153	98
	Soybeans	494	342	255	201

The amounts of N fixed by the crops at each harvest under increasing rates of fertiliser N are presented in Table 1. Soybeans fixed smaller quantities of N at 30 days although the rates of reduction in N fixation were similar in both species. At 55 days soybeans fixed greater quantities of N than lentils, and this could be attributed to the greater demand for N at the time of flowering. However, reduction in rates of N fixation was greater in soybeans at this harvest, thereby indicating the greater susceptibility of N fixation by soybeans to added fertiliser N at later stages of growth.

Alexander, M. 1982. In: Priorities in Biotechnology Research for International Development. National Academy Press, USA, 208–229.
Mengel, K. and Kirkby, E.A. 1982. In: Principles of Plant Nutrition. Int. Potash Institute, Bern, Switzerland, 336–340.

Estimation of Residual Effect of Faba Bean and Pea on Two Succeeding Cereals Using ^{15}N Methodology

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FIELD experiments were conducted using ^{15}N methodology to study the effect of cultivation of barley, faba bean and pea on the N status of soil and their residual effect on two succeeding cereals (sorghum followed by barley). Faba bean, pea and barley took up 29.6, 34.5 and 53.0 kg N/ha from the soil, but returned through roots only 11.3, 10.7 and 5.7 kg N/ha to soil respectively. Hence, removal of stover in faba bean, pea and barley resulted in a −N balance of about −18, −24 and −47 kg/ha respectively. Nitrogen sparing effects in the soil, evident following the cultivation of faba bean and pea compared to barley, were of the order of 23 and 18 kg N/ha respectively. Cultivation of legumes resulted in a significantly higher A_N value in the soil compared to barley ($P < 0.05$). However, the A_N of the soil following the fallow was significantly higher than following legumes ($P < 0.05$). This implies that the cultivation of faba bean and pea had depleted the soil less than barley but had not enriched the soil compared to the fallow. This is in accord with the values obtained from the succeeding crop on N yield and dry matter production. The beneficial effect of legume cropping was reflected even in the N yield and dry matter production of the second succeeding crop. When roots were incorporated, the total carryovers of N from faba bean and pea to the two succeeding crops were about 18 and 24 kg N/ha respectively. Incorporation of both roots plus stover resulted in slightly less carry-over effect, due probably to immobilisation of soil N. Cultivation of legumes led to a greater exploitation of soil N by the succeeding crops. Hence, appreciable yield increases observed in the succeeding crops following legumes compared to cereal were due to the N-sparing effect, carryover of N from the legume residue and to greater uptake of soil N.

Effect of Seed Pelleting on Rhizobial Survival on Inoculated Seed and Yield

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IN China legume inoculant is usually mixed with seeds before sowing. This conventional method is not good enough for legume nodulate. In order to examine the effect of inoculation, experiments were conducted during the years 1979–1984.

Legume seeds were inoculated with rhizobia using gum arabic or CMC as adhesive and calcium carbonate or calcium magnesium phosphate as coating material. Non-pelleted seeds inoculated with rhizobia were used as controls in pot and field experiments.

One–three per cent molybdenum (ammonium molybdate) added to coating material did not affect the survival of rhizobia. Survival of rhizobia on inoculated seeds was negatively and highly correlated with storage time (x_1) and temperature (x_2). Regression equations were as follows:

Pelleted treatment

$\log y = 2.822 - 1.330 \times 10^{-3}x_1 - 0.083x_2$

$R = 0.863^{**}$; $ry\ 1.2 = -0.957^{**}$; $ry\ 2.1 = -0.775^{**}$

Non-pelleted control

$\log y = -1.448 - 1.168 \times 10^{-3}x_1 - 0.076x_2$

$R = 0.751^{*}$; $ry\ 1.2 = -0.613^{**}$; $ry\ 2.1 = -0.635^{**}$

At the same storage time and temperature, numbers of rhizobia on pelleted seeds were higher than on non-pelleted seeds. Under adverse circumstances, such as in dry, acid or saline soils, in direct contact with calcium superphosphate fertiliser, pelleted seeds had significantly more viable rhizobia than non-pelleted seeds.

Rhizobia were recovered from pot and field experiments using fluorescent antibody techniques and streptomycin-resistant strains. The pelleting treatment increased recovery percentage by 8.3–25.0% over non-pelleting control.

The differences between pelleting treatment and non-pelleting control in number of nodules and nodule weight per plant, number of seedlings per hectare and dry weight per plant were significant at 0.05 or 0.01 probability level. Pelleting increased yield of *Astragalus sinicus* and peanut by 15.1 and 7.5% respectively.

According to the results, pelleted seeds should be stored at low temperature and sown as soon as possible after coating. A maximum storage period of about one week is advised.

Response of *Arachis hypogaea* to *Rhizobium* Inoculation in Acid Soils in Malaysia

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OBJECTIVE: Assessing need to inoculate in new and established areas using two highly effective strains.

This report gives results from two sites of a multilocation trial representing different agroecological environments — a peat soil not previously sown to legumes and a sandy clay loam previously sown to *Pueraria* and *Calopogonium* covers. Variety Matjam was inoculated with either strain MS 13 or NC 92; uninoculated and +N (100 kg N is equally split at planting and 50% flowering) included as control. Basal fertiliser (56 kg P as triple superphosphate, 56 kg K as muriate of potash and 1 t lime/ha as ground magnesium limestone) was applied at sowing.

In peat soil (Pontian) the result showed a response to inoculation. A significant difference in nodule dry weight and the yield was obtained between the two strains NC 92 and MS 13. In the sandy clay loam (Bertam) there was no significant difference between treatments. The naturalised strains in the soil, possibly those nodulating the covercrops, were able to nodulate groundnut effectively. These results illustrate the need to demonstrate that inoculation is required before strain selection and inoculum production need be considered.

Soybean Rhizobia of Northern Thailand

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THE post-war development of the U.S. soybean seed industry has not only been dramatic and well publicised, but has tended to be the model for development of the industry in other countries, even those of Asia where the crop has probably been grown for centuries. There are two very significant features of the U.S. soybean industry:

a) a very narrow genetic base;

b) common acceptance of the need for legume inoculant, containing strains isolated from U.S. soils.

The sources of the soybean rhizobia present in U.S. and Canadian soils are not known but must be assumed to be introductions from Asia and also to have a very limited genetic range. The result is that some notable cases of specificity are evident in U.S. soybean germplasm, presumably as a result of the host and rhizobia coming from different geographic regions of Asia (e.g. Devine and Breithaupt 1981).

In Africa, U.S. cultivars without inoculants are generally poorly nodulated while local lines nodulate well. This finding has now led the soybean breeders at IITA to incorporate the nodulation promiscuity of the local lines into exotic U.S. cultivars so that nodulation may be achieved without the use of inoculant (e.g. Kueneman et al. 1984). The possibility of a similar approach is being investigated in Thailand.

In 1985 a range of trap hosts for rhizobia was sown at 25 sites in Thailand using wild soybean, cowpea, local soybean lines and lines of U.S. origin. Sixteen sites were sown in the cool dry season and nine in the wet season. Nodules were collected during vegetative growth.

Significant findings:

1. Nodules were collected from all hosts, including those of U.S. origin, at almost all sites. Exceptions were not necessarily considered to be due to specificity, as some sampling conditions were difficult. Glasshouse and control environment studies so far indicate complete infection compatibility of all rhizobia with all hosts.

2. Some of the rhizobia isolated are fast growers, as was also found for recent collections in China (Keyser et al. 1982).

3. Serological screening (F.A.) using antisera of U.S. origin has revealed only limited cross reaction with Thai isolates.

Devine, T.E. and Breithaupt, B.H. 1981. USDA Technical Bulletin No. 1628, 42p.
Keyser, H.H., Bohlool, B.B., Hu, T.S. and Weber, D.F. 1982. Science, 215, 1631-1632.
Kueneman, E.A., Root, W.R., Dashiell, K. and Hohenburg, J. 1984. Plant and Soil, 82, 387-396.

Influence of Different Daylengths on the Development of Nodules of Food Legumes

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THE effect of different daylengths on the nodulation of faba beans (*Vicia faba* cv. Diana) and vetch (*Lathyrus sativus* cv. Gitta) was studied in a two-year experiment. The daylength treatments in growth chamber trials were 10, 13, 16 and 19 hours and those of the field experiment were 7, 10, 13 and natural daylength as control. Harvests were taken at 14-day intervals starting 4 weeks after emergence. At time of harvest, leaf area, plant dry matter (DM) and numbers of nodules were determined.

TABLE 1. Effect of daylength on plant parameters of *Lathyrus sativus* (field experiment 1985).

Harvest	59 DAE				LSD (P = 0.05)	101 DAE				LSD (P = 0.05)
Day length (h)	7	10	13	CON		7	10	13	CON	
Height (cm)	13.7	18.8	29.3	45.5	6.2*	32.0	44.5	71.8	62.0	6.9*
Plant DM (g)	0.9	1.3	1.3	2.2	0.5*	7.2	13.7	17.3	15.2	4.3*
Nodule (No)	108	100	130	79	n.s.	134	131	104	28	n.s.
Nodule DM (g)	0.15	0.22	0.30	0.39	0.08*	0.57	0.48	0.29	0.25	n.s.
Leaf area (cm^2)	88	137	128	224	47*	451	388	304	47	112*
Pod DM (g)	0.0	0.0	0.0	0.3	0.2*	0.1	3.1	7.2	10.0	2.3*
N/plant (g)	0.04	0.05	0.05	0.08	0.01*	0.27	0.45	0.52	0.41	0.09*

DAE = Days after emergence
DM = Dry matter
* = significant at P = 0.05
n.s. = not significant
CON = natural daylength.

Plant DM, total nitrogen content and pod DM increased with increasing daylength (Table 1). Due to the longer assimilation period, and the greater leaf area, plants grown under higher daylength produced significantly higher nodule DM in the first half of the growing period. Balatti and Montaldi (1981) found similar results in soybean experiments. But at the onset of senescence the differences in nodule DM were not significant. An early decline in nodule production at the longer daylength was observed. This may be due to a higher competition for assimilates between pods and nodules. Single nodule weight was significantly lower at shorter daylength, but the total number of nodules was not significantly influenced by daylength.

Balatti, P.A. and Montaldi, R.M. 1981. Revista de la facultad de agronomia, 57/58, 23–29.

Section 7

Biological Factors

Review of Contributed Papers

G.J. Persley *

TWENTY-FIVE papers concerned with the protection of food legumes were contributed to the workshop. They include reports on:

1) surveys of diseases of food legumes in Thailand and Indonesia (2 papers);

2) research reports related to particular pests and diseases of individual crops. In these reports, interest was focused on:

(1) pigeonpea	— 6 (3I, 3D)
(2) peanut	— 5 (5D)
(3) chickpea	— 4 (3D, 1I)
(4) soybeans	— 1 (D)
(5) cowpea	— 1 (I)
(6) green gram	— 1 (I)
(7) faba beans	— 1 (D)

3) One paper concerned with herbicides was also submitted.

Surveys

Thailand

Wongkaew reported on a survey of virus diseases of food legumes in Thailand. There are presently 17 different virus diseases affecting eight species of food legumes in Thailand. Most of the food legumes concerned are not indigenous to Asia and most of the viruses have been introduced — some in germplasm introduced for experimental purposes. The introduction of peanut stripe into Thailand has been of particular concern. It is recommended future (research) attention be directed to (1) establishing suitable quarantine measures to prevent the inadvertent introduction of new virus diseases (2) the identification and control of seed-borne legume viruses, including epidemiological studies.

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Indonesia

Rizvi et al. reported on a survey of diseases of soybean and peanut in Indonesia. Diseases are considered to be a major cause of yield loss in both these crops.

For soybean, the major diseases are (1) soybean mosaic virus, (2) rust and (3) bacterial pustule. For peanut the major diseases are (1) peanut mottle, (2) *Cercospora* leaf spots, (3) dust, and (4) bacterial wilt.

The significance of peanut diseases in Indonesia was further amplified by Middleton and Machmud, who made a quantitative assessment of the relative importance of different diseases in several locations in Indonesia in 1985. The objective of the survey was to provide a quantitative database for future research. The survey showed that bacterial wilt (*Pseudomonas solanacearum*), fungal foliar diseases and virus diseases (particularly peanut mottle and peanut mosaic) are important in Indonesia. There were marked differences in the relative importance of these diseases in different growing environments; the distribution of the diseases was also non-uniform. The significance of the diseases varied with varieties. In general, the local Indonesian varieties had a lower disease incidence than more recently introduced varieties.

Future research in Indonesia will be concerned with: (1) continued breeding for resistance and bacterial wilt; (2) characterisation of virus pathogens; (3) control of fungal leaf spots and rust.

Peanuts

Bacterial Wilt

Bacterial wilt resistance has been studied in considerable detail in Indonesia. Hayward et al. compared two inoculation methods, one by inoculating the axil of the third fully expanded leaf, and the other by root dipping. The leaf axillary inoculation method gave a more reliable differentiation of resistant and susceptible varieties. The root inoculation method was too severe, with varieties known to be field resistant showing 20-30% wilted plants. Other factors such as the source of the bacterial isolate and the age of the plant at inoculation also affected the behaviour of the peanut varieties to inoculation.

Machmud and Middleton used the leaf axil inoculation technique to evaluate resistance to bacterial wilt infection of local and introduced peanut varieties in Indonesia. Comparable results were obtained by field and glasshouse evaluation techniques, leading them to suggest that initial evaluation of material can be done by greenhouse screening. Most Indonesian varieties screened were resistant to bacterial wilt at different locations, while most introduced material was susceptible.

Peanut Rust — Philippines

Another important disease of peanut is peanut rust (*Puccinia arachides*). Opina and Valencia compared the behaviour of the pathogen on resistant and susceptible varieties. They showed that resistance in a variety was correlated with the blockage of the germination process and the suppression of appressorium formation and sporulation; the suppression of these factors in the pathogen consequently reduced the rate of epidemic development.

Peanuts — Northwestern Australia

Peanut rust and *Cercospora* leaf spots are reported by McNeil and Bennett to be major yield constraints in peanuts grown in northwestern Australia. Both diseases may be controlled by the use of fungicides. However, varying intensity of the diseases from year to year and the high cost of chemicals and their application necessitate the establishment of optimal spray schedules. Alternative disease control practices were compared by the authors, to identify the most economic control strategy.

The results suggest that a combination of partly (tolerant?) resistant varieties and a climate-based spray decision model have the potential to maximise returns to investment both in years of intense and moderate disease pressure.

Pigeonpea

Pigeonpea (*Cajanus cajan*) is grown predominantly in South Asia. It is grown to a lesser extent in Africa, Central America, Australia and Southeast Asia. It is a crop of potential commercial interest in Australia and some Southeast Asian countries. It is likely to encounter more disease problems in these areas as acreages increase.

Approximately 50 pathogens have been reported to infect pigeonpeas, but only a few are of economic importance. These are:

Fusarium wilt	— India and Africa
Sterility mosaic	— India
Phytophthora blight	— India
Witches broom	— C. America
Rust	— C. America
Leaf spot	— Africa

Annual losses of $A113 m are due to *Fusarium* wilt and sterility mosaic in India.

Raju and Nene report from ICRISAT on the breeding for resistance to *Fusarium* wilt, sterility mosaic and *Phytophthora* blight for several years. Sources of resistance to these diseases have been identified. Some lines with multiple disease resistance have been released in India and Fiji (cv. Kamica).

Pigeonpeas in Fiji

One of the important factors limiting pigeonpea cultivation in Fiji is stem canker disease, caused by *Botryosphaeria xanthocephala*. The disease occurs at late flowering and green pod stages. It may be associated with the severe flower drop problem in Fiji.

Kumar et al. report on research in Fiji on the identification of resistant/tolerant varieties (cf. Kamica and Station 154), and the need for further studies to clarify the linkage of the disease with flower drop.

Insect Resistant Pigeonpea

Insects are a major problem on pigeonpea. Approximately 200 insect species have been reported as damaging pigeonpea in India. Most are of little importance. The two important pests are the pod borer (*Heliothis armigera*) and the pod fly (*Melanagromyza obtusa*).

Lateef et al. report on attempts at ICRISAT since 1976 to develop pigeonpea with useful insect resistance. They have used innovative mass-screening techniques over several years to identify useful sources of resistance to both *Heliothis* pod borers and pod flys.

Current research is aimed at combining resistance to insect pests with other desirable agronomic traits and resistance to major diseases.

Pigeonpea Pest Management in India

Sachan describes the spectrum of insect pests affecting pigeonpea in India. Pigeonpea varieties are grown for different maturity periods (early, medium and late). Most are intercropped and grown under rainfed conditions. The insect pests associated with early pigeonpeas differ greatly from those affecting medium and late maturing types. For early types, the major pests are spotted pod borer (*Maruca testulalis*), podfly, *Heliothis* borers, *Bruchus* spp., leaf webber and butterfly. Medium and late types are affected by *Heliothis*, podfly eriophyid mite, blister beetles, and others.

Effective pest management is possible using insecticides. Little success has been achieved with host resistance on biological control to date.

Pigeonpea Pests in India

Sehgal and Ujagir have quantified some of the losses caused by pests of pigeonpea in India particularly podfly (*Melanagromyza obtusa*) pod borer (*Heliothis armigera*) and the flower and pod webber (*Maruca testulalis*). Maximum yield losses occur during pod formation and maturation stages.

Bilapate has reported studies on the population dynamics of *Heliothis armigera* in India, including studies on the key mortality factors over several seasons. These types of studies may provide a basis for integrated pest management of *Heliothis* on pigeonpea.

Chickpea

Multiple Disease Resistance

Major diseases of chickpea are: *Ascochyta* blight (*Ascochyta rabiei*); Grey mould (*Botrythris cinerea*); Wilt (*Fusarium oxysporum* f. sp. *ciceri*); Foot rot (*Operculella padwickii*); Root rot (*Rhizoctonia pataticola*). These diseases cause heavy losses in production, and often occur in combination. Singh et al. report that these diseases can now be overcome by the use of multiple disease resistance, which is now available in India.

Ascochyta Blight

Verma and Singh report in more detail on the genetics of *Ascochyta* blight in the Punjab. Several stable genetic sources of resistance have been identified from studies on the genetics of the host and the pathogen. Resistance is due to a number of major genes in the host, reinforced by several minor genes. Long-term genetic control of chickpea blight can be achieved by developing multiline varieties or by concentrating diverse major and minor genes for resistance into a desirable agronomic base.

Studies by Singh are concentrating on the development of *durable* resistance to *Ascochyta* blight, a goal which has proved elusive in earlier attempts at breeding for resistance, but which now looks more promising.

Insect Pests

Chickpeas are also attacked by gram pod borers (*Heliothis armigera*), especially in irrigated areas. Chauhan and Ombir report on studies on their management in Hisar, India by use of insecticides and appropriate cultural practices, particularly intercropping with wheat.

Soybean

Bacterial Pustule

Perhaps surprisingly, only one paper was contributed on soybean pests or diseases. This was a report from Wang and Tschanz concerned with bacterial pustule (*Xanthomonas campestris* pv. *glycines*). Bacterial pustule is one of the most important diseases of soybean in Southeast Asia, especially during the rainy season. High levels of resistance are available in several lines of tropically adapted soybeans developed at AVRDC. Some of these lines are high yielding, widely adapted and resistant to other diseases.

However, a rapid mass screening technique is needed to incorporate available pustule resistance into other locally acceptable cultivars. Unfortunately, recent attempts to develop a seedling test have been unsuccessful, due to low or variable infectivity of the pathogen into soybean seedlings. Field screening remains the most reliable indicator of resistance susceptibility of soybean varieties to bacterial pustule.

Cowpea

Rust

Cowpea is a crop of growing interest in northeast Thailand. Pachinburavan and Siriwong have studied the effects of rust on cowpea yields, and shown that rust is a major limiting factor in cowpea production in northeast Thailand. The rust spreads rapidly in dry-season irrigated plantings and during the sporadic rains at the beginning and end of the rainy season.

Faba Beans (*Vicia faba*)

The major diseases of faba beans are: chocolate spot (*Botrytris fabae*); *Ascochyta* blight (*Ascochyta fabae*); rust (*Uromyces viciae-fabae*). These diseases often occur together and act synergistically to create complex disease problems.

Hanounik and Saxena report on ICARDA's program to identify sources of resistance to each of these diseases and to combine them into progenies with multiple disease resistance. Faba beans with purported resistance to two or three major diseases will be available for testing in different geographical areas in 1986–87.

Green Gram *(Vigna radiata)*

Rajapakse and Charles report on the pulse beetle (*Callosobruches maculatus*) as the most important storage pest of green gram in Sri Lanka. The pest initiates damage in the field, and completes its life cycle when the mungbean seeds are brought into storage. There are varietal differences in susceptibility to beetle damage, with some varieties such as Utong (which is widely grown in Thailand) being resistant to beetle damage.

Peas (*Pisum sativum*)

Criteria for assessing resistance to pea leaf miner (*Chromatomyia horticola*) were studied by Sehgal et al. in India. Satisfactory criteria were identified to differentiate resistant and susceptible varieties.

Herbicides

Weeds are a major constraint to food legume production in the Philippines and probably elsewhere in Asia. In the Philippines, soybean and peanut production are seriously hindered by weeds.

Pamplona and Tinapay report on herbicide trials, using new generation, post-emergence herbicides. Some of these gave effective control of grass weeds in legume crops. The economics of the use of such herbicides needs further consideration.

Life-Tables and Key Mortality Factors for Field Populations of *Heliothis armigera* on Pigeonpea

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Heliothis armigera is a major pest of pigeonpea in India. Under natural field conditions, weather factors and natural enemies are known to play an important role and limit its population increase (Bilapate 1984). The use of life-tables in the natural environment has been considered one of the most important approaches in understanding population dynamics of an insect pest (Harcourt 1969; Morris and Miller 1954). The studies on key mortality factors of *H. armigera* on pigeonpea (1979–80 through 1983–84) are summarised in Table 1.

TABLE 1. Key mortality factors in larvae and pupae of *H. armigera* during three generations on pigeonpea.

Year	Vulnerable instar X	Percentage mortality 100 qx	Trend index (I)
1979–80	III–VI	3.56–21.61	Negative
1980–81	I–VI	2.04–10.36	Negative
1981–82	I–VI	2.56–10.00	Positive-negative
1982–83	I–VI	3.13–16.00	Negative
1983–84	I–VI	1.12–39.10	Positive-negative

Heliothis completed three regular generations during crop growth on pigeonpea. The positive trend index values indicated an increase in pest population in succeeding generations. The parasite *Campoletis chlorideae* was an important factor in mortality of *Heliothis* larvae on pigeonpea, occurring in the third instar. The *Carcelia* sp. parasitised *Heliothis* larvae in late instars. Mortality of larvae also occurred due to nuclear polyhedrosis virus infections. The pupal parasite, *Goniophthalmus halli* parasitised the pupae during crop growth. Other parasites viz. *Enicospilus biconatus*, *Eriborus argenteopilosus*, *Chelonus* sp. and *Palexorista* sp., were recorded. Except during September, the population levels of the pest always remains high and requires control. Studies of this type may indicate certain clues for integrated pest management in pigeonpea.

Bilapate, G.G. 1984. Agril. Rev. 5 (1), 13–26.
Harcourt, D.G. 1969. Ann. Rev. Ent. 14, 175–196.
Morris, R.F. and Miller, C.A, 1954. Can. J. Zool. 32, 283-301.

Management of Insect Pests of Chickpea

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Gram pod borer *Heliothis armigera* inflicts heavy losses to chickpea, especially in irrigated areas. Peak activity is during the podding phase, from mid-March to April. During the vegetative phase, severe winter conditions keep the population low. A single spray of endosulfan 0.07% at pod initiation has been effective and economical. Monocrotophos 0.04% and the synthetic pyrethroids cypermethrin 0.006%, decamethrin 0.002% and fenvalerate 0.008% are also effective. However, since this is a regular and serious pest, efforts have been made towards integrated pest management. Two cultural practices have been investigated.

Intercropping chickpea with wheat or *Gobhia sarson* (one row of wheat/*Gobhia* between two of chickpea) reduced pod damage by pod borer in the chickpea crop, and also reduced the larvae population (Table 1).

TABLE 1. Effect of intercropping chickpea on pod borer populations, damage and yield.

Treatment	1983–84		1984–85
	larvae/sq m	% pod damage	% pod damage
Chickpea alone	19.6	7	16.7
Chickpea + wheat	7.8	4	8.3
Chickpea + *G. sarson*	7.2	6	8.6

Removal of the weed *Vicia sativa* between the last week of February and mid March reduced pod loss by an amount comparable to the use of endosulfan (Table 2).

TABLE 2. Effect of weed removal and endosulfan on pod borer incidence in chickpea.

Treatments	% pod damage	% reduction in damage
No weed removal	64.5	—
Weed removal	16.0	75.2
Endosulfan 0.07%	13.1	79.5
Weed removal + endosulfan	10.2	84.5

When chickpea and *V. sativa* were both present, very few chickpeas were chosen as a site for egg lay, whereas 71% of weed plants carried eggs. Over 80% of eggs on the weed were on leaves, and were removed with the weeds during the weeding process.

Sowing chickpea as an intercrop with wheat or *Gobhia sarson*, together with removal of the weed *Vicia sativa* immediately after maximum egg deposition and endosulfan spray at pod initiation will effectively and economically manage pod borer.

Multiple Disease Resistance in Faba Beans

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CHOCOLATE spot (*Botrytis fabae*), ascochyta blight (*Ascochyta fabae*), and rust (*Uromyces viciae-fabae*) are among the most important diseases of faba beans (*Vicia faba*) throughout Asia, North Africa and Europe (Hebblethwaite 1983). These diseases are rarely found in nature separately. Most often they overlap and interact to create complex pathological conditions. Although these diseases individually are quite destructive (Moore 1948), when two or more act in concert, their combined effect becomes even greater (Omar et al. 1985). Therefore, development of cultivars with multiple disease resistance should help stabilise crop production in regions known to suffer from such complex disease problems.

The disease distribution patterns throughout major production regions of faba bean were studied by ICARDA through a system of international disease screening nurseries, and genotypes with resistance to different diseases were identified. Genes for resistance to these diseases were combined and progenies tested under artificial inoculation in the field (ICARDA 1983). These efforts resulted in the development of faba bean lines with resistance to two or three diseases (Table 1).

TABLE 1. Multiple-disease-resistance of F_4 faba bean families to chocolate spot, ascochyta blight, and rust compared with certain local cultivars.

Families and local cultivars	Disease reaction (1)			Recommended planting regions
	Chocolate spot	Ascochyta blight	Rust	
L82003	R	R	NT	N. Africa and Europe
L82005	R	R	R	W. Asia, N. Africa, Europe
L82006	R	R	R	W. Asia, N. Africa, Europe
L82007	R	R	R	W. Asia, N. Africa, Europe
L82010	R	NT	R	Egypt and N. Africa
L82013	NT	R	R	N. Africa and W. Asia
ILB 1814	S	S	S	
Giza-4	S	S	S	
Maris Bead	S	S	S	

1 = Disease readings were recorded three weeks after inoculation where R = resistant, S = susceptible and NT = not tested.

At present, F_6 progenies from these studies are being evaluated in preliminary yield trials. Seeds from these lines will be distributed to different geographical regions in the 1986–1987 season to test the stability of their resistance.

Hebblethwaite, P.D. 1983. The Faba Bean. Butterworths, London, 573p.
ICARDA 1983. Faba Bean Pathology Progress Report-3, 31p.
Moore, W.C. 1948. Bull. 162. Min. of Agr., London, 35p.
Omar, S.A.M., Chapman, G.P. and Bailtss, K.W. 1985. Quad. Vitic. Enol., Univ. Torino, Italy, 243p.

Susceptibility of Peanut Cultivars to Bacterial Wilt in Indonesia: Effect of Method of Inoculation and Isolate Source

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BACTERIAL wilt caused by *Pseudomonas solanacearum* is a problem on peanut in Indonesia, southern China (Mehan et al. 1986) and Malaysia (Lee Choo Kiang, pers. comm.). In order to assess the susceptibility of local and introduced peanut cultivars to bacterial wilt in the glasshouse, two methods of inoculation were used. The first involved injection of 50–100 μl of a suspension containing 10^8–10^9 cfu/ml into the axil of the third fully expanded leaf from the top; in the second the roots of 10–15 cm seedlings raised over water were trimmed with scissors and the seedlings allowed to stand for 30 min in a water suspension of the bacterial pathogen prior to planting in steam sterilised Muara soil. The cultivars Gajah and Pelanduk which were consistently resistant by the axillary inoculation method, showed 20–30% irreversibly wilted plants by the root inoculation method.

There were clear differences in the resistance of peanut cultivars by the axillary inoculation method, Gajah and Pelanduk being the most resistant and Red Spanish, Chico, Tifton 8, A32-20, A27-146 and Mani Pintar the most susceptible. The Indonesian lines 469 and 467 showed some resistance to bacterial wilt, with 469 consistently more resistant than 467.

Some isolates of *P. solanacearum* from crop plants other than peanut and a weed, *Crassocephalum crepidioides*, were as virulent for susceptible peanut cultivars as the most virulent isolates from peanut. There was a marked difference in host susceptibility depending on age of plant at inoculation. Cultivar Red Spanish was more susceptible when inoculated 7 days after transplantation than when inoculated 21 days after transplantation (Table 1). Some isolates of *P. solanacearum* from potato were without effect on any cultivar of peanut following axillary inoculation.

TABLE 1. Reaction of three peanut cultivars of different ages to axillary inoculation with four isolates of *Pseudomonas solanacearum*.

	Cultivar			
	Red Spanish		Gajah	A32 20
Age of plants in days after transplantation	7	21	14	7
Isolate inoculated				
B034C1 ex-peanut	5.0* (12)	3.1 (15)	1.4 (12)	NT**
B01 ex-peanut	5.0 (12)	NT	1.7 (12)	4.6 (5)
B015B ex-bean	4.8 (9)	NT	1.0 (6)	3.2 (6)
B081C ex-*Crassocephalum*	5.0 (9)	NT	1.3 (6)	3.3 (6)

*Average disease index 10 days post-inoculation. Assessment of disease severity based on He et al. (1983): 1 — no symptons; 2 — inoculated leaf wilting; 3 — two or three leaves wilting; 4 — four or more leaves wilting; 5 — plant dead. Figures in parenthesis are the number of plants inoculated.

**Not tested.

He, L.Y., Sequeira, L. and Kelman, A. 1983. Plant Disease, 67, 1357–1361.

Mehan, V.K., McDonald, D. and Subrahmanyam, P. 1986. In: Persley, G.J., ed., Bacterial Wilt in Asia and the South Pacific. ACIAR Proceedings, No. 13, 112–119.

Stem Canker Disease of Pigeonpea in Fiji

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ONE of the important factors which limits pigeonpea cultivation in Fiji is the stem canker disease. This disease was first noticed at Legalega Research Station, Nadi in August, 1984 and was later observed at other places. It usually occurs at late flowering and at green pod stages. The flower drop problems in Fiji may be partly associated with this disease.

Stem canker is caused by a fungus, *Botryosphaeria xanthocephala*. Brown to black small circular lesions (1–2 mm diam) appear along the stem and these may coalesce into bigger spots while others appear as superficial marks. Larger lesions are depressed, with a brown to black scab-like encrustation covering the surface. In most, there is a longitudinal split running parallel to the stem. The margin is bordered by a black shiny gum-like exudate. When pricked with a needle, the centre of the lesion shows a dark brown rotten mass of tissue. Where it has penetrated the bark, a defined dark brown necrotic area is seen surrounded by healthy tissues, and this sometimes develops into a deep-seated canker. Usually the affected stem shows swelling at the base. There is loss of leaves and flowers, and when the canker completely girdles the stem base the plant wilts and dies.

A number of varieties are being screened for resistance to the disease. In 1984, at Legalega Research Station, the varieties Kamica and Station 154 showed a high degree of resistance while other introduced lines at Nasarawaqa were susceptible. In 1985 the disease incidence was low (range 1.0–3.7) at Nasarawaqa and in non-irrigated plots at Legalega Research Station, but was much higher in irrigated plots at Legalega (Table 1).

TABLE 1. Disease incidence on pigeopea lines at Legalega under irrigated conditions, 1985.

Disease range*	
1.0–1.5	Kamica, Royes, Station 43, Station 55, and Station 209
2.0–2.5	Station 8 Early, Station 198, QPL 511 and Kamaal
3.0–3.5	QPL 116 and QPL 265
3.5–4.0	QPL 100, 135, 423, Hunt
4.0–5.0	QPL 38, 40, 67, 69, 103, 122, 123, 128, 131, 146, 207, 322, 356 ICPL 4, 5
5.0+	QPL 3, 10, 17, 44, 58, 61, 95, 97, 102, 134, 136, 148B, 490, 500

*Disease rating 1-9 where 1 = least and 9 = severe disease.

Studies of pathogenicity test procedures and the method of infection of pigeonpea plants cv. Hunt have been initiated at Koronivia. At Legalega Research Station, 20 local and introduced lines are being assessed for stem canker disease using the sick plot technique.

Further studies are needed to evaluate the disease effects under water stress and soil nutrient deficiency conditions. In addition, there is a need to devise quick screening methods for evaluation of varietal resistance to stem canker, and to study the role of the disease in the flower drop problem.

Insect-Resistant Pigeonpea is Feasible

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ABOUT 200 insect species have been reported as damaging pigeonpea in India. However, most of these are of minor, localised or sporadic importance. ICRISAT surveys of farmers' fields showed that two insect pests are of widespread, major importance; *Heliothis armigera*, the pod boror and *Melanagromyza obtusa*, the podfly (Bhatnagar et al. 1981).

Research to develop pigeonpea genotypes that have useful resistance to insect pests began at ICRISAT in 1976. We developed a field screening technique in which we expose large numbers of germplasm accessions in unreplicated small plots to natural pest attacks, and reject all those that have both more damage, and lower yields than in the control cultivars of the same duration group. We then test the survivors in trials containing genotypes with a narrow range of times to flowering, with increasing replication and plot size in each year. From these trials we again reject all that are poorer than the controls. In this way we have screened over 9000 germplasm accessions and have found a few genotypes that have consistently reduced damage, and others that show tolerance.

The large size of the plants and natural outcrossing have posed special problems in this method of screening, but we now have useful levels of resistance to both *H. armigera* and *M. obtusa*. For example, the following are data on percentage of pods damaged by lepidopteran borers and seed yields recorded from genotypes resistant to *H. armigera* compared to control cultivars in one of our advanced screening trials at ICRISAT Centre in 1985–86.

TABLE 1

	Resistant selections		Control cultivars		
	ICPL 332	ICPL 84060	ICPL 131	ICPL 138	SE
Borer damage, (%)	12	8	21	33	+3.4
Yield kg/ha	1840	1400	1320	1440	+168

In a trial at IRRI in the Philippines involving 24 pigeonpea genotypes, 4 of our pest resistant selections, out of the 6 that were entered, were among the 5 top yielding entries. In a trial at ICRISAT Centre (1984–85) the mean podfly damage in podfly-resistant selections ICP 7050, 7946 and 7941 ranged from 1.9% to 7.7%, compared with 22.5% in a susceptible cultivar ICP 7337-2-S4.

Unfortunately our podfly-resistant selections generally have small seeds and our *H. armigera*-resistant selections are very susceptible to fusarium wilt. We are now attempting to combine resistance to insect pests with other desirable traits, and to increase the levels of resistance, by crossing selected parents. We are confident that cultivars incorporating useful levels of resistance to these insect pests will be utilised profitably in farmers' fields in the near future.

Bhatnagar, V.S., Lateef, S.S., Sithananthan, S., Pawar, C.S. and Reed, W. 1981. Proceedings of the International Workshop on *Heliothis* Management, ICRISAT, 385–396.

Evaluation of Bacterial Wilt Resistance in Peanut

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BACTERIAL wilt caused by *Pseudomonas solanacearum* is a potential problem of peanut production in Indonesia. Field surveys during the wet season 1984–85 and dry season 1985 indicated that bacterial wilt was widely distributed in Indonesia and on various host plants including peanut. Most of the *P. solanacearum* isolates from peanut were of race 1 or biovar 3 which were highly pathogenic to peanuts and other hosts (BORIF 1986; Machmud 1986; Hayward et al. 1986, unpubl.).

Field screening by natural infection showed that most of the Indonesian cultivars were resistant to bacterial wilt at different localities. Many of the introduced cultivars and lines showed variable reactions, although in the greenhouse tests by artificial inoculation they were susceptible (Table 1).

TABLE 1. Reactions of 12 peanut varieties and lines to bacterial wilt, *Pseudomonas solanacearum* (BORIF 1986; Machmud 1986).

		Disease reaction[1]		
Variety/Line	Origin	Cikeumeuh Field	Jakenan Field	Greenhouse
Gajah	Indonesia	R (8.8)	R (0.5)	R (8.0)
Tupai	Indonesia	R (9.1)	R (0.0)	R (9.6)
Kidang	Indonesia	R (8.5)	R (0.2)	R (8.4)
Pelanduk	Indonesia	MR(12.8)	R (0.0)	MR (20.4)
No. 467	Indonesia	S(77.7)	R (5.8)	S (80.0)
No. 469	Indonesia	S(75.3)	R (5.4)	S (76.0)
Mani Pintar	S. America	S(70.5)	R (5.1)	S (84.0)
Chico	USSR	S(88.7)	R (0.2)	S (96.0)
Early Bunch	USA	S(88.2)	R (6.5)	S(100.0)
Tifton 8	USA	S(69.8)	R (6.0)	S (96.0)
A27-146	Australia	S(70.4)	R (5.8)	S(100.0)
A32-20	Australia	S(78.6)	R (6.5)	S (96.0)

[1]Disease reactions: R = resistant; MR = moderately resistant; S = susceptible.
Numbers within the brackets are wilt intensity (%); greenhouse trials using leaf axil inoculation technique.

Several artificial inoculation techniques used in the greenhouse to evaluate the resistance of peanuts to bacterial wilt gave good results (Table 2).

TABLE 2. Bacterial wilt intensities on four peanut cultivars inoculated with *Pseudomonas solanacearum* using different inoculation techniques (Machmud 1986).

	Bacterial wilt intensity (%)[1]			
Inoculation technique	Gajah	Tupai	Red Spanish 119	Early Bunch
Leaf-axil wounding	8	4	80	84
Tooth-pick method	8	8	84	88
Hypodermic method	12	8	88	88
Root dipping	28	20	100	100
Root drenching	16	20	80	80

[1]Gajah and Tupai resistant; Red Spanish 119 and Early Bunch susceptible.

Greenhouse tests should be used in initial evaluation of bacterial wilt resistance on peanuts, followed by field (sick plot) verification.

BORIF 1986. Balai Penelitian Tanaman Pangan Bogor. 19p.
Machmud, M. 1986. Proc. Symp. Tanaman Pangan. Sukamandi, Indonesia. Jan 16–18.

Management Systems for Peanut Leaf Diseases in Northwestern Australia

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LARGE kernel peanut production is an expanding industry in the Ord River Irrigation Area (129°E, 16°S). Production is on deep sands with supplementary overhead irrigation during the monsoon season. The resultant high humidities and temperatures during this period make leaf diseases (rust (*Puccinia arachidis*) and leaf spot (*Cercospora* sp.)) a major limitation to yield. Effective chemical means are available to control these diseases. However, the varying intensities of disease from year to year and the high cost of chemicals and application necessitate the establishment of an optimal spray schedule. Several means of scheduling sprays either alone or in combination with other factors were tested for three years. One set scheduled sprays on a time basis, either at constant intervals or for only part of the growing season. A second method was to base spray decisions on a simple climate model. In this model a scheduled 10-day interval spray was omitted if there had not been at least two rain days and a total rainfall of greater than 20 mm in the preceding four days or since the last omitted spray. U.S. based work has indicated that spray advisories can give good control of leaf disease in peanuts (Jensen and Boyle 1966). However, their system has not been shown to work adequately in an area in eastern Australia (Qld. DPI, pers. comm.). Such a system may not then be useful in different conditions. Use of partly resistant or tolerant, high yielding varieties may also be of some benefit as may varying the fungicide used. Table 1 indicates the economic returns from some of the alternative control strategies tested. These are based on hand harvested yields and are thus the maximum potential returns. The data are simplified as only the changes in chemical and aerial application costs are included (I–C or extra income–extra disease control costs in Table 1).

TABLE 1. Economic benefits of different spray strategies using chlorothalonil (1.3 kg/ha) to control leaf diseases in peanuts.

	1983–84		1984–85		1985–86	
Spray option	Sprays	I–C ($A/ha)	Sprays	I–C ($A/ha)	Sprays	I–C ($A/ha)
VB 20 day[a] interval	-	—	5	−358	4	195
VB 10 day[a] interval	10	1858	10	−86	8	904
VB 10 day[a] early season	6	1118	6	−240	—	—
VB climate[a] model	—	—	—	—	4	949
NC 5 none[b]	—	—	—	—	0	709
NC 5 10 day[b] interval	—	—	—	—	8	273
NC 5 20 day[c] interval	—	—	—	—	4	331
NC 5 10 day[c] interval	—	—	—	—	8	468

VB = Virginia Bunch standard variety, NC 5 = partially resistant new variety.
[a]uses unsprayed VB as control.
[b]uses VB with same spray regime as control (effect of variety alone).
[c]uses unsprayed NC 5 as control (effect of sprays alone).

The data suggest that a combination of partly resistant varieties and a climate-based spray decision model may give the highest return on investment in both years of intense and moderate disease pressure. The data also suggest however, that several years data are essential to evaluate any model.

Jensen and Boyle 1966. Plant Disease Reporter, 810–814.

Indonesian Peanut Disease Survey

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DISEASES are suspected of being a major constraint to production of peanuts in Indonesia, but published disease records from the area (e.g. Schwarz and Harley 1926) are sparse and considered out-of-date. Certainly such records are an unreliable base from which to select an appropriate direction for an interdisciplinary, collaborative program aimed at reducing or removing such constraints.

As an initial phase of peanut improvement in Indonesia, disease trap nurseries were established at Tamanbogo in southern Sumatra, Cikeumeuh in west Java, Jakenan in central Java, Muneng and Jambegede in east Java and Bontobili in South Sulawesi during the 1985–86 wet season. At each site, seven Indonesian cultivars and seven introduced cultivars were sown in each of two blocks.

Severity of seven diseases was recorded at 14-day intervals during crop growth, using a 0–4 scale for each rated plant. Individual ratings were aggregated into a percentage of the maximum possible score. The diseases rated were Peanut Stripe Virus (PStV), Peanut Mosaic, Witches Broom, Bacterial Wilt (*Pseudomonas solanacearum*), Late Leafspot (*Phaeoisariopsis personata = Cercosporidium personatum*), rust (*Puccinia arachidis*) and fungal root rots. Bacterial Wilt, PstV, Witches Broom and the fungal foliage diseases could be accurately identified by symptoms; the causal agent of mosaic needs to be more accurately determined; and fungal root rots included any fungal infection of roots or the plant crown.

Fungal root rots were not serious. PstV severity was uniformly high on all cultivars at three sites in central and east Java, but some of the introduced cultivars were less severely affected at Tamanbogo and Cikeumeuh, while only one (introduced) entry was appreciably infected at Botobili. Mosaic severity was highest at Jakenan and Muneng, and low at Jambegede, Cikeumeuh and Bontobili, irrespective of cultivar. At Tamanbogo three introduced cultivars were less severely affected than the others. Witches Broom was severe only at Jakenan, and at that site some Indonesian cultivars were less diseased than the remainder. At Cikeumeuh, the only site where Bacterial Wilt was severe on Indonesian cultivars, the two most recently released Indonesian cultivars had most disease. At Bontobili, the introduced material was also severely diseased, but some variability in wilt severity was evident.

At sites where leafspot pressure was low, some introduced material seemed to be less severely affected. A similar pattern was seen for rust. The apparent lack of these diseases at Cikeumeuh was due to absence of test plants, killed by Bacterial Wilt.

The results show that Bacterial Wilt, fungal foliage pathogens and virus diseases can be important in the Indonesian environment. Marked differences existed between sites, so appropriate sites suited to particular phases of the project can be selected for all important diseases. Variations in disease severity among cultivars were common for all diseases, but these differences were often overcome by heavy disease pressure.

Future research towards control of Bacterial Wilt will concentrate ultimately on host plant resistance and understanding its inheritance. Better characterisation of the virus pathogens is planned, while leafspot and rust may be manageable using combinations of chemical and genetic controls. Assessment of losses due to these diseases is in progress.

Schwarz, M.B. and Hartley, C. 1926. Inst. V. Plantenziekten (Dutch East Indies). Meded, 71, 37p (English summary).

Cohort Life and Reproductivity Tables of *Puccinia arachidis* Causing Rust of Peanut

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LIFE and reproductivity tables are used extensively in ecology for better understanding of the dynamics of animal populations. Since the assumption of such techniques does not generally apply to plants or fungal pathogens, we used another type, the cohort life table to which reproductivity is added to analyse the population dynamics of *P. arachidis*. Cohort life and reproductivity tables contain statistics such as mortality and survival of infection units undergoing various states of infection cycle, reproductive rate, generation time and maximum relative growth rate of *P. arachidis*. These statistics could be used as parameters to evaluate epidemic development of peanut rust and give insight into how it could be managed effectively.

When a cohort of uredospores (about 24 units/sq cm) was allowed to undergo an infection cycle on intact leaves of three peanut varieties, survival of infection units varied according to the states of infection process and variety (Table 1). Low survival rates were associated with uredospore germination and appressorium formation that were more apparent on UPL-Pn4. This resulted in about two-fold reduction of infection efficiency (IE) compared with the two susceptible varieties. Consequently, a lower estimate of the relative growth rate was obtained. The mean generation time (14 days) did not vary among varieties.

TABLE 1. Survival and reproductivity of *P. arachidis* on leaves of peanut cultivars.

State of Infection	BPI-Pq	UPL-Pn2	UPL-Pn4
Survival			
Germinated — total spore ratio (GTR)	0.43	0.30	0.18
Germtube — germinated spore ratio (GSR)	0.53	0.48	0.60
Appressorium — germtube ratio (AGR)	0.30	0.33	0.26
Pustule — appressorium ratio (PAR)	0.74	0.85	0.94
Pustule — total spore ratio (IE)	0.05	0.04	0.02
Reproductivity			
Net reproduction rate (unit/pustule)	262	153	64
Generation time (days)	14	14	14
Max. relative growth rate (unit/day)	0.40	0.36	0.30

Results indicate that the degree of resistance conferred by UPL-Pn4 against *P. arachidis* can be attributed to its ability to block the germination process and appressorium formation, suppress sporulation and consequently reduce the rate of epidemic development.

Effects of Rust Disease on Yield of Cowpea

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UROMYCES APPENDICULATUS is an important foliar pathogen causing rust disease on cowpea. Rapid spread of cowpea rust in dry-season irrigated plantings and during the sporadic rains at the beginning and end of the rainy season has been observed in northeast Thailand and elsewhere (Williams 1975). Low yield of cowpeas grown locally was in part attributed to rust infection. This study was designed to determine the effect of rust infection on yield of cowpea.

The experiment was conducted at the end of the rainy season, from October to December 1985, at Khon Kaen University Experiment Station. A susceptible cultivar (Red Cowpea U.S. 6-1) was planted at 30 × 50 cm spacing within and between rows in 3 × 5 m plots. A rust epidemic was developd by artificial inoculation of infector rows planted two weeks earlier. Fungicide applications with oxycarboxin 200 g/l E.C. (0.4 l/ha) were made on a biweekly schedule to suppress rust infection in control plots. Treatments were arranged in a randomised block of four replications. Disease assessments were made 50 days after planting, using the infection index method (Horsfall and Heuberger 1942). Five centre rows of each plot were manually harvested for yield determination.

TABLE 1. Effect of rust disease on total yield of cowpea.

	Infection index (%)	Total yield (kg/ha)
Rust	94.8	829+
Control	19.6	1045+

+ Significantly different at P = 0.05.

Rust infection was first observed three weeks after emergence and became widespread throughout experimental plots by the time of disease assessment. Fungicide treatment provided a good level of disease control through most of the growing period, resulting in significant yield differences as shown in Table 1. The results indicate that rust is a major limiting factor in cowpea production. Effective and economical means for its control need to be studied in greater detail.

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The Potential of New Generation Post-Emergence Herbicides for Increasing Food Legume Production in the Philippines

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ONE of the major constraints to yield of food legumes in the Philippines, particularly soybeans (*Glycine max*) and peanut (*Arachis hypogaea*) is weed competition. Of major concern is the grass weed (*Rottboellia exaltata*) which dominates more than 60% of the areas grown to legumes in this country. Studies show that weeds reduced the yield of soybeans and peanut by 68% or more (Robles 1979).

The most common methods of weeding used in these crops, namely mechanical cultivation and the application of pre-emergence herbicides, do not adequately control weeds. With mechanical interrow cultivation, the weeds between the rows but not within the rows are destroyed. Weeds that are left in the rows reduce yield by 40% or more (Pamplona 1979). In the case of pre-emergence application of herbicides, particularly pendimethalin (N-(ethyl propyl)-3, 4 dimethyl-a, 6-dinitrobenzinamine), the duration of control of 20–30 days is inadequate to cover the critical period of crop-weed competition, which in these crops is 40–50 days. Weeds which emerge after 20–30 days are still capable of reducing the yield by 50% or more.

Studies carried out for the last two years in the Philippines show that a number of post-emergence herbicides can adequately and selectively control grass weeds in legumes. Two of these most promising herbicides are fluazifop-butyl (butyl 2-(4-5-triflurometheyl-2-pyriloxy)) propionate and sethoxydim (2-(2-ethoxydim) butyl-5 (2-ethylthio propyl) — 3-hydroxy-2- cyclohexen-1-one) (Table 1).

TABLE 1. The influence of herbicide application on the weed weight and bean yields (t/ha) of soybeans and peanut (average of four trials).

Herbicide treatment	Rate (kg a.i./ha)	Soybeans		Peanut	
		Weed wt.	Bean yield	Weed wt.	Bean yield
Fluazifop-butyl	0.15	0.17^{b} +	1.47^{b} +	0.04^{b} +	1.83^{ab} +
Fluazifop-butyl	0.19	0.11^{b}	2.04^{a}	0.06^{b}	1.93^{a}
Sethoxydim	0.40	0.90^{b}	2.32^{a}	—	—
Sethoxydim	0.80	0.01^{a}	2.37^{a}	—	—
Pendimethalin	1.25	1.50^{bc}	0.50^{c}	0.21^{c}	1.10^{c}
Unweeded	—	2.30^{c}	0.33^{c}	0.00^{a}	0.40^{d}
Weed-free	—	0.00^{a}	2.40^{a}	0.37^{d}	1.87^{ab}

+Numbers having similar superscript in the same column are not significantly different at 5% level, DMRT.

As revealed in a series of trials, these herbicides are more effective when the grass weeds are sprayed at five-leaf stage rather than at the early or later stage. Moreover, it has been found that efficacy of herbicides is improved when used with mineral oil.

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Robles, R.P. 1979. Weeds and Weed Control in Legumes. In: Developments in Pest Management in the Philippines, 134–149.

Laboratory Observations on Rate of Development and Oviposition of *Callosobruchus maculatus* on Different Varieties of Green Gram

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THE pulse beetle *Callosobruchus maculatus* (Bruchidae, Coleoptera) is the most important storage pest of green gram (*Vigna radiata*) in Sri Lanka. The pest initiates damage in the field where green gram is grown as a rotational field crop in the dry zone of Sri Lanka, and completes its life cycle when brought into the storehouse. El-Sawaf (1956) bred *C. maculatus* on cowpea over the range 18–35°C and 55–90% RH. Rahman et al. (1943) have compared the susceptibility of 11 kinds of seeds to attack by *C. maculatus*.

The rate of development and oviposition of *C. maculatus* was studied over a wide range of constant temperatures and humidity with the use of different varieties. The mean developmental period of the pest was shortest at 30°C and 70% RH, although most beetles emerged at 25°C. As components of this development period, the duration of the egg stage was shortest at 70% RH (and longest at 30% RH) and 90% egg hatch occurred at 70% RH (poorest egg hatch occurred at 90% RH). Similarly, high (80%) egg hatch occurred at 20–30°C, and no eggs hatched at 40°C. Green gram varieties Utong 1, H101 and CES 87 were considered relatively resistant to beetle damage with prolonged developmental periods. MI 3, Local CVI, Type 51 varieties were heavily susceptible to beetle attack. Most of the eggs were laid on the first day of free adult life in all experimental conditions by *C. maculatus*.

The most important lines for future research with *C. maculatus* would appear to be nutritional studies analysing dietetic requirements, inhibitory factors and influence of physical properties of seeds and oviposition studies determining attractiveness of seeds.

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The Value of Disease-Resistant Pigeonpea

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PIGEONPEA (*Cajanus cajan*), an important food legume crop, is grown in the Indian subcontinent, Southeast Asia, Africa, Central America and Australia. More than 50 pathogens have been reported to affect pigeonpea (Nene et al. 1984) but only a few are of economic importance (Kannaiyan et al. 1984). These are fusarium wilt (*Fusarium udum*) in the Indian subcontinent and Africa, sterility mosaic (virus?) and phytophthora blight (*Phytophthora drechsleri* f.sp. *cajani*) in India, Witches Broom (mycoplasma?) and rust (*Uredo cajani*) in the Americas and leaf spot (*Mycovellosiella cajani*) in Africa.

Based on the pigeonpea disease surveys conducted during 1975–1980 Kannaiyan et al. (1984) estimated annual loss of US$113 million due to fusarium wilt and sterility mosaic in India alone and a loss of $5 million due to fusarium wilt in eastern and southern Africa.

The most effective means of minimising such huge losses is to grow resistant varieties. ICRISAT realised this and started research on developing resistant cultivars. Effective field and glasshouse techniques to screen a large number of genetic resources, accessions and breeding materials against fusarium wilt, sterility mosaic and phytophthora blight were developed. Several sources of resistance to fusarium wilt (Nene and Kannaiyan 1982), sterility mosaic (Nene and Reddy 1976), and phytophthora blight (Kannaiyan et al. 1981) were identified. Some of these have multiple resistance to two or more diseases and are being used in ICRISAT's breeding program. Multilocation screening of sterility mosaic-resistant lines in India and of some wilt-resistant lines in India and parts of Africa indicated that some (e.g. ICP 7786 for sterility mosaic, ICP 8863 for wilt) have resistance across locations.

Some pigeonpea lines from ICRISAT have been released for cultivation in India and Fiji. ICP 8863 was released as 'Maruthi' for cultivation in Karnataka state of India mainly for its fusarium-wilt resistance. ICPL 151 (tolerant to sterility mosaic) is a candidate for release in northern India and ICP 7035 (resistant to fusarium wilt and sterility mosaic and tolerant to Phytophthora blight) has been released in Fiji as Kamica.

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Food Legume Improvement Constraints in Indonesia — A Disease Survey

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SOYBEAN and peanut are the most important food legumes in Indonesia and are mostly used for human consumption. However, soybean is also used for animal feed and as a raw material in industry. Average yields for soybean and peanut are 1.0–1.5 t/ha and 0.9–1.6 t/ha, respectively. These yields are much lower than in USA, Canada and Japan (Nurdin and Zen 1985). Several factors influence these lower yields. One of these is plant disease. An average yield loss of 50% of soybean due to soybean mosaic virus, transmitted through seed and by insect vector, has been reported if there was no crop protection (Sinclair 1982). Similarly, bacterial wilt (*Pseudomonas solanacearum*) can cause a total yield loss in case of susceptible peanut cultivars (Porter et al. 1984).

During 1983-1986, farmers' fields in various provinces of Indonesia were surveyed and research experiments were conducted at the Maros Research Institute for Food Crops (MORIF) in South Sulawesi to identify and characterise the major diseases of soybean and peanut in Indonesia. A collaborative survey (between the Indonesian Central Research Institute for Food Crops (CRIFC) and the Australian Centre for International Agricultural Research (ACIAR)) of peanut diseases was completed during 1985.

The results of the surveys and experiments are shown below. Major diseases and the causal agents were:

- *Soybean* Soybean Mosaic Virus (SMV); rust, caused by *Phakospora pachyrhizi*; Bacterial Pustule, caused by *Xanthomonas campestris* pv. *glycines*.
- *Peanut* Peanut Mottle Virus (PMV); leaf spots caused by *Cercospora arachidicola* or *Cercosporidium personatum*; rust, caused by *Puccinia arachidis*; Bacterial Wilt, caused by *Pseudomonas solanacearum*.

These diseases cause heavy losses in the absence of protection. For the first time, the occurence and identification of soybean mosaic virus (SMV) was reported from South Sulawesi.

Efforts are now under way at MORIF to develop effective measures to increase the production of soybean and peanut in Indonesia by an integrated use of various chemicals (to control food legume diseases and their vectors), cultural practices, and introduction and selection for adaptation of disease-resistant and high yielding varieties.

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Pigeonpea Pest Management in India under Major Farming Systems

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USING maturity period, pigeonpeas may be grouped into three categories viz; early, medium and late. The early crop is usually planted during June–July, harvested by late November to mid-December, and followed by wheat. The medium and late maturity crops are planted in July and harvested during March to early May. Early and late pigeonpea crops are generally intercropped with cereals like sorghum and pearl millet, pulses such as urdbean, mungbean and cowpea, oilseeds like sesame, sunflower, safflower, groundnut and cotton, or vegetables such as chillies and tomatoes. In India the major cropped area is under late pigeonpea and mainly under rainfed conditions. The most prevalent crop combinations of pigeonpea + sorghum, and pigeonpea + pearl millet are widely grown throughout the country.

The insect pests associated with early pigeonpea greatly differ from those in medium and late maturing types. In general, damage caused to the crop by insect pests at the vegetative stage is negligible; however, severe damage to the crop occurs at reproductive stage. Important insect pests damaging early pigeonpea are spotted pod borer *Maruca testulalis*, leaf webber *Cydia critica*, bud butterfly *Lampides boeticus* and *Euchrysops cnejus*, podfly *Melanagromyza obtusa*, gram pod borer *Heliothis armigera* and *Bruchus* spp. In case of medium and late types the major insect pests recorded are gram pod borer, podfly, plume moth *Exelatis atomosa*, brown bug *Clavigralla gibbosa*, eriophyid mite *Aceria cajani* and blister beetles *Mylabris* spp. Surveys carried out during 1975–81 to assess the extent of damage by pod borers revealed that average damage to pods was 33.8(NZ), 44.0(NWZ), 48.0(CZ) and 49.9(SZ) per cent in different zones of the country (Lateef and Reed 1983). No significant differences in pod borer damage have been recorded in pigeonpea crops grown alone or intercropped with other crops (Table 1) (Sachan 1983–1985).

TABLE 1. Effect of intercropping of various pulses on the incidence of insect pests in pigeonpea.

Treatments*	% pod damage***	Treatment**	% pod damage	
			Podfly	Pod borer
Pigeonpea alone	30.42	Pigeonpea alone	34.07***	30.15***
Pigeonpea + urdbean	46.37	Pigeonpea + sorghum (3:2)	24.09	30.95
Pigeonpea + green gram	41.71	Pigeonpea + sorghum (1:1)	31.56	31.85
Pigeonpea + cowpea	37.19	Pigeonpea + sorghum (2:2)	28.95	32.78
Pigeonpea + maize	42.18	Pigeonpea + sorghum (in line)	32.59	34.39
Pigeonpea + sorghum	43.49	Pigeonpea + sorghum (broadcast)	30.77	35.47
Pigeonpea + pearl millet	43.37			
Pigeonpea + cotton	38.38			
LSD (P = 0.05)	N.S.	LSD (P = 0.05)	N.S.	N.S.

*Badnapur (India), **Sehore (India), ***Angular transformed values.

Effective management of the insect pests in the crop is possible with the use of insecticides. Spraying with endosulfan (with high volume sprayers) is very effective against *Heliothis* and other lepidopteran borers. However, where podfly is the major problem, spraying with monocrotophos or dimethoate is effective. First spraying is recommended at pod initiation stage, subsequently 1-2 sprayings should be carried out at 10-15-day intervals, depending upon the incidence of pests. So far, little success has been achieved in evolving borer-resistant cultivars, biological control and other methods of pest management (Sachan 1986).

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Resistance in Peas, *Pisum sativum* L., against Pea Leaf Miner, *Chromatomyia horticola*

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FIELD incidence, developmental biology and ovipositional preferences of pea leaf miner, *Chromatomyia horticola*, were studied on 25 cultivars of field peas at Pantnagar (29°N, 79°E), in northern India, to assess resistance against this pest. Field incidence of damage started during the third week of December and continued till mid-April, at which time the crop also matured. The field incidence of leaf miner larvae and puparia was significantly higher on lower and middle portions than on the upper portions of the plant. The maximum increase in the amount of leaf damage, larvae and puparia occurred during the inflorescence and pod formation stage of crop growth. Significant differences in the field incidence of leaf damage, degree of developmental success in completing biology and ovipositional preferences amongst the test cultivars were found to be satisfactory criteria for evaluation of varietal resistance against this pest. The test cultivars grouped as resistant viz. JP-6, JP-9, JP-15, JP92A, JP-179A, JP-232, JP-Batri brown, P-200 and P-402 had comparatively late initial field infestations, lower field incidence of leaf damage, lower developmental success rate and were also least preferred for oviposition.

Pigeonpea Crop Phenology and Damage by Major Insect Pests at Pantnagar, India

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SELECTED pigeonpea cultivars of different maturity groups were sown at the Experiment Station at Pantnagar (29°N, 79°E) during normal June 24 to July 7 sowing in the 1984-85 and 1985-86 rainy seasons, to study the crop phenology, the incidence of major insect pests and the damage caused by them. Maximum yield loss occurred during pod formation and maturation stages and was caused mainly by podfly, *Melanagromyza obtusa*, pod borer, *Heliothis armigera*, and flower and pod webber, *Maruca testulalis*.

Due to severe winter conditions at Pantnagar, pigeonpea cultivars were grouped into three phenological groups. Cultivars in the first category (i.e. those which flower and mature before winter) included both the extra extra-early cultivars ICPL-81 and ICPL-316, and the extra-early cultivars TAT-10, Pant A-1 and UPAS-120. The former group flowers in late August and matures by mid-November, while the latter flowers in mid-September and matures by mid-December.

Cultivars in the second category flower and mature during winter i.e. early October and mid-January, resp. and include PPE-45-2, Schore-197 and Type 21.

The cultivars in the third category flower and mature after winter, and may include mid cultivars ICP-1903, ICP-3009, ICP-3328, ICP-4070, ICP-6840 and ICP-7946 or late cultivars ICP-4745, ICP-7176, ICP-8090, ICP-8102, ICP-8127 and ICP-9008.

Total pod damage at maturity was 72% in the third category, and 35% in the first and second categories. Podfly was the dominant pest in all categories. It accounted for 50% of damage in the first and second categories and 80% of the total pod damage in the third category. Pod damage by *Heliothis* was higher (26%) in the first and second categories and low (8.3%) in the third category, probably because of the population shift to more preferred hosts, chickpea and tomato. *Maruca* is primarily a flower webber but also damages the pods. Its damage was highest in the first category, low in second and negligible in the third categories, being 26.7, 10.2 and 0.6% of the total pod damage respectively. Severe flower damage by this pest induces a second flush of flowers and thus delays maturity.

Durable Resistance in Chickpea to *Ascochyta* Blight

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CHICKPEA blight (*Ascochyta rabiei*) is found in severe form in 26 countries. There is evidence of physiological races and in the past chickpea cultivars identified to be resistant to this disease soon became susceptible (Aujla 1964; Vir and Grewal 1974; Singh et al. 1981; Singh 1984). The desirable parameters of durable resistance are genotype resistance to all or many races, consistency of resistance over a number of years and slow progress of the disease after infection. Twelve physiologic races were identified. ICC 1467 was resistant to all 12 races tested. ICC 2165 was resistant to 11 races; *Cicer pinnatifidum* and ICC 7002 were resistant to 10 races. ICC 7000 was resistant to 9 races. Chickpea lines ICC no's 76, 2342, 4075, 6373, 6981, ILC 183, E 100Y(M) and GLK 83146 were resistant to 6 races.

Four *desi* ICC lines — no's 76, 1467, 1468 and 1416 — gave disease scores of 1-3 on a 9-point scale consistently for 5 years. Another seven *desi* ICC lines — no's 12, 2160, 2165, 5033, 7002, JM 595, NEC 138-2 — and 9 *kabuli* ILC lines — no's 72, 182, 183, 191, 195, 196, 200, 1380, 2956 — gave disease scores of 1-3 during 4 years of testing. These lines showed consistency in their disease reaction over a number of years.

Chickpea lines that exhibit slow infection progress and do not suffer yield loss were identified. The previously mentioned *kabuli* lines, which gave foliage score 3 and pod score 1, fall into this category. These *desi* and *kabuli* lines have characteristics of durable resistance.

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Use of Multiple Disease Resistance to Remove Limits Imposed in Chickpea Production by Major Diseases

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MAJOR chickpea diseases are ascochyta blight caused by *Ascochyta rabiei*, grey mould caused by *Botrytis cinerea*, wilt caused by *Fusarium oxysporum* f.sp. *ciceri*, foot rot caused by *Operculella padwickii* and root rot caused by *Rhizoctonia bataticola*. These diseases, singly or in combination, cause heavy losses in production. This can be overcome by utilising multiple disease resistance which is now available. From 1980-81 to 1984-85, 5727 germplasm/advance breeding lines were tested for resistance to ascochyta blight, 2148 to grey mould and 3913 to wilt, foot rot and root rot.

ICC 5033 was resistant to wilt, foot rot, root rot, ascochyta blight and tolerant of grey mould.

GG 763, GG 774, GL 83150, GLB 84140, ICC 12 and ICC 1532 were resistant to wilt, foot rot, root rot and ascochyta blight.

Six lines, GLB 1224, GLB 84096, ICC 4000, NEC 123, JM 595 and C 8 were resistant to wilt, foot rot, ascochyta blight and tolerant to grey mould.

GL 1194, GL 1278, GLB 1223, GLK 1224, GLK 1281, GL 83063, GL 84005 and ICC 607 were resistant to wilt, foot rot and ascochyta blight.

P 1528-1-1 was resistant to wilt, root rot and ascochyta blight and tolerant of grey mould.

GL 84212 was resistant to foot rot, root rot and ascochyta blight and tolerant of grey mould.

GL 84098 and GL 85156 were resistant to foot rot, root rot and ascochyta blight.

Thirteen lines — GG 786, GG 575, GG 612, GG 712, GG 866, GG 993, GL 83122, GL 94224, P 330, P 1489, P 3779, PG 80-39 and ICC 3428 — were resistant to wilt, foot rot and root rot.

GL 1169, GG 570, BG 236 and NP 4241-1 were resistant to wilt and foot rot.

GL 868 and PPL 13 were resistant to foot rot and root rot.

ILC lines 72, 202, 2380, 2506, 2956, 3274, ICC 2160, P 919, CPI 56566, G13-1, JM 595, E 100Y and two wild species, *Cicer pinnatifidum* and *C. judaicum* were resistant to ascochyta blight and tolerant of grey mould.

Chickpea production can be stablilised and substantially increased with the use of these lines in a stable resistance breeding program, combining this trait with good agronomic characteristics.

Genetic Control of Chickpea Blight (*Ascochyta rabiei*), a Serious Bottleneck in Chickpea Production

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ALL recommended varieties of chickpea in Punjab, including C 235 and G 543 were badly damaged by chickpea blight caused by *Ascochyta rabiei* in the three crop seasons 1980–81 to 1982–83. An efficient screening technique has been developed and several stable genetic resources have been identified (Singh et al. 1982; Verma et al. 1985). In addition to genetic variability in the host, variability in the pathogen for morphological and cultural characters and for pathogenicity has been demonstrated (Singh 1985). Twelve host genotypes were inoculated with 13 pathotypes and the disease score is presented in Table 1.

TABLE 1. Host genotype-pathotype test involving 12 host genotypes (G) and 13 pathotypes (P) — disease score on 1-9 scale.

Patho/ type	L550	C235	ICC 5124	C 8	NEC 138-2	JM 595	ICC 76	ICC 7000	ICC 7002	*C. pinnatifidum*	ICC 2165	ICC 1467	Mean
3072	8.0	7.2	3.0	1.0	1.7	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.4
4080	9.0	7.0	7.0	6.2	7.0	7.0	7.0	6.2	2.2	3.0	2.2	2.2	5.6
3844	9.0	8.0	9.0	5.5	3.0	2.0	1.0	1.0	1.0	4.0	1.0	2.0	3.9
3492	9.0	7.0	1.0	5.0	5.0	2.0	5.7	1.0	1.0	3.5	1.0	1.0	3.5
3968	7.0	8.0	7.0	5.0	5.0	3.0	3.0	2.0	2.2	2.2	1.0	2.0	4.1
4064	9.0	8.0	7.0	9.0	5.0	6.0	3.7	1.0	1.0	2.7	1.0	1.7	4.6
3968	8.2	7.0	7.0	5.0	5.0	3.0	3.0	2.0	1.0	1.0	1.5	1.7	4.6
3560	9.0	9.0	1.0	6.0	5.0	7.0	5.0	3.0	5.0	1.0	2.0	1.0	4.5
3744	9.0	7.0	7.0	3.0	5.0	1.0	3.7	3.0	1.0	2.5	1.0	1.0	3.7
3904	9.0	7.0	5.0	3.7	3.0	5.9	3.0	2.7	2.0	1.5	3.0	2.2	4.0
4088	9.0	9.0	5.0	7.5	7.0	7.5	6.5	5.0	7.0	1.0	2.2	1.5	5.7
1744	3.0	5.0	9.0	3.0	6.5	5.0	3.0	7.0	2.2	1.2	1.0	3.0	4.1
3522	9.0	8.0	3.0	8.0	7.0	7.0	1.2	1.0	1.5	2.2	7.0	2.0	4.7
Mean	8.2	7.6	5.5	5.1	5.1	4.4	3.6	2.8	2.2	2.1	1.9	1.7	—

The most resistant host genotypes were ICC 1467, ICC 2165, *C. pinnatifidum*, ICC 7002 and ICC 7000. The most susceptible ones were L 550 and C 235. Pathotype 3072 was the least virulent whereas pathotypes 4088 and 4080 had the maximum virulence. Analysis of variance indicated that mean squares due to differences among host genotypes, among pathotypes and interaction genotypes x pathotypes (I) were highly significant. The estimate of σ_G, σ_P, σ_I and σ_e were 4.63, 0.48, 2.68 and 0.78, respectively. These results suggest that in addition to several major genes for resistance in the host and corresponding virulence genes in the pathogen (as indicated from the significant interaction), there are minor genes reinforcing the resistance of major genes (significant main effects). Long-term genetic control of chickpea blight can be achieved by developing multiline varieties and/or by concentrating diverse major and minor genes for resistance into a single desirable agronomic base. Work in this direction is in progress. The promising resistant genetic resources ICC-1467, -2165, -7000 and -76 are black-seeded whereas ICC-7002 is brown-seeded.

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Effect of Soybean Development on Susceptibility to Bacterial Pustule

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BACTERIAL pustule caused by *Xanthomonas campestris* pv *glycines* is one of the most important diseases of soybean during the rainy season in Southeast Asia. Chemical control of this disease is not feasible. However, high levels of resistance to *X. campestris* pv. *glycines* in tropically adapted soybeans have been identified (AVRDC 1986). Several of these lines are high yielding, widely adapted, and carry resistance to other pathogens. Among the best of these lines are AGS 129 and PK 7386 (AGS 269). The cultivar CNS, the most widely used source of resistance to *X. campestris* pv. *glycines* (Tisselli et al. 1980), was found to be only moderately resistant at AVRDC.

A rapid mass screening technique is needed to efficiently incorporate *X. campestris* pv. *glycines* resistance into locally acceptable cultivars. Field screening for disease resistance is expensive and frequently affected by adverse environmental conditions. This study was conducted to determine the effect of plant age on infectivity of *X. campestris* pv. *glycines* and the possibility of developing a seedling screening test.

A susceptible cultivar, Tainung No. 4, was planted at weekly intervals so that plants at eight different growth stages, V1-R4 (Fehr and Caviness 1977), could be simultaneously inoculated with a bacterial suspension of *X. campestris* pv. *glycines*. Lesion number and density were recorded 8 and 11 days after inoculation.

The infectivity of *X. campestris* pv. *glycines* was significantly affected by the age of susceptible soybean plants (Table 1). Lesion numbers and densities were low when plants were inoculated at the early growth stages (V1-V4), intermediate during the vegetative stages just prior to flowering and high when inoculation occurred during the reproductive stages (R1-R4). Full expression of susceptibility occurred only during the reproductive stage. Therefore, inoculation at or after the R1 stage will allow the best differentiation between resistant and susceptible plants.

TABLE 1. The effect of soybean ontogeny on infectivity of *X. campestris* pv. *glycines*.

Growth stage at inoculation (DAP)	Lesion no. at 8 day		Lesion no. at 11 day	
	Leaflet	cm^2	Leaflet	cm^2
R4 (53)	339.7	8.47	413.0	10.09
R3 (46)	313.3	9.08	370.6	9.77
R1 (39)	316.8	8.40	397.0	9.82
V7 (32)	215.9	6.07	347.0	7.44
V5 (25)	84.2	2.29	88.9	2.54
V4 (18)	17.5	0.72	21.7	0.85
V2 (11)	6.3	0.38	13.5	0.67
V1 (4)	0.0	0.00	0.0	0.0
LSD 0.05	95.76	2.44	96.33	2.56

The data indicate that it is improbable that a seedling resistance screening test for bacterial pustule can be developed because of very low or variable infectivity of *X. campestris* pv. *glycines* in a susceptible cultivar during the early vegetative stages. Therefore, field screening for pustule resistance is the only practical screening technique.

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Virus Diseases of Food Legumes: The Situation in Thailand

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At present, there are approximately 17 different virus diseases reported to affect eight species of food legumes in Thailand (Deema and Kittipakorn 1985). From this number, 15 causal viruses have been positively identified and partially characterised.

Since most of the major food legumes grown in Thailand are not indigenous, it can be assumed that the viruses found naturally infecting the crops are mostly, if not all, imported along with the seed. In fact 80% of those viruses are seed borne. With the increasing activity of germplasm exchange for crop improvement and the lack of strict and reliable quarantine measures, introduction of new viruses or new strains is likely to continue, perhaps at an even faster rate. With 600–700 accessions of peanuts (*Arachis hypogaea*) being exchanged annually, it is not surprising to find all known variants of Peanut Stripe Virus infecting peanuts in Thailand (Wongkaew et al. 1986). This virus has recently been reported to affect peanuts in China (Xu et al. 1983) and the USA (Demski et al. 1984). It is believed that the virus was introduced into the USA through germplasm received from China. Thailand has participated with both countries in germplasm exchange. A closer collaboration between plant breeders and virologists and tighter quarantine regulations should reduce the rate of introduction of new legume viruses, if not eliminate it.

Most of the current research on legume virus diseases aims to elucidate the true identity of the cause. Although this is the first and the most important step one should take in solving problems from any disease, the time spent for this step should be minimised by using type antisera or the best information currently available. Under Thai farming conditions, more effort should be put into research on crop loss assessment, disease epidemiology and control measures. The information concerning these aspects is sparse, even though they are the most meaningful to the farmers. It is suggested that plant virologists should conduct more collaborative research with agronomists or make themselves more acquainted with field experiments. This statement does not mean to undermine the significance of basic research currently conducted but rather to point out the widening gap between lab and field information, particularly in legume virus diseases.

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Section 8

Genetic Factors:

Review of Contributed Papers

R. Shorter *

GENETIC limits to food legume improvement have been reviewed in these proceedings by Byth, Shorter and Sumarno. The papers contributed to the Genetic Factors Section will be reviewed in the context of those limits.

Phenological Adaptation and Crop Duration

Selection for phenological adaptation to, and optimum crop duration in agricultural environments are major objectives in the genetic improvement of food legumes. Several contributed papers addressed these objectives.

Byth et al. outlined investigations of short-season pigeonpea cultivars in several Asian countries. Cropping systems into which pigeonpea might fit differ among the countries and this influences the research emphasis in each region. Gupta et al. report that ICRISAT is developing pigeonpea cultivars in several maturity groups to fit a range of cropping systems in India and Africa. Singh and Tomer consider that for intensive multiple cropping with high inputs and irrigation in Hisar, India, only short-duration pigeonpeas are suitable. They have identified genotypes of this maturity which produce higher yields than controls in high density sowings.

Malik reported that in Pakistan early-maturing mungbeans, lentils and chickpeas have been identified for use in rice-based systems while early-maturing pigeonpeas are being tested as relay crops with cotton, sugarcane and wheat.

Photoperiod insensitivity allows greater flexibility in sowing dates and is being sought in several food legumes. At AVRDC, Shanmugasundaram reported that soybean and mungbean germplasm insensitive to photoperiod has been identified. Shaikh indicated that in Bangladesh short-duration, photoinsensitive mungbeans have been bred for use between jute and wheat or autumn and winter rice.

Photoperiod insensitivity is not always desirable, however. In Australia, Putland and Imrie developed photoperiod-sensitive lines with delayed maturity so that seed quality of early sown crops was not adversely affected by rainfall and high humidity during pod ripening.

Production and Distribution of Biomass

Differences exist among and within food legume species for biomass production and for its partitioning into seed and non-seed components (harvest index, HI).

Bell et al. are assessing potential productivity of a range of peanut germplasm in Indonesia and Australia and effects of environmental variables on genetic differences in HI. Malik reported that in Pakistan four recently released mungbean cultivars have higher HI (28–32%) than their parents (13–20%).

Singh et al. reported considerable genetic diversity within indeterminate and determinate groups of pigeonpea cultivars for many traits including total dry matter per plant and harvest index. They considered that total dry matter was the most important yield component associated with seed yield. Singh et al. claim these results have implications in developing high-yielding plant ideotypes. However, such studies of unrelated cultivars are not considered useful to the breeder in predicting the genetic consequences of manipulating the variability.

Plant Morphology

Several papers discussed morphological modifications which may contribute to higher seed yield of food legumes.

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Ariyanayagam and James found that outcrossing produced a threefold yield increase in pigeonpea and suggested that floral modification away from a wrapped or twisted corolla may promote outcrossing. They also considered that the disparity in pod set between autogamous and allogamous matings may be related to an inhibitory mechanism in autogamous matings which promoted post-fertilisation abscission.

Shaikh reported that in Bangledesh a black gram mutant cultivar had upright pods, which may permit higher plant densities to be used. According to Malik, new mungbean cultivars in Pakistan are top podding which, together with an erect plant type and lodging resistance, facilitates mechanical harvesting.

Stress Resistance or Tolerance

For many food legumes, tolerance of either drought or waterlogged conditions is required, because crops are grown during both wet and dry seasons.

Singh reported that the influence of moisture stress on pollen fertility was more severe in synchronous-type mungbeans than in non-synchronous types, and that this may be related to the relative humidity within their canopies. Thus, mungbean plant habit may influence the relative adaptability of genotypes to varying moisture deficits.

Although pigeonpeas generally are intolerant of waterlogging, Dubey and Asthana reported that genotypes tolerant of waterlogging had been selected in India by using artificial flooding for short periods. Notwithstanding the title of their paper, their results indicated that tolerance was not closely related to plant type.

Nutritional Adaptation

An example of the genetic resolution of a specific nutritional constraint is provided by Field and Kameli. On the calcareous soils of Timor, severity of iron chlorosis varied among species, with groundnuts being most susceptible and pigeonpea least susceptible. Local varieties of food legumes other than peanut were fairly tolerant, although the problem has restricted introduction of higher yielding germplasm. Genotypic variation in tolerance to iron chlorosis has been found in some introductions of peanut, mungbean, soybean, cowpea and pigeonpea.

Broad Versus Narrow Adaptation

Several papers considered genotype x environment (g x e) interactions or adaptations in chickpea or pigeonpea. Sumarno et al. assessed the performance of short season pigeonpea genotypes in Indonesia. Results indicated which regions produced consistently high yields and which had potential for expansion of production. Although some lines exceeded check cultivars in particular trials, the consistency or otherwise of performance of specific lines was not apparent from results presented.

Govil et al. indicated that for chickpea in India, wide adaptability generally was lacking, although they did not suggest if or why it would be desirable. Mehra et al. implied that pigeonpea cultivars in India should be high yielding and responsive, presumably to better environmental conditions or higher management inputs. Both papers attempted to identify combinations of plant traits associated with adaptation or responsiveness by examining mean performance and regression parameters obtained from multi-environmental genotypic evaluation.

A clearer perception of adaptation goals for a breeding program would be obtained if the nature and causes of genotype x environment interactions in the target environments were studied. The value of particular plant traits in conferring cultivar *stability* (variability over years at a site) or cultivar *adaptability* (variability across regions averaged over years) could then be examined in a more logical investigative framework.

Biotic Factors

Development of pest disease resistance is a major objective of soybean and mungbean improvement at AVRDC, according to Shanmugasundaram.

Knowledge of the inheritance of disease resistance or of epidemiology of the pathogen is not considered essential for the development of resistant cultivars. However, such information can increase the efficiency of the resistance breeding program and in some cases guide the deployment of resistant cultivars in order to prolong their period of effectiveness. In this context, Bell et al. outline plans to determine the inheritance of bacterial wilt resistance of peanuts in Indonesia, while Shorter and Middleton discuss the inheritance of peanut rust resistance.

Insect damage may be reduced by choice of appropriate host phenology or plant habit, as Singh and Tomer have discussed for pigeonpea in India.

Breeding for Product Quality

Quality of food legumes can influence their nutritive value or aesthetic acceptance. Faris et al. report that high protein pigeonpea cultivars have been developed from intergeneric crosses between *Cajanus cajan* and *Atylosia* spp.. Importantly, their protein quality is similar to that in *Atylosia* spp. and normal cultivars.

Imrie et al. found that resistance to weather damage in mungbean was a complex trait with low heritability. However, they have identified hardseededness as an important factor in weathering resistance. Their results indicate that although inheritance of hardseedness is not simple, it is possible to select agronomically acceptable cultivars with potentially better quality.

Expansion of Genetic Variability

There is an increasing recognition of the importance of access to genetic diversity in cultivated and wild forms of food legumes, and of the need to conserve vanishing germplasm. This has been highlighted by Chomchalow, who suggests that existing collections of local Southeast Asian food legume germplasm are restricted in their amount and variability, and that they are poorly documented. Future action by IBPGR will concentrate on soybean, mungbean, peanut, cowpea, ricebean, pigeonpea and lima bean. However, as germplasm collections expand, a concomitant need should follow for effective utilisation of their contents in crop improvement.

In his paper, Remanandan indicated that the ICRISAT pigeonpea collection contains a wide range of the variability existing in many traits. Most of the traits listed are easily identifiable. I believe a challenge exists for germplasm centres to evaluate their collections for less easily identifiable adaptive traits such as response to temperature, photoperiod, and moisture stress or excess.

Herath indicated that in Sri Lanka the extensive Asian winged bean collection is being evaluated for a range of traits, including yield and photoperiod sensitivity. From this collection, germplasm has been selected to use in initiating breeding programs.

Lawn et al. reported that the wild species *Vigna radiata* var. *sublobata* is being screened for traits conferring tolerance to environmental stresses in mungbean. Variation has been found for a number of traits of adaptive significance.

Malik in Pakistan, Shaikh in Bangladesh, and Cheah in Malaysia have used mutation breeding techniques to expand the genetic variability in their breeding programs for chickpea, mungbean or *Phaseolus vulgaris*. In view of the unexploited genetic diversity in germplasm collections of food legumes, I question the use of mutation breeding techniques to create additional variability at this stage.

Breeding Methodology

To be effective and efficient in time and resource costs, breeding programs need to use appropriate strategies for choice of parents, recombination and selection. The research base of the technology of plant breeding can provide guidance in the choice of appropriate strategies.

Maheshwari and Mathur report a quantitative genetic study of gene action in chickpea. Their results imply that for yield per plant, early generation selection of heterozygous lines would probably be less effective than later generation selection of fixed lines.

Prakash and Aradhya examined the effect of intergenotypic competition on identification of elite cowpea lines. They concluded that it would be inappropriate to use bulk breeding methods in early generations.

The fundamental importance of adaptation of food legumes was emphasised by several speakers at the Workshop. Photoperiod and temperature play particularly significant roles in the phenological response or biomass distribution of several species. The inheritance of photoperiod response in most tropical food legumes is poorly understood. In the Environmental Factors Section, Summerfield and Roberts suggest that a three- or four-environment test may be appropriate to select for rate of flowering in breeding populations. Further research to develop selection criteria and strategies will facilitate logistically possible genetic manipulation of photoperiod responses in large scale breeding programs. Such programs are appropriate for peanuts, while photoperiod effects appear to be on number of flowers and assimilate distribution post-flowering, rather than rate of first flower appearance.

Hybrid Cultivars

The potential for exploitation of hybrid vigour in many food legumes is limited by the absence of a suitable system of pollination control, inadequate hybrid vigour and cost or unreliability of seed production. However, for pigeonpea, Saxena et al. report the possibility of commercial exploitation of hybrid cultivars, which have exceeded standard cultivars by more than 30% for seed yield. As seed production is relatively cheap and easy where labour costs are low, they conclude that hybrid cultivars should be accepted by farmers in developing countries. However this may require that farmers recognise the need to purchase fresh seed each year.

Multi-environmental Testing

Multi-environmental evaluation trials of breeding materials are a regular feature of all genetic improvement programs. The analysis and interpretation of data from such trial series vary. The rigorous analysis of such data is considered essential because of the potentially useful information embedded in it. It is not sufficient to merely publish reports listing analysis of performance within each environment. Appropriate combined analyses across environments and/or genotypes are required.

An attempt at a more rigorous analysis was made by Govil et al. who evaluated 92 chickpea cultivars in an international trial grown at 14 locations. Joint linear regression analysis indicated a large significant non-linear component of the g x e interaction. Their results suggest that the linear regression analysis was inappropriate for those data, as the significant adaptation parameters (i.e. deviations from regression) do not facilitate examination of the dynamic response of genotypes across environments, nor of the contribution of particular environments to that response. The authors should consider using pattern analysis methods, whereby the actual response of genotypes or genotype groups can be examined.

Conclusion

Since the objectives of plant breeding commonly are complex, plant improvement requires integration of knowledge from many disciplines in addition to genetics. This holistic view of plant improvement was evident in several of the contributed papers.

Shanmugasundaram indicated that to achieve maximum yield advance, AVRDC integrates breeding and agronomy to develop appropriate management practices for various combinations of cultivars, seasons and locations. Herath reported on a similar philosophical approach to winged bean improvement in Sri Lanka. Embedded in the ACIAR food legume improvement programs outlined by Byth et al. for pigeonpea and Bell et al. for peanuts is the integration of breeding, agronomy, physiology, plant pathology, entomology and other disciplines.

The view expressed by Byth, Shorter and Sumarno in their invited paper earlier in these proceedings seems a fitting conclusion to this review: 'the most effective plant improvment is done by motivated scientists working in well-serviced, integrated and multidisciplinary teams'.

Self Inhibition of Fertilisation — A Potential Cause of Floral and Pod Abscission in Pigeonpea

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THE reproductive biology of pigeonpea is variable within and between cultivars. On one extreme is autogamy assisted by floral modifications such as wrapped or twisted corolla, and on the other allogamy is favoured, due to male sterility. Most cultivars, however, exhibit a mixture of both modes of reproduction.

Pod set and yield resulting from the two forms of reproduction differ substantially and Onim (1981) and William (1977) reported higher levels associated with out-crossing. The disparity in pod set appears in our study to be related to a pronounced post-fertilisation inhibitory mechanism among autogamous matings.

Four cultivars shown in Table 1 were treated at anthesis as follows: flowers were left undisturbed (A), tripped (B), tripped with intravarietal pollination (C), tripped with intervarietal pollination (D). Tripping was achieved by manually depressing the keel petal.

TABLE 1. Pod set percentage at maturity in four pigeonpea cultivars.

Cultivar	Treatments				Mean of Variety
	A	B	C	D	
UW17	13.9	19.4	32.7	31.3	24.33
D	16.9	26.4	32.0	34.7	27.50
#10	13.9	30.6	28.5	36.1	27.28
#2	8.3	22.2	29.2	29.9	22.40
Mean	13.25	24.65	30.6	33.0	—

LSD ($P = 0.05$): main effects 4.78; V × T 2.39.

The undisturbed flowers (A) screened from the influence of foreign pollen set fewer pods in comparison to matings involving pollen from other sources (C) and (D). In view of the substantial amounts of residual heterozygosity in pigeonpea, intravarietal pollination (C) could be considered as a form of out-crossing. Since nutritional and growth-promoting factors were adequate and uniform, differences in pod-set should have been due to the treatments.

The inability of autogamous mating (A) to sustain pod set at the level of allogamous matings (C) and (D) in all probability was due to a self-inhibiting mechanism which promoted post-fertilisation abscission.

Tripping (B) and the undisturbed flowers had identical reproductive methods. Nonetheless, the former produced significantly more pods. The cause, though uncertain, may have been due to the disruption of the inhibitory barrier occasioned by the act of tripping.

It is evident from this study that an approximate three-fold yield increase could be achieved through encouraging outcrossing. It would also appear that scope for reducing the influence of the inhibitory mechanism exists via the selection of appropriate genotypes.

Investigations on the chemical and/or the physical nature of the inhibitory mechanism are in progress.

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Peanut Improvement in Indonesia

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PEANUTS are a major food legume in Indonesia and are used almost entirely for human consumption. Annual production is approximately 0.5 million t of unshelled nuts from 550 000 ha, with yields ranging from 0.5-1.5 t/ha. This project is directed to assist Indonesia in raising peanut production, both in the major production areas of Java (70% of current production) and in relatively newer areas outside Java.

Collaborative research between Indonesia and Australia is being undertaken in both countries in three main areas: genetic adaptation and breeding, crop agronomy and water use, and plant pathology. Applied field studies in the adaptation, breeding and agronomy components of the program have been initiated at the Malang Research Institute for Field Crops (MARIF), E. Java. A simple experiment aimed at assessing the relative importance of a number of yield-limiting factors under an upland cropping system in the wet season has commenced. Factors of importance in yield limitation in the wet season will be investigated in more detail in subsequent experiments, and will be used to set priorities for research in other seasons and other areas.

Four sowings over a twelve month period at MARIF using a range of indigenous and international germplasm are planned, in February 1986, early May (post rainy season), August (dry season) and late November (early wet season). These experiments involve regular sampling of crops grown under non-limiting conditions, and aim to provide data on potential productivity across a range of seasonal conditions which will be combined with Australian data to gain an understanding of crop adaptation.

The importance of diseases as factors limiting peanut production in Indonesia during the wet season has been assessed in survey plots, and those results appear elsewhere (Middleton and Machmud, these proceedings). Similar techniques are being used for dry season assessments, and characterisation of causal agents will be carried out as necessary. Assessments of crop losses due to the foliage diseases Late Leafspot and rust and to Bacterial Wilt have commenced, and appropriate disease control practices compatible with Indonesian cultural conditions are to be developed.

Activity in the breeding component of the project has included incorporation of leaf spot and rust resistance into backgrounds of early maturity, and a number of these lines are being evaluated under Indonesian conditions. Much of the Indonesian peanut germplasm is resistant to Bacterial Wilt although the resistance may have arisen from one source, Schwartz 21. International germplasm is being screened at Bogor to identify additional sources of resistance to Bacterial Wilt. Breeding populations are being developed to determine the inheritance of Bacterial Wilt resistance.

The Indonesian program is supported by research in Australia on ecophysiological adaptation (particularly with regard to temperature, photoperiod and water relations), water stress physiology and foliar diseases. Research in both countries will contribute to the development of a yield prediction model for peanuts.

It is anticipated that the project will provide a sound basis for breeding improved peanut cultivars and developing approprite agronomic and disease management systems in Indonesia and Australia. Central to these objectives is the development of an improved understanding of adaptation of peanuts to the tropics and subtropics.

Objectives and Progress of the ACIAR/University of Queensland Pigeonpea Improvement Project

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SHORT-SEASON pigeonpea has emerged as a new crop in world agriculture during the last ten years. The sown area is expanding rapidly, particularly in eastern Australia and the northern plains of India. The ACIAR Pigeonpea Improvement Project is supporting collaborative research between the University of Queensland and research institutes in Fiji, India, Indonesia and Thailand aimed at extending the range of environments in which short-season pigeonpea is grown and improving the productivity of the crop.

The differing status of short-season pigeonpea in the various countries has led to differing emphases within the project. In Fiji an established market exists for pigeonpea, and long-season types have been extensively cultivated. However, productivity of short-season types under experimental conditions has been severely limited by a number of stresses, including some not encountered elsewhere. These include a stem canker disease (*Botryosphaeria xanthocephala*), soil fertility limitations related to low pH and high aluminium saturation, poor pod retention from as yet unknown causes, and water limitation. As a result, seed yields have often been lower than those of traditional late types (Sivan et al. these proceedings).

Short-season pigeonpea is currently not a commercial crop in Indonesia or Thailand, but considerable potential productivity has been demonstrated by seed yields in excess of 1.0 t/ha in a wide range of environments. The greatest potential for production of pigeonpea is seen in the harsher environments, and agronomic studies will be expanded in these areas to evaluate productivity under farming conditions. In Indonesia, the prospects that pigeonpea can partially replace soybean in the manufacture of tempeh for human consumption appear excellent, and evaluation of various blends is continuing. Little prospect exists for significant human consumption of pigeonpea in Thailand. However, the production of processed feeds for intensive animal enterprise is a major industry, and pigeonpea may be able to partially replace import sources of protein. Initial studies on inclusion of pigeonpea into diets for chickens have been promising.

India is by far the world's largest producer and consumer of pigeonpea and devotes substantial resources to pigeonpea research. In the past, both production and research have been dominated by long-season, photosensitive plant types, but the interest in short-season pigeonpea is increasing. Rather than developmental studies, research will concentrate on the agronomic and physiological basis of high seed yield in both short-season and later pigeonpea types.

Disciplinary studies at the University of Queensland will be conducted by both Australian staff and scientists visiting from collaborating institutions. The major disciplines are plant breeding, physiology and agronomy, but consultative expertise is also available in entomology, plant pathology, animal nutrition, processing and marketing.

The project makes available elite germplasm for testing in a large number of countries. Enquiries on the exchange of germplasm and/or information are welcomed and should be forwarded to the authors at the address above.

Extending the Genetic Limits of Yield Components by the Induction of Micromutations in *Phaseolus vulgaris*

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A STUDY of the effectiveness of gamma rays in the induction of micromutations in *Phaseolus vulgaris* was carried out. The dose of 30 Krads (equivalent to LD_{50}) was used to treat freshly-produced seeds at approximately 12% moisture content. The plants were maintained under a fertiliser regime of 20:90:90 kg/ha of N, P and K. Five different starting populations, namely M_1, M_{2BS}, M_{2BP}, M_{1R} and M_{2R} were compared to the original population of Nicaragua 209-480.

In the first season, seed weight was found to be the only component of yield that was significantly different between the populations. In the second season, this character did not show significant differences between the populations. However, 14 individuals in the various treated populations expressed single plant means that were higher than the mean of the original population. The probability for chance occurrence of these values ranged from $p = 0.16$ to 0.02. Fourteen potential mutants were selected based on their high values for seed weight and for total yield (pod weight/plant). These were tested using plant-to-progeny plots. During the third season, from these 14 populations 10 were found to be significantly different in seed weight from the original at $p = 0.05$. Based on the ANOVA for the field trial, 78% of these differences were attributable to genetic causes. Parent–offspring regression across seasons two and three for the 10 mutants and the original line indicated a heritability of 0.65 for seed weight.

From this, it can be concluded that:

a. the dose of 30 Krads of gamma radiation was effective in inducing micromutations in one component of yield, namely seed weight;

b. selection based on seed weight appeared to be more effective if carried out at M_2 generation than later;

c. selection based on high seed weight together with high yield (podweight/plant) was effective in picking out a mutant with significantly higher seed weight, higher pod number/plant and higher yield (podweight/plant);

d. the micromutations increased the seed weight of the 10 mutants by 8–15% of the original line.

Status of Food Legume Genetic Resources in Southeast Asia

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AT present the yield levels of most legumes remain low, especially in comparison to cereals, and as such, there is a great need for improvement of food legumes through the utilisation of genetic diversity, particularly of local materials which are adapted to local conditions. The Green Revolution, or the adoption of the modern HYV cereals, during the past two decades has resulted in the genetic erosion of not only primitive cereal varieties but also other low yielders, including food legumes.

This paper will review the past activities on food legume genetic resources in four countries in Southeast Asia, viz. Indonesia, Malaysia, Philippines and Thailand. It will also discuss the plan of action proposed by the IBPGR SE Asia Regional Working Group on Food Legumes (Chomchalow 1986).

Although a number of collecting missions have been launched in the region, the amount, and especially the variability of the materials were small. There are still big gaps in the collections. Besides, not much information about the collected materials has been available. Documentation was almost completely lacking. Conservation facilities were either not available or not up to standard. No wonder that breeders rarely used locally collected materials in their breeding programs and have to depend entirely on imported germplasm.

Of all the food legumes which are presently cultivated in Southeast Asia, the Working Group recognised seven most important ones for further regional cooperative action, viz. soybean, mungbean, groundnut, cowpea, rice bean, pigeonpea and lima bean.

Chomchalow, N. (ed.) 1986. Report on the First Meeting, IBPGR/SEAP Working Group on Food Legumes. IBPGR, FAO, Rome (in press).

Selection of Plant Type for Resistance to Water Logging in Pigeonpea

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In India pigeonpea occupies an area of 3.2 m ha and produces 2.7 m t annually at an average yield of 829 kg/ha (1984-85). The main constraints in pulse production are pests and diseases, plus susceptibility to drought, water logging and salinity. Pigeonpea is highly susceptible to water logging, which occurs in India as a result of rain for a week or more in the monsoon season during August and September. To stabilise productivity in areas where water logging is a problem it is necessary to develop suitable genotypes. Little selection for water logging tolerance has occurred in pigeonpea.

In breeding crop varieties for stress environments, Blum (1985) emphasised development of screening techniques for tolerance to major stresses such as drought, salinity, heat and freezing. Dodds et al. (1982) emphasised physiological aspects of water logging resistance in *Vicia faba*. Singh and Shrivastava (1976) studied the various plant types of pigeonpea grown under different agroecological situations.

One hundred and twenty genotypes were screened for water logging tolerance under field conditions during kharif 1983-84. Forty-three genotypes performed relatively better. During 1984-85 kharif these 43 genotypes were tested in a replicated trial under artificial flooding, created for 24 hours at 35 and 60 days after sowing. The genotypes were classified into four groups on the basis of plant type. Survival, plant height, width and plot yield were recorded.

TABLE 1. Effect of water logging on different plant types in pigeonpea.

Plant type	No. of genotypes		Plant height (m)	Width (cm)	Seed yield (t/ha)
	Tested	Survived			
A. Tall, compact	5	2	1.6-2.0	60	0.6-3.3
B. Tall, spreading	26	14	1.6-2.1	120	1.0-3.2
C. Short, compact	2	1	1.3	40	1.2
D. Short, spreading	12	10	1.2-1.5	80	1.4-3.09

Among the 43 genotypes tested only 27 survived until harvest. Data on seed yield were analysed after log transformation as some of the plot yields were zero due to the incidence of wilt (*Fusarium udum*) at a later stage of plant growth.

All the surviving genotypes matured in 240-260 days. Highest seed yield of 3.3 t/ha was obtained by PDA(WL) 85-2, followed by 3.2 t/ha for PDA(WL) 85-6. The former is tall and compact in growth and the latter is tall and spreading. Other water logging tolerant genotypes were also evident in the short spreading group. PDA(WL) 85-8, developed from cross ICP 4213XT.17, yielded 3.0 t/ha. The promising lines selected from this study are under test at four different locations.

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The Promise of High Protein Pigeonpea

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RESULTS obtained from progeny of intergeneric crosses made at ICRISAT between *Cajanus cajan* and *Atylosia* spp. indicate that it is possible to produce pigeonpea cultivars with protein as much as 40% higher than that in existing cultivars (Table 1).

TABLE 1. Percent protein of high protein lines compared to the nearest control cv C 11 at ICRISAT Centre. (Protein determined on dehulled seed).

Line	100-seed mass (g)	1981	1982	1983	Mean	% increase over control
HPL 7	10.0	29.3 (21.5)[1]	29.5 (23.4)	28.0 (23.7)	28.9 (22.9)	26.2
HPL 19	8.8	27.8 (20.8)	32.7 (22.1)	28.9 (23.8)	29.8 (22.2)	34.2
HPL 29	6.4	27.6 (20.8)	32.2 (22.3)	33.0 (23.6)	30.9 (22.2)	39.2

[1] Figures in parentheses represent percent protein of the nearest control plot.

Although the full potential of this material is yet to be exploited, preliminary yield trials suggest that it will be possible to identify high protein lines with performance and seed size similar to existing adapted cultivars (Table 2).

TABLE 2. Performance of a high protein line derived from a *Cajanus cajan* × *Atylosia albicans* cross. (From high-protein yield trial 1985).

	Days to maturity	100-seed mass (g)	Grain yield (kg/ha)	Protein (%)	Protein (kg/ha)
HPL 40-5	169	9.6	2100	26.9	565
BDN 1 (control)	168	9.6	2020	23.2	465
SE	0.9	0.18	181	0.46	46.6
Mean (n = 25)	170	9.1	1809	26.3	475
CV %	0.9	3.4	17.3	3.0	17.0

These results have important implications, particularly in countries of tropical Asia such as Thailand and Indonesia which spend foreign currency to import soybean as a protein supplement for animal feed. Pigeonpea can produce a good crop in these countries where soybean is unadapted. Feeding trials show that pigeonpea can substitute for much of the soybean in pig (Visitpanich et al. 1985) and poultry (R. Elliot, pers. comm.) rations. Pigeonpea can also replace soybean in fermented human food products such as tempeh and tofu (E.S. Wallis, pers. comm.). High protein pigeonpea also can improve the human diet where pigeonpea is already grown and used, as the protein quality, measured by the proportion of sulfur bearing amino acids, is similar in *Atylosia* spp., high protein derived lines, and normal cultivars.

Research at ICRISAT has also shown that environment has a marked effect on protein percent although environmental factors influencing these differences have yet to be identified. In these experiments if the mean square for either genotypes (g) or environment (e) is high, that for their interaction is relatively low. This suggests that substantive differences among genotypes in protein percent can be consistently identified.

The protein content in the pigeonpea germplasm collection at ICRISAT over years ranged from 12.4 to 29.5%. In the *Atylosia* spp. used in crosses the protein content was 28.7% (*A. albicans*), 29.2% (*A. cajanifolia*) and 32.6% (*A. lineata*).

A high protein male sterile line has been identified at ICRISAT. This may be important if high protein hybrids are to be produced as results at ICRISAT suggest that there is a strong maternal effect on protein level.

Finally, the high protein pigeonpea lines so far identified are all of mid-duration. Crosses have been made to breed short-duration lines with a high protein level.

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Food Legumes for the Calcareous Soils of Nusa Tenggara Timur, Indonesia

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Food legumes are an important component of the cropping system in much of Timor: the most widely grown, mungbean and groundnut, are used for cash and local consumption, while pigeonpea, cowpea and ricebean are grown mainly to supplement the maize-based diet. However, the soils of Timor, which have been developed from limestone-rich marine materials, and are highly calcareous (pH 7.5–8.5), present a major constraint to food legume production.

The main problem is induced iron chlorosis, the severity of which varies, among species, in the order: groundnut > mungbean > cowpea > ricebean > soybean > pigeonpea.

Except for groundnut, local varieties are fairly tolerant of the calcareous soils. With groundnut, however, even the local variety develops severe chlorosis and its production is restricted to the least calcareous soils. Typically, leaves of groundnut are yellow-white, and in severe instances, large necrotic areas develop. With the other species, the chlorosis is usually interveinal, although in severe cases, leaves may be completely chlorotic.

Apart from limiting the production of local varieties of these crops, the problem places a severe constraint on the introduction of improved, disease resistant varieties. For example, the local variety of mungbean is late-flowering, vegetatively vigorous and susceptible to lodging and *Cercospora* leaf spot. Average yields are low (< 500 kg/ha). Yet improved lines such as No. 129, which was selected on the basis of adaptation to acidic soils in Java, are often severely chlorotic.

Fortunately, field experiments over the past two years have revealed genotypic variation in introduced improved lines of most of the species. With groundnut, the commercial line Virginia Bunch, introduced from Queensland, has proved to be much less susceptible to induced Fe-chlorosis than the local variety.

With mungbean, although most of the introduced lines have been susceptible, several, including VC 1000C and VC 1482 from AVRDC and Celera from Australia, are almost as tolerant as the local unimproved variety, although none equals it. The most tolerant of the introduced lines still exhibit some chlorosis in the seedling stage but rapidly outgrow the symptoms. Interestingly, the wild mungbean, *Vigna radiata* var *sublobata*, which occurs throughout the area, exhibits no symptoms of induced Fe-chlorosis.

Likewise, genotypic variation has been observed among introduced soybean and cowpea varieties, and in each case, tolerant genotypes have been identified. With pigeonpea, most of the introduced materials have proved to be as tolerant as the long-duration local variety, although some lines such as ICP 6 have developed chlorosis.

Biological Adaptability in Chickpea

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CHICKPEA, the major pulse crop of India, has a low level of productivity and generally wide adaptability is lacking in most of the cultivars. There is a need to delineate the range of response types available and extent of GXE interaction as a prelude to a successful future breeding program in chickpea.

In an earlier paper, Murty (1975) reported a diversity of genetic mechanisms associated with processes of adaptation in cultivars of chickpea selected from the world collection of IBP. He suggested the need to further examine the associations between various parameters of adaptation.

Thus, 92 chickpea cultivars, selected on the basis of productivity from the world collection under the program 'Biology of Adaptation in Chickpea' (Murty 1975), were evaluated for 24 characters in an international trial grown at 14 locations. The objective was to identify traits associated with adaptation of chickpea cultivars. Stability parameters were examined following Eberhart and Russell (1966) and associations between different stability parameters were worked out. Based on path coefficient analysis (Dewey and Lu 1959), the major components associated with productivity were identified.

In an analysis of variance, partitioning of the GXE interaction indicated the presence of a large significant non-linear component for all the traits when tested against the pooled error. These traits including flowering, reproductive length, height, leaflet size, seed wrinkling and grain yield.

There was wide variability among cultivars with respect to the three stability parameters — mean (μ_i); linear response (β_i) and pooled mean squared deviations ($\sigma^2 d_i$).

TABLE 1. Pooled regression analysis of flowering, pods/plant and yield/ha.

	μ_i		β_i	$\sigma^2 d_i$
	General mean	PCV	Range	Range
Flowering (days)	73.2	8.80	0.64–1.15	1.2–89.7
Pods per plant	58.0	49.3	0.32–1.82	15–1310
Yield/ha (kg)	1192.8	61.37	0.32–1.57	41120–1231757

In order to differentiate between the possible causes of large non-linear interactions, the populations were placed into a number of groups on the basis of pairwise correlation between residuals from the line of regression (Perkins and Jinks 1968). The analysis of variation between and within groups for the non-linear interaction component indicated that a large part of it was accounted for by 'Between-groups' component. The 'Within-group' component of non-linear interactions was non-significant when tested against pooled error.

The correlation between various adaptability parameters suggest that the main component of yield stability was stability of the major yield component-pods per plant.

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Promising Pigeonpea Varieties from ICRISAT

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PIGEONPEAS are grown under a wide range of cropping systems in tropical and subtropical countries. Based on maturity, pigeonpea types can be broadly divided in early (up to 150 days), medium (160–180 days) and late (more than 200 days) groups. The early-maturing cultivars are suitable for sole cropping and are often grown as part of a rotation, for example with wheat. Medium-maturing cultivars are common in peninsular India and usually intercropped with cereals, while late-maturing cultivars are commonly grown as an intercrop with cereals in central and northern India and eastern Africa. Identification and development of extra early pigeonpea lines, maturing in less than 100 days, are providing the basis for innovative cropping systems, for example, in rotation with post-rainy season (rabi) sorghum in peninsular India and in other comparatively dry areas.

ICRISAT's pigeonpea improvement program is involved in the development of cultivars of all the maturity groups to fulfil the requirements of different cropping systems. The following pigeonpea cultivars have been developed by ICRISAT.

ICPL 87: This cultivar has been released for peninsular India under the name PRAGATI. It is an early maturing line derived from cross T 21 × JA 277. This is a morphologically determinate short stature type, which has a more or less flat-topped crop canopy with the pods borne in clusters at the top of the plants. It has large brown seeds and wilt tolerance. The plants are capable of producing a good ratoon crop. In trials at ICRISAT Centre, this cultivar produced 5.4 t/ha yield in three harvests in about 220 days in 1982 and 3.8 t/ha in two harvests in 1983.

ICPL 151: This line has been identified as promising for release in north and central India under the name JAGRATI. It is a high yielding (about 3 t/ha), early maturing line derived from the cross ICP 6997 × Prabhat. It has determinate growth, cream seeds and field tolerance to sterility mosaic disease.

ICP 8863: This cultivar has been released in Karnataka, India, under the name MARUTI. It is a medium-maturing, high-yielding line selected from cv. 15-3-3. This line has a very high level of resistance to wilt disease. It has also shown resistance to *Alternaria* and *Phytophthora* blights.

ICP 7035: This cultivar has been released in Fiji under the name KAMICA. It is a mid-late duration, high yielding line developed from a single plant collected from Bhedaghat, M.P., India. It has large pods, large seeds (21 g/ 100 seeds) and resistance to sterility mosaic disease. It is liked by Fijian farmers both as dry seeds in dhal and as a green vegetable.

Besides these, an early-maturing ICRISAT line has been released in Australia under the name HUNT. Also several lines have been identified as promising and are being tested again to confirm their performance in different countries viz: Quantum (Australia); ICPLs 147 and 151 (Surinam); ICPL 148 (Mali); ICPL 155 (Indonesia); ICPLs 8308 and 8313 (Burma); ICPLs 87, 8313, and 8310 (Argentina); and ICPLs 186, 265, 269, 304, 310, 311, 317, 358, 8306, and 8327 (India).

Progress on the Improvement of Winged Bean

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ONE of the most remarkable and potentially useful underutilised crops rediscovered by scientists is the winged bean, *Psophocarpus tetragonolobus*. No other underutilised plant has so captured the imagination of agricultural scientists, and results from investigations suggest that this highly nutritious legume can contribute more than any other food crop to overcoming malnutrition. The enthusiasm for the development of winged bean stems from several unique features of the plant. It can fix large amounts of atmospheric nitrogen (Masefield 1957) and distribute it in all parts in the form of protein. Mature seed compare favourably in protein content with soybean. The tubers contain 5–8 times more protein than other tuber crops grown in the tropics. The seed also contains 35% carbohydrate and 18% oil. Estimated production potential is given in Table 1. Varieties that are capable of producing both high seed and tuber yields have been developed. A Sri Lankan variety which can produce 4793 kg/ha of mature seed and 6759 kg/ha of tubers is now available.

TABLE 1. Estimated production potential (kg/ha).

	Yield	Protein %	Protein Yield	Protein Total yield	Carbohydrate %	Carbohydrate Yield	Carbohydrate Total yield	Oil %	Oil Yield	Oil Total yield
1. Vegetable crop										
Green pods	20000	3.0	600		6.7	1340		0.4	80	
Tubers	5000	12.0	600	1200	30.0	1500	2840	0.4	20	100
2. Grain crop										
Mature seed	3500	35.0	1225		35.0	1225		18.0	630	
Tubers	4000	12.0	480	1705	30.0	1200	2425	0.4	160	790
3. Cover crop										
Mature seed	1500	35.0	525		35.0	525		18.0	270	
Tubers	4000	12.0	480	1005	30.0	1200	1725	0.4	160	430

Green pods or mature seeds are produced in 3-4 months. In addition, tubers can be harvested if the crop is allowed to remain for over six months.

The total germplasm collection in Thailand, Indonesia, Malaysia, Papua New Guinea, Philippines, India and Sri Lanka exceeds 1000 accessions. These are being evaluated for such characters as seed yield, tuber yield, seed colour (cream colored seed are preferred for processing), seed coat quality and sensitivity to photoperiodism. Lines with desirable characters have been selected for initiating breeding program with defined objectives. The breeding programs have taken into account the desired uses of the bean as a green vegetable, a source of ripe seed, a tuber crop, a cover crop, a forage crop and soil improver.

Agronomic practices suitable for different agroclimatic conditions and practices that enhance yields have been developed. Resarch is also in progress on methods of incorporating winged bean into existing farming systems, including crop rotation, intercropping and mixed cropping.

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Breeding for Resistance to Weather Damage in Mungbean

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WHEN mungbean crops encounter rainfall or humid conditions during pod ripening the mature and ripening seeds absorb water. This results in testa discoloration and damage, reduced germinability, and increased fungal contamination, rendering the seed unsuitable for sprout production and reducing its value. Weather damage increases progressively with the duration of wetting or the number of cycles of wetting and drying.

Attempts to select in the field for resistance to weather damage were unsuccessful due to low heritability ($h^2 = 0.04$) or resistance (Imrie 1983). This low heritability is probably partly due to weather resistance being conferred by a combination of several traits, and partly because of variable coincidence of rainfall with pod ripening in lines which mature at different rates and at different times. Hardseededness which prevents, or substantially reduces water absorption has been identified as a major factor contributing to weather resistance (Williams et al. 1984). From two tests on 324 *Vigna radiata* and *V. mungo* accessions, 18 accessions with a hardseed content exceeding 90% were identified. Additionally, some accessions of the wild mungbean *V. radiata* var. *sublobata* have been found to have 100% hardseed (see Lawn et al. these proceedings). The commercial cultivars Berken and Celera had 0.0 and 14.6% hardseed respectively. The potential for selection for hardseededness has been assessed in several experiments.

Selections within lines

Plants of cvs Berken and Celera and three breeding lines (N63, LWR, 82-15) were grown for two generations in a glasshouse. Selection for hardseed content was applied in each generation (13.5% and 8.4% selection intensity respectively). Mean hardseed content was increased from 24.4 to 38.7% after two generations of selection. Whilst this was a significant increase the hardseed level was still too low to provide adequate protection against weather damage. Further increases were expected to be minimal as genetic variation was reduced by selection.

Hybridisation between lines

Crosses were made between three accessions (CPI 2/078, CPI 29758, CPI 77230) having > 90% hardseed but being agronomically unacceptable and cv. Berken (0 hardseed). The parent, F_1, F_2, and backcross generations were grown in a glasshouse and harvested seed scored for hardseed content. In two of the crosses hardseed was inherited as a dominant character, whilst in the third cross recessiveness was indicated. Inheritance does not appear to be under simple genetic control, but the occurrence of F_2 and backcross plants with hardseed content similar to their hardseed parents indicates the possibility of selecting agronomically-acceptable hardseed lines in subsequent generations.

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Status of Research on Pulses in India

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INDIA is a major pulse producer, growing more than a dozen pulses. Chickpea is the most important, covering 30% of the total area under pulses and comprising 37% of pulse production. Other pulses in order of importance are pigeonpea, urdbean, mungbean, horsegram, moth bean, lathyrus, lentil, field pea, cowpea and drybean.

Research on pulses in India

Research work on pulses in India has been a high priority for a long period. In 1967, the Indian Council of Agricultural Research launched the All India Coordinated Pulses Improvement Project. There are 15 main centres for multidisciplinary research, 10 subcentres for regional testing, 3 off-season nurseries for advancing the material and 3 special centres (one each for lathyrus, moth bean and horsegram). During 1977 the Directorate of Pulses Research was established at Kanpur for taking up basic and fundamental research.

Achievements

In the varietal improvement the main emphasis has been given to (1) increase the yield potential, (2) incorporate resistance against disease, insect pests and abiotic stresses, (3) introduce earliness and (4) improve quality. Twenty-two varieties of chickpea, 16 varieties of pigeonpea, 11 varieties of mungbean, 6 varieties of urdbean, 7 varieties of lentil and 5 varieties of field pea have been developed recently. Improved production technology has been developed in order to exploit the yield potential of the varieties. Efficient and productive intercropping and multiple cropping involving various pulses have also been developed.

Success has been achieved in isolating lines resistant to diseases. The following lines have been isolated: (1) chickpea — 6 wilt-resistant and 8 blight-resistant varieties; (2) pigeonpea — 6 wilt resistant, 2 stem rot-resistant and 3 resistant to stem mosaic virus; (3) mungbean — 7 varieties resistant to yellow mungbean virus, 6 resistant to *Cercospora* leaf spot, 2 resistant to macrophomina blight; (4) urdbean — 4 resistant to yellow mungbean virus; (5) lentil — 2 rust-resistant varieties; (6) field pea — 4 varieties resistant to powdery mildew.

Future strategy of research on pulses

1. Breeding varieties resistant to biotic stresses
2. Breeding varieties resistant to abiotic stresses such as drought, excessive moisture, salinity, alkalinity for bringing more area under pulses
3. Development of efficient plant types responsive to inputs
4. Breeding early maturing varieties for multiple cropping
5. Breeding varieties for intercropping with cereals and commercial crops
6. Basic research on physiological and nutritional characters
7. Collection, evaluation, maintenance and utilisation of germplasm
8. Development of location-specific production technology, emphasising dryland situations
9. Isolation of efficient strains of *Rhizobium*
10. Monitoring diseases and pests to improve plant protection
11. Development of integrated pest and disease control
12. Research on seed production and storage.

Wild Germplasm as a Source of Tolerance to Environmental Stresses in Mungbean

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STUDIES in Australia are investigating the potential utility of the wild species *Vigna radiata* var. *sublobata* as a source of traits conferring tolerance to environmental stresses in mungbean (*V. radiata* var. *radiata*). The wild variety is of southern and eastern Asian and Austronesian distribution, and is widely accepted as the progenitor of the cultivated variety.

Over one hundred accessions have been collected from geographically diverse areas within Australia, Timor and Papua New Guinea. Within Australia, the species is widely distributed in the coastal, subcoastal and adjacent tableland regions throughout the tropics and subtropics, from northern NSW (lat. 30°S) to Torres Strait (lat. 10°S) and across the north to the Kimberly Region in the west. This distribution is characterised by a summer-dominant rainfall in the range 500–2000 mm.

Typically, the wild plants are fine-stemmed, indeterminate and twining, with strongly dehiscent pods and small, usually hard, brown/black seeds. Both annual and perennial types have been observed in the field, although the extent to which this is conditioned by the local environment remains to be clarified. Perenniality is usually restricted to higher rainfall areas, although in some dry areas regeneration occurs from fleshy roots.

A total of 27 crosses involving 9 wild accessions and 5 cultivars has shown that the Australian material can be readily crossed with mungbean. Populations from several of the crosses have been advanced to the F_4 with no indications of fertility problems. Hardseededness is one trait of potential use in developing resistance to weather damage (see Imrie et al. these proceedings). F_2 segregation ratios in two crosses between a hard-seeded wild accession and soft-seeded cultivars indicate the hard-seed trait is conditioned by a single dominant gene. Recombinants with large green but hard seed have been recovered.

Variation exists for a number of other traits of adaptive significance. Differentiation is apparent among accessions in terms of daylength response, correlating with latitude of origin, and preliminary observation suggests accessions from high latitude are more tolerant of low temperature than mungbean. Detailed glasshouse studies have shown that several wild accessions are more tolerant of salinity than either mungbean or black gram, and accessions recently collected on saline-degraded soils in Timor appear even more so. Other accessions, collected on highly calcareous soils in Timor (pH > 8.5), show no iron chlorosis in situations where chlorosis in mungbean cultivars is severe.

Gene Action Estimates for Yield Traits of Chickpea in India

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INDIA alone accounts for nearly 74% of chickpea production in the world. The average yield is about 650 kg/ha which is very low. In a study on genetic limitations to yield improvement, data were recorded in 1978 at the Agricultural Research Station, Sri Ganganagar on parents, F_1, F_2 and F_3 generations of two chickpea crosses. Various genetic parameters were estimated for two characters viz. pods per plant and yield per plant. The epistatic model was used in the estimation of these genetic parameters (Hayman 1958; Jinks and Jones 1958). The parameters used in this model were m, d′, h, i, j and l.

Data have been discussed separately for individual crosses because in the presence of epistatic effects it is not possible to compare parameters from different crosses (Hayman 1958).

TABLE 1. Estimates of genetic parameters in two crosses of chickpea.

Cross	Character	Genetic parameters					
		m	d′	h	i	l	h–i
1. RS11 × GNR114	Pods/Plant	157.50**	-07.12*	-24.17	-47.05*	171.33**	22.88
	Yield/Plant	034.30**	-00.98	-10.13	-22.76**	070.67**	12.62
2. S26 × GNR114	Pods/Plant	177.50**	-11.87	-09.16	-22.91	042.50	13.75
	Yield/Plant	042.72**	-01.65	-03.59	-14.63*	014.83	11.04

** Significant at 1% level. * Significant at 5% level.
m = F_2, d′ = measures the additive and interaction between additive and dominance effects because in the absence of back cross generations d and j could not be separated. h = dominance, i = additive × additive, l = dominance × dominance.

Cross-I (RS11 × GNR114): For pods per plant the dominance × dominance component was significant and higher than fixable components of genetic variance. Dominance effects (component h) were not significant for either trait, so that inferences cannot be made from relative magnitudes of h and i or l components. For yield per plant the predominant contribution was made by additive × additive and dominance × dominance epistatic components, with the former being relatively more important.

Cross-II (S26 × GNR114): Other than the F_2 mean effect, additive × additive epistasis (component i) for yield per plant was the only significant component for either trait.

In both crosses the consistent opposite sign of h and l components for both traits, even though some of these components were non-significant, may indicate duplicate epistatic gene action. Singh (1976) obtained similar results. In cross one, non-fixable gene effects were more important than fixable ones, whereas in cross two only fixable genetic effects were significant. Thus, accumulation of favourable genes for high yield in pure lines may be more difficult in cross one than in cross two.

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Food Legume Cultivars Released to Improve Farming Systems in Pakistan

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An annual population increase of 3% is causing an increased demand for food legumes. New approaches have been initiated for production and productivity increase per unit area, through fitting food legumes into various farming systems. The breeding strategies have been tailored to develop cultivars of various food legumes (mungbean, black gram, chickpea, lentil, peanut and pigeonpea) suitable for three farming systems prevailing in Pakistan, namely, rainfed-based, rice-based and irrigation-based systems. Four mungbean cultivars have been released by NIAB breeders in 1985-86. The characters along with their parents are given in Table 1.

TABLE 1. Yield and yield components of new mungbean cultivars and their parents.

Cultivar	Days to flower**	Days to maturity**	Harvest index %	Per day productivity kg/ha	Yield kg/ha**
1. NM-19-19	36	66	31.55	15.37	1022
parent PAK-22	48	87	19.12	6.31	550
2. NM-121-25	40	70	29.62	14.65	1021
parent RC-71-27	48	85	20.45	6.89	588
3. NM-13-1	34	56	28.01	24.66	1362
parent 6601	43	75	13.16	13.00	995
4. NM-20-21	34	58	31.15	25.86	1500
parent 22	44	76	12.89	13.24	1016

** Av. 4 years data

The maturity range of new cultivars is 56-70 days against their parents of 80-90 days, with 40-45% yield advantage and better resistance to yellow mosaic virus. These cultivars also produce pods on the top of the plant, and mature uniformly, so that multiple pickings are not needed. Due to erect plant type, better lodging resistance and pods on the upper part of the plant, machine harvesting is easier. Two crops can be easily obtained in rainfed and irrigated farming systems. Experiments to test these early mungbrean cultivars as a catch crop between wheat and rice or between lentil and rice are in progress. Similarly early maturing lentils and medium maturity chickpeas for rice-based farming systems have been identified for post-rice situations. A wheat-pigeonpea system is being considered using ACIAR and ICRISAT early-maturing pigeonpeas. Cotton-pigeonpea, and sugarcane-pigeonpea are other systems where pigeonpea is planted as a border row crop, and in which early and medium maturity material is being tested against long maturity local material. New mungbean cultivars fit well as intercropped materials with sugarcane and cotton in irrigated farming systems.

Analysis of Adaptability in Pigeonpeas

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THE parameters of adaptability in medium maturity duration pigeonpeas were studied over 15 locations for yield and other traits.

An examination of the data in relative stability parameters of different genotypes suggested that none of the varieties sampled exhibited uniform stability and responsiveness for all the traits examined. The stability/responsiveness levels appear to be specific for individual characters.

The relationship between stability parameters for different traits were examined through correlation analysis. Results suggested that within the early maturity group of varieties (140–150 days duration), a high yielding and responsive variety should combine the following attributes:

(i) high number of pods per plant with responsiveness and stability for the same;
(ii) high number of seeds per pod but non-responsive for this trait;
(iii) stability for plant height;
(iv) relative short maturity duration with attributes of photo- and thermo-insensitivity.

The following undesirable associations in this material need to be broken through breeding efforts:

1. positive correlation between response and instability for number of seeds per pod;
2. negative correlation between single plant yield and mean seed size;
3. negative correlation between response of seed size and single plant yield.

Future studies of adaptability of short duration pigeonpeas should take into account the seasonal effects, especially in time variation in environmental parameters and their individual contribution to stability of yield.

Implications of Intergenotypic Interactions of Food Legume Breeding with Special Reference to Cowpea

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FOOD legumes have been and are being grown in marginal environments with moisture stress and low fertility. In contrast to cereals, they have been subjected more to natural selection than to directed selection by man. Natural selection is concerned with the morphological and physiological characteristics of the plant that impart fitness under highly competitive situations, but these may be a disadvantage in intensive agronomic practices (Jain 1975). Further, competitive interactions monitored by natural selection processes influence the selection in pedigree and bulk breeding systems (Hamblin and Donald 1974). The intergenotypic interactions operating in these breeding systems have a bearing upon food legumes for pure and mixed cropping situations.

With a view to studying this phenomenon in food legume breeding programs, investigations were carried out in cowpea in a series of experiments in autumn, 1979. To examine these interactions in simulated segregating populations of seven genotypes of cowpea, a modification of the bee-hive design as suggested by Fasoulas (1977) was used. For a competitive diallel experiment involving these genotypes, the fan design was utilised. In addition, efforts were made to characterise these genotypes based upon plant growth, development and plant architecture and to associate these with their competitive abilities. The statistical model provided by Hamblin and Rowel (1974) was helpful in investigating the efficiencies of the above breeding methods in the light of these interactions. The data obtained from competition diallel studies were subjected to joint regression analysis.

The three genotypes viz. TVX-922042E, Copusa-2 and C—152, which were found to be strong competitors, had better seedling vigour, higher dry matter accumulation and more vigorous growth than S-209, which was found to be a weak competitor and had minimum expression of these characters. All the genotypes were relatively inefficient in their plant architecture with their horizontal leaf orientation. The more competitive genotypes exhibit high lateral spread. The genotypes were mutual inhibitors in mixtures, and consequently all genotypes had depressed yields. However, competitive genotypes were high yielding in monocultures.

The proposal that selection should be practised in segregating populations grown in crop conditions was supported by the conclusions derived from these investigations. Pedigree selection of higher yielding genotypes, followed by the bulk breeding method of selection based on heritable morphological traits such as plant height and number of branches correlated with seed yield was suggested. It was concluded that in most food legumes the potential exists for further genetic improvement via directed selection. Evidence was obtained of the relative inefficiencies and unsuitable morphological features of pulse crops in monoculture systems. It was also concluded that intergenotypic competition studies are useful in selecting genotypes for mixed cropping systems.

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Interactions Between Crop Duration and Yield in Mungbean

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In northern Australia, early maturing mungbeans sown in December-January, when daylength is near maximum, produce higher yields than later sowings when daylength is declining (Lawn 1979; Putland, unpublished data). However, seed quality of early sown crops may be adversely affected by rainfall and high humidity during pod ripening. To avoid quality decline, photoperiod sensitive lines in which maturity is delayed until the end of the wet season were bred.

This paper reports results from a split-plot experiment conducted in 1985 to measure sowing date effects on 20 genotypes with different crop durations. Main plots were sowing times (January 3 and January 29) and sub-plots (6 rows spaced 36cm apart and 5m long) contained genotypes. Genotypes were classified into groups on the basis of sowing time effects on phenology (Table 1). Groups 2 and 3 which were similar in their days to flower differed in duration of flowering when sown late. Most commercial cultivars are in group 4.

TABLE 1. Mean days to flower, duration of flowering and seed yield of genotype groups.

	Days to flower		Duration of flowering (days)		Seed yield (kg/ha)	
Group	Early sown	Late sown	Early sown	Late sown	Early sown	Late sown
1	49	40	9	8	1670	2140
2	39	36	9	5	1930	1970
3	39	35	9	8	2050	1940
4	32	32	7	4	2530	1730

Yield differences between genotypes (range 1161 to 2348 kg/ha) and sowing times (2213 and 1800 kg/ha) and the genotypes × sowing time interaction were all highly significant ($P < 0.01$) The nature of the interaction is illustrated by the mean yields of each group (Table 1). The late maturing lines in group 1 had higher yields when sown late; yield of lines in groups 2 and 3 were similar at both sowings; and lines in group 4 had lower yield when sown late. Yield reduction in the early maturing group of 4 lines was due to an average 44% decrease in pods per plant and an average 5% decrease in seed size.

This result was achieved in a season when late rains provided sufficient moisture to maintain growth and productivity of the later maturing lines which flowered about eight days later and matured on average 40 days later than the early maturing lines. Further research is being done to determine the yielding ability of late sown, late maturing lines when soil moisture is more limiting.

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Genetic Variation in Pigeonpea Germplasm

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Germplasm is the raw material for crop improvement and its utility depends upon the useful genetic diversity it contains (Mengesha 1984). The effort given to improve traditional pigeonpea types has been less than that given to major cereals, and therefore relatively large genetic gains can be achieved rapidly in pigeonpea (Byth et al. 1981). Though many improved lines have been developed since the 1920s, yield levels have remained virtually static. A major reason for this is the limited use made by breeders of the genetic resources available to them (Ramanujam and Singh 1981). The key to rapid improvements, therefore, lies in greater exploitation of the wide genetic diversity available in pigeonpea (Byth 1981; ICRISAT 1982).

The world collection of germplasm assembled at ICRISAT contains a wide range of the variability existing in all important traits (Table 1). Examples are days to maturity, plant type, seed size, number of seeds per pod, and resistance to environmental and biotic stresses. Future pigeonpea improvement will depend largely upon the effective utilisation of this diversity.

TABLE 1. Range of variability in the pigeonpea germplasm.

Character	Minimum	Maximum	No. of lines evaluated
50% flowering (days)	55.0	210.0	8582
75% maturity (days)	97.0	260.0	8561
Plant height (cm)	39.0	385.0	8526
Primary branches (no.)	2.3	66.0	5812
Secondary branches (no.)	0.3	145.3	5793
Racemes (no.)	6.0	915.0	5812
Seeds per pod	1.6	7.6	8413
100 seed weight (g)	2.8	22.4	8475
Harvest index (%)	0.6	62.7	5772
Shelling ratio (%)	5.8	86.6	5759
Protein percentage	12.4	29.5	8206

Based on genetic variation, the germplasm has been classified into a number of well defined sections and a catalogue will soon be published. The germplasm maintained at ICRISAT is available to anyone who wishes to use it, and depending upon the need of the user a search for genotypes with the desired combination of traits can be efficiently done now with the aid of the Institute's computer.

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The Potential of Early Maturing Pigeonpea Hybrids

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EARLY maturing pigeonpeas are becoming important because of their ability to fit into a wide variety of cropping systems including their adaptation to higher latitudes. Unlike other pulses, the presence of natural out-crossing (average 20%) in pigeonpea coupled with the discovery of a stable genetic male sterility (Reddy et al. 1978) has opened the possibility of commercial exploitation of heterosis in this crop.

Extensive evaluation of experimental pigeonpea hybrids at ICRISAT and in the All India Coordinated Trials has clearly shown that substantial gains in seed yields are possible in pigeonpea hybrids over a range of conditions (Saxena et al. 1985). Among early maturing hybrids ICPH 8 was found to be the most promising. In 1981, 1983, and 1984 station trials at Hisar this hybrid yielded on an average 53% more than the control cultivar UPAS 120 (Table 1).

TABLE 1. Performance (kg/ha) of hybrid ICPH 8 in station trials at Hisar.

Entry	1981	1983	1984	Mean % increase over control
ICPH 8	3900	3560	3752	53.1
UPAS 120 (control)	2225	2569	2528	
SE	± 145	± 176	± 363	
CV%	7.8	12.6	23.3	

This hybrid also performed well in multilocation trials conducted in 1984 in India. In 15 of these trials the yield of the hybrid ranged from 480 to 4310 kg/ha. The superiority of the hybrid over the control cultivar in these tests ranged from -5% to 124%, averaging 26%.

To attempt to stabilise the performance of hybrids across environments and production systems, improved early maturing male steriles with high combining ability, large seed size, and resistance to major diseases are being bred at ICRISAT.

Large scale hybrid seed production in pigeonpea is fairly easy and cheap where labour costs are relatively low. Estimates of the cost of hybrid seed production in India (Rs.2/kg; excluding land cost) should not pose a problem for the acceptance of pigeonpea hybrids by farmers in developing countries. This cost should be even further lowered by reducing the number of pollinator rows and the use of relatively photo-insensitive parents that can be ratooned to produce more than one harvest from the same plants within a single year without the need for further roguing.

The heterotic advantage of 30% or more over commercial varieties demonstrated by ICRISAT in pigeonpea hybrids has attracted the attention of two private seed companies in India. Although no hybrid pigeonpea seed is presently available commercially it is only a matter of time before it will be.

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Improved Food Legume Genotypes for Bangladeshi Farming Systems

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INCREASING population has resulted in a steady transformation of the traditional farming systems of Bangladesh. Increasing demand for staple cereals has continuously relegated the pulses towards more marginal growing conditions (Shaikh 1977). Consequently their total area, production and even productivity have declined (Anon. 1975). Breeding efforts have, therefore, been directed towards development of varieties with higher yield, higher protein content, synchrony in pod maturity, altered plant architecture, resistance to diseases and pests, wider adaptability and early maturity for fitting in the changed intensive farming systems. Induction of mutations has been used intensively, due to the narrow genetic base in this group of crops (Shaikh et al. 1978). A mutant variety of chickpea named Hyprosola (high-yielding-high-protein chickpea) with 20% higher yield and 4% greater protein than its parental cultivar, Faridpur-1, was released in 1982. Increases in its yield and protein content combine to give 45% higher protein production/unit area of land. There is no change in its amino acid content (Shaikh et al. 1982). It has less branching and semi-erectness providing possibilities of an increased population/unit area, increased pods and seed/plant and higher harvest index. It matures earlier than Faridpur-1, making possible earlier sowing of jute and summer-rice. It has increased field tolerance to *Alternaria* spot disease and pod borer.

Gamma-irradiated mungbean populations yielded dwarf, erect, bold seeded, synchronous and higher-yielding mutants. Some mutants showed varying resistance to MYMV and *Cercospora* leaf spot (Ahmed et al. 1978). Traditionally mungbean is grown during winter in Bangladesh. But short-duration, photo-insensitive summer strains with higher yield have been identified from local and exotic germplasm for sowing in August-September i.e. in between major crops such as jute and wheat, winter and autumn rice, and for April sowing replacing the fallow phase now preceding autumn rice in the northwest region (Begum et al. 1983). Two cycles of single plant selections from a local line have resulted in the development of MB-55, a winter strain with resistance to *Cercospora* leaf spot and 15% higher yield than the commercial variety, Kishoregonj.

The black gram mutant M-25 is a dwarf, higher yielding than the parent B-10, and moderately resistant to YMV and Cercospora leaf spot. Mutant M-23, although lower yielding, is determinate and bears upright pods compared to downward/horizontally-borne pods of the existing cultivars. The altered architecture of the mutants may permit an increased plant density and consequent higher yield (Shaikh et al. 1983).

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Crop Improvement Research on Legumes at AVRDC

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SOYBEAN and mungbean are among the most important crops in the tropics and subtropics. The objectives of legume improvement research at AVRDC are to increase the average yield, incorporate resistance to major diseases and insects, minimise the stress due to various environments, and develop wide adaptability.

AVRDC has one of the largest germplasm collections in the world for soybean and mungbean. By screening the germplasm, lines insensitive to photoperiod have been identified (Shanmugasundaram 1981). Resistance to soybean rust, downy mildrew, bacterial pustule, and soybean virus diseases have been identified and used in developing high yielding cultivars. Similarly in mungbean, resistance to *Cercospora* leaf spot, powdery mildew and mungbean virus diseases have been identifed and bred into the high yielding lines (Shanmugasundaram and Tschanz 1986, AVRDC 1985). Resitance to beanflies, stink bug and pod borer in soybean, and beanflies, pod borers and storage weevils in mungbean has also been isolated and is being utilised by the breeders (Talekar and Chen 1985). Improved soybean and mungbean breeding lines with a yield potential of 4 t/ha and 2.5 t/ha, respectively, combined with different levels of disease resistance, are available to cooperators.

After evaluating the germplasm and breeding lines received from AVRDC, 13 countries released 18 mungbean varieties, and eight countries released 10 soybean varieties.

AVRDC conducts crop management trials in relation to the farming systems in which soybean and mungbean are involved. The Center proposes to develop methodologies which the national programs can use to identify the key constraints and the appropriate management practices for specific seasons, locations and varieties to obtain maximum economic yield.

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Rust Resistance in Peanuts

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RUST (*Puccinia arachidis*) is a serious disease of peanuts in most production regions, including South and Southeast Asia. Cultural and chemical control strategies are available but may be inappropriate or expensive in particular cropping systems. Resistance in *Arachis hypogaea* is of the rate-limiting type with important components of resistance being incubation period, infection frequency, pustule size and spore production. When evaluated as a qualitative trait in *A. hypogaea* crosses, resistance generally has been found to be recessive with either monogenic or digenic inheritance. We have examined the inheritance of rust resistance using incubation period to assess resistance.

A single uredospore isolate of *P. arachidis* from a susceptible cultivar was used to inoculate plants of two susceptible (S) cultivars (Virginia Bunch 223 and Shulamit), three resistant (R) accessions (PI 314817, EC 76446(292) and PI 259747), and F_2 plants for R × S and R × R crosses. Reciprocal crosses were kept separate. From daily assessments of ruptured pustule numbers, incubation period (defined as time from inoculation to rupture of 50% of final pustule number) was calculated.

The incubation period ranged from 14 to 17 days among plants within susceptible parents and was generally greater than 39 days for resistant parents. However, a small number of resistant parent plants had incubation periods of 25-30 days. No differences in F_2 progeny distributions were observed between reciprocal crosses which suggests absence of cytoplasmic effects. Incubation periods pooled over reciprocals in R × S crosses ranged from 14 to greater than 39 days with the distributions skewed towards susceptibility. The three resistant accessions produced similar F_2 progeny distribution among R × S crosses. In R × R crosses, incubation periods ranged from 18 to greater than 39 days, with 55-90% of F_2s in particular crosses being greater than 39 days. Thus some F_2s in R × R crosses had shorter incubation period than their resistant parents, which suggests that genes conditioning resistance were not identical in the three resistant accessions.

These results suggest that for the incubation period component of peanut rust resistance, selection for resistance should be delayed until the F_2 or later generations.

Influence of Water Stress on Pollen Fertility in Mungbean

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AMONG the various short-duration food legumes, mungbean is most important and is cultivated during the summer season (April–June) after the harvest of wheat crops in northern parts of the country. Under these conditions, an assured supply of water is essential to realise the genetic potential of the crop. Accordingly, an understanding of growth and reproduction in relation to water availability is important in evolving an appropriate irrigation strategy. Plant response to soil-water deficit can be expressed in terms of morphological, anatomical, metabolic and physiological characters. However, very little information is available on the reproductive behaviour of mungbean genotypes in response to water stress. Such information could form a physiological basis for scheduling water supply and be useful in determining the relative adaptability of these genotypes to varying water deficits.

Present studies on pollen germination clearly indicate that *synchronous*-type cultivars, in general, have a poor percentage of pollen germination compared to nonsynchronous types both under irrigated and nonirrigated conditions. The relative decrease in pollen germination percentage in the nonirrigated plants compared to irrigated plants was larger in synchronous-type cultivars than in nonsynchronous types. Pollen germination percentage was significantly positively correlated with atmospheric relative humidity (R.H.) in both cultivar types under nonirrigated conditions but only in the synchronous types under irrigated conditions. Nonsynchronous types may maintain a higher R.H. within their canopies because of their plant habit. In contrast, the R.H. within canopies of synchronous types may equilibrate faster with atmospheric R.H. because of their plant habit, so that for these synchronous types, pollen germination is dependent on atmospheric R.H. even under irrigated conditions.

The present study indicates the necessity of scheduling water supply so as to make water available at the time of flowering and pod development, thus obtaining higher grain yields in two mungbeans genotypes differing markedly in their fruiting and maturity behaviour.

Morphophysiological Considerations for Maximisation of Productivity in Early Pigeonpea

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BASED on the study of different plant parameters, an attempt has been made to construct plant ideotypes for a set of given cropping situations. Attention has been given to morphophysiological traits by taking as many as 20 different traits — components of more complex traits such as yield, harvest index etc.

Fifty-five populations in the indeterminate group and 42 in the determinate group of pigeonpeas were sampled. Basically indeterminate group populations were associated with late maturity and basipetal behaviour of flowering, whereas determinate groups were associated with medium maturity and acropetal behaviour of flowering.

Seven traits — namely distance of first vegetative and fruiting nodes from ground level, raceme length, pod number, total dry matter per plant, harvest index and single plant yield — showed high coefficients of variation. Four characters — namely flowering and maturity within a group and grain weight and density — showed low variability.

The pattern of associations between different character pairs in the two groups appeared similar, except for slight changes in the strength of associations. Plant spread, fruiting branches, pod number, total dry matter and harvest index have positive correlations with flowering and maturity period within a group. Distance of vegetative and fruiting node from the ground level, grain weight, canopy ratio and seed volume showed negative correlation with seed yield per plant in both groups.

Total dry matter was the most important yield component, having high direct and indirect correlation towards yield in its association with different traits. Harvest index and pod number were other important traits in this regard.

These associations have implications in relation to breeding for high-yielding plant ideotypes for different situations.

Breeding Pigeonpea Cultivars for Intensive Agriculture

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PIGEONPEA is best suited to light soils in moisture stress areas, due to its deeprooting and drought tolerance. Traditionally, it is mixed or intercropped with other crops, presumably due to its long duration.

Under intensive agriculture with improved management, where irrigation and other inputs are assured, farmers prefer multiple cropping. Only short-duration cultivars are suited to such a system. In such areas, pigeonpea cultivars grow tall, making plant protection operations difficult. Therefore, extra-early-maturing cultivars with genetically dwarf plant type are needed for such a system. Since maturity duration and seed yield are negatively associated, early maturing cultivars should be responsive to higher planting densities.

Extra-early-maturing cultivars, even if not genetically dwarf, can be agronomically dwarfed by late sowings with little delay in maturity. Attempts in breeding pigeonpea cultivars have been concentrated in this direction. Screening of germplasm, hybridisation among promising parents, pedigree selection and other breeding methods were followed in developing new strains. Seed yields of promising cultivars in high density sowings and with full crop protection are given in Table 1.

TABLE 1. Seed yield (kg/ha) of extra-early-maturing cultivars sown after mid-July.

Cultivar	Maturity (days)	1982	1983	1984	Mean
H81-1	133	2750	1140	2513	2134
H76-44	135	2722	1040	2249	2004
ICPL-4	131	2361	1215	1614	1730
UPAS-120	142	1972	850	1587	1470
LSD (5%)	—	410	135	205	—

Pod borer damage is often severe in determinate type cultivars and potentially less in the indeterminate extra-early cultivars. Strains H82-1 and H82-12 with indeterminate growth have been developed, and these are the earliest maturing indeterminate genotypes. Their performance is given in Table 2.

TABLE 2. Performance of newly developed indeterminate cultivars during the monsoon season 1985.

Cultivar	Maturity (days)	Seed yield (kg/ha)
H82-1	115	2063
H82-12	120	1905
UPAS-120	128	1865
Prabhat	120	1785
LSD (5%)	—	184

Evaluation of Short-season Pigeonpea Lines in Indonesia

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PIGEONPEA is a traditional yet minor crop in Indonesia. Recent research indicates that consumption may be increased by incorporating pigeonpea in popular soybean-based food products, such as tempeh, kecap and tofu.

The productivity of short-season pigeonpea has been tested for up to three years on four islands — Java, Sulawesi, Sumatra and Timor. Presently, yields from Java, Sulawesi and Sumatra are available (Table 1).

Highest consistent yields have been recorded in East Java (Muneng), however promising yields in the less fertile sites in S. Sulawesi and W. Sumatra point to a potential expansion of production in those areas.

Two sets of lines were evaluated. Set I comprising 15 lines, including cultivar Qantum as a check, was tested in 1983. Set II, with 20 lines and cv. Hunt as check, was tested in Java and Sulawesi in 1984 and Sumatra in 1985.

In the current season (1986-87), 20 lines are being evaluated at 8 sites — Sumatra (4), East Java (2), West Java (2) and South Sulawesi (2).

TABLE 1. Summary of yields of pigeonpea line evaluation in Indonesia, 1983-85. Yields (t/ha) of highest yielding line and check are presented in relation to trial mean.

Year	1983			1984			1985
Site	Muneng	Muara	Mojosari	Muneng	Muara	Lanrang	Sitiung
Locality	E.Java	W.Java	E.Java	E.Java	W.Java	S.Sulawesi	W.Sumatra
Highest yield	1.83	0.95	0.90	2.5	1.2	0.7	1.0
Check 1983 = Quantum 1984/5 = Hunt	1.83	0.95	0.44	2.0	0.4	0.7	0.7
Trial mean	1.17	0.62	0.5	1.9	0.7	0.5	0.5
LSD (5%)	0.41	0.21	—[a]	0.4	0.1	0.1	—[a]
CV (%)	28	24	—[a]	22	15	12	—[a]

a = unavailable.

Section 9

Processing and Utilisation:

Review of Contributed Papers

G.J. Persley *

THERE were eight papers submitted on the subjects of processing and utilisation. These could be placed in four categories:

1. processing and utilisation — one paper
2. obstacles to utilisation — three papers
3. nutritional considerations — three papers
4. postharvest considerations — one paper.

Processing and Utilisation

Anumbuk et al. briefly described the small pilot plant set up by the Thai Ministry of Agriculture and Cooperatives which currently produces 200 kg defatted soy flour per day. It is hoped that local commercial production of defatted soy flour will reduce the current reliance on imports from the USA.

Obstacles to Utilisation

Bhat described how excessive reliance on the legume *Lathyrus sativus* as a staple in parts of India, Bangladesh and Ethiopia had resulted in the degenerative disease Lathyrism. The cause, an unusual amino acid, has been isolated. A number of suggestions aimed at preventing the disease have been made. These are: legislative procedures; detoxification; social management; and the offering of incentives to grow alternative crops.

Chitra and Sadasivam described the methods employed to reduce the action of trypsin inhibitor in black gram. This inhibitor restricts the digestion of protein, and rats fed an untreated extract of black gram failed to thrive. Treatments to black gram such as dehusking, splitting, soaking in water, germinating up to 48 hours or various heat treatments result in improved digestibility.

Poulter outlined the potential for using milk-type products based on legumes and oil seeds. There are a number of technical matters to be considered, since not all legumes produce sufficiently stable emulsions for satisfactory pasteurisation. Ways to reduce certain antinutritional factors and characteristic flavours also need to be addressed to ensure improved acceptibility.

Nutritional Considerations

Singh et al. compared the nutritive values of pigeonpea as dry mature seed and as green seed harvested 25–30 days after flowering. They found that green seed used as a vegetable was superior to dry mature seed in all aspects of digestibility and nutrition.

Tiwari and Tiwari contrasted their findings from 10 elite lines of pigeonpeas and chickpeas with the earlier findings of Jambunathan and Singh (1982). Where Jambunathan and Singh had recorded wide variation in protein content and cooking times of pigeonpeas sampled, Tiwari and Tiwari noted a much narrower range for both cooking time and protein content. While no association of seed size or maturity period was found with protein or cooking characteristics in chickpea, late maturing pigeonpeas had a higher protein content, took less time to cook, and expanded more in cooking. They suggest that the protein content and cooking characteristics of early maturing pigeonpeas could be improved by introgression of genes from late maturing types.

Widowati and Damardjati evaluated 23 high yielding lines of pigeonpea from Australia and five local Indonesian varieties for their physical and chemical characteristics and overall nutritional quality. They found that the Australian lines had

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slightly higher bulk density and grain weight but were generally lower in protein content than the Indonesian lines. They also used pigeonpea to make tempeh and evaluated it against soybean tempeh and tempeh made from different ratios of pigeonpea and soybean. While pigeonpea tempeh was less preferred than pure soybean tempeh, no difference could be detected between 2:1 soybean:pigeonpea tempeh and pure soybean tempeh.

Postharvest

Heslehurst and Hohenhaus gave details of a procedure which enabled prediction of rates of deterioration of seeds in storage. A graphical relationship was established between seed quality and accumulated heat, and this relationship can be extrapolated to predict the rate of warehouse deterioration. The importance of initial high seed quality for longevity in storage was demonstrated.

Processing and Utilisation of Soybean in Thailand

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THAILAND produces about 300 000 t of soybean seed per annum, two-thirds being sent for oil extraction. As there is no commercial production of defatted soy flour in Thailand, the Ministry of Agriculture and Cooperatives has established a small pilot plant which produces a maximum of 200 kg defatted soy flour per day.

Oil is extracted from soybean flakes by n-henane at 60°C and 40 mm Hg for 60 min. If moisture content is less than 10% a granular flour with a Protein Dispersibility Index of over 90% is produced. When mixed with vitamins and moisture under high temperature and pressure a textured vegetable protein, equivalent to animal protein, is produced.

Defatted soybean flour can be used as a substitute for animal protein by vegetarians and in curries, sausages and blended wheat flours. Of the 50–70 t of defatted soy flour imported annually from USA at present, it is estimated that 45–50 t are used for vegetarians and 10–20 t are used for other purposes.

Naturally Occurring Toxins in Legumes and their Elimination, with Special Reference to *Lathyrus sativus*

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FOOD legumes occupy an important position in the Indian diet since they provide a high component of protein in the average diet, especially for those who subsist on vegetarian diets. Besides the problems of cookability, digestibility and comparatively higher cost, the occurrence of naturally occurring toxins like haemagglutinins, trypsin inhibitors, flatulence factors and certain toxic amino acids hinder utilisation of certain legumes. Population groups depending on subsistence farming are forced to cultivate and consume the locally grown legumes even if they are known to contain toxic principles. They are cultivated because of their obvious advantages like drought- and disease-resistance, high protein content and easy cultivation.

Consumption of the legume *Lathyrus sativus* as a staple in parts of India, Bangladesh and Ethiopia has resulted in the disease Lathyrism in the past. It is a non-progressive upper motor neuron degenerative disease resulting in dragging of the legs, increased reflexes and impaired ability to walk. The cause, an unusual amino acid (β oxalyl aminoalanine) has been isolated, characterised and synthesised. The following approaches for preventing the disease have been suggested: (1) Legislative measures — attempts have been made to ban the cultivation as well as sale of *Lathyrus sativus* through legislation. However, presently only the legislation pertaining to the sale of *Lathyrus sativus* is in vogue in most of the states of India. These measures have not met with much success in reducing the cultivation or intake of the pulse. (2) Detoxification of the seeds — a simple process, both at the household as well as on an industrial scale, to remove the toxin has been evolved. Results of a recent study to detoxify *L. sativus* on an industrial scale, which was conducted jointly by the Madhya Pradesh State Agro Industries Corporation, Bhopal, the Central Food Technological Research Institute, Mysore and the National Institute of Nutrition, Hyderabad, indicate that by soaking the seeds overnight in water at an initial temperature of 75°C and then drying, the toxin could be reduced from an initial 0.82 gm% to 0.05 gm%. (3) Genetic methods — although certain varieties like P-24 which contain a minimal amount of toxin were identified, they have not been adopted on a large scale because of disadvantages such as shrivelled grain, lack of seed multiplication facilities and lack of a proper extension network. (4) The social management approach — during the last decade in India despite increased *Lathyrus* cultivation, increased outbreaks have not been reported in the community. A study conducted to find the reasons for the declining incidence of the disease identified the higher price of *Lathyrus* as the main reason for a reduced consumption of *Lathyrus*. Social management of disease outbreaks like Lathyrism involve a multisectoral approach of coordination between agriculture, health, rural development, cottage and cooperative sectors. In addition, the cultivation of alternative pulse crops like pigeonpea and lentil by offering price support, supplying modern agricultural inputs like quality seeds, fertilisers and agrochemicals and levying an additional land tax for cultivating *L. sativus* have been suggested as disincentives for growing *L. sativus*.

Investigations on Trypsin Inhibitor of Black Gram for Better Utilisation

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Food legumes, being a rich source of proteins complement cereals in the diet of the majority of people in the developing countries of Asia. Although legumes are rich in protein they also contain many antinutritional factors like protease inhibitors. Among protease inhibitors, trypsin inhibitor (TI) is of great practical significance due to its ubiquitous presence and its effect on food legume digestion and utilisation. In the present investigation an attempt was made to study the TI of black gram (BG) which is consumed almost every day in India.

Trypsin inhibitor activity (TIA), total protein (TP) and water soluble protein (WSP) content varied markedly in 20 different cultivars of BG. TIA was correlated with WSP of the cultivars, but not with the TP. The TIA was concentrated in the cotyledons and was very low in the husk. During ontogeny of seeds, the TIA and WSP increased gradually. During germination the TIA decreased for the first 48 hours, followed by a steep increase, but the WSP content was almost constant.

Marked reduction of TIA was observed in dehusked, split grains on soaking in water due to leaching, compared to unhusked and unsplit grains. Heat processing of BG such as open-vessel cooking, shallow fat frying, deep fat frying and autoclaving reduced the TIA. Autoclaving was the most effective in destroying the TIA. The recipes made with BG batter when steamed, shallow fat fried or deep fat fried registered a considerable reduction in the TIA. Fermentation of the batter did not affect the TIA.

Albino male weanling rats fed a lyophilised crude extract of BG revealed the deleterious effect of TI by having a reduced weight gain, protein efficiency ratio (PER), protein digestibility and liver weight and by showing hypertrophy of the pancreas, compared to rats fed autoclaved lyophilised extract of BG.

In conclusion, dehusking, splitting, soaking in water, germinating up to 48 hours and various heat treatments used in the preparation of various recipes reduce the TIA of BG, thereby improving its digestibility.

Laboratory Predictions of Bean Seed Life During Storage

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Seed germination and vigour at the time of sowing have a major bearing on crop establishment and subsequent productivity. On-farm storage has been notoriously unsuccessful in relation to quality control, in terms of genetic drift and low seed vigour. High variability of seasonal rates of deterioration pose serious problems in warehouse storage systems. Even where environment (cool/dry) control is imposed to limit deterioration, exact quantification is not easily identified by the seed industry. Furthermore, this material is subsequently subjected to the vagaries of the market place, where immediate use does not always occur. Similarly, hermetically sealed packs with superior storage life are subjected to differential times and temperatures of storage.

Some means of accurately predicting deterioration would provide useful marketing advantages in assisting decisions about how long to store seedlots and which seedlots to market quickly or retain, and could provide appropriate sowing rate recommendations even with seriously depleted lines.

A laboratory regression procedure with the capacity to mimic warehouse deterioration has been established (Heslehurst 1986) and relies on the principles of controlled deterioration (Matthews 1980) developed from the original accelerated ageing test (Delouche and Baskin 1973).

Seed that has been brought to a constant high moisture content (18%) is then subjected to varying durations in high temperature (42°C) to artificially age the seed. Some measure of seed quality (% germination, conductivity, TZ) on a probit scale is then plotted against accumulated heat. Such a regression not only identifies initial quality (intercept) far more accurately than conventional germination testing (Ellis and Roberts 1980, 1981; Heslehurst 1986), but also on extrapolation backwards can be related to warehouse deterioration. Roberts' probit theory of deterioration (Ellis and Roberts, 1980, 1981) predicts that all seedlots of a cultivar will follow a parellel slope, separated only by their differences in initial quality.

Warehouse deterioration was linearly related to an accumulated heat unit sum with three cultivars (*Phaseolus vulgaris* cv. Sinatra, Black Magic, Provider) following a parallel slope. Another Sinatra seedlot with high levels of mechanical damage was also found to follow the same slope, indicating there was no promotion of the deterioration rate from mechanical damage.

Laboratory deterioration mimicked these warehouse events, with 36 h = 12 months of cold storage (10°C, 40% RH) and 80 h = 12 months in the warehouse. Such data points taken from the regression also have the advantage of being far more accurate than isolated controlled ageing tests. Each unit hour of laboratory ageing was equivalent to the accumulation of 100 heat units in cool store, or 116 heat units in the warehouse, with this difference caused by the higher seed moisture level in the warehouse. In Brisbane's subtropical climate, higher day temperatures were associated with lower relative humidity, thus balancing effects on deterioration and allowing such a linear response. If moisture levels varied greatly and were not associated with temperature changes, such a simple heat sum would not work unless hermetically sealed packs were used. More complicated equations would have to be developed involving both temperature and moisture terms.

Graphical relationships can form an important tool in the management of seedlots, and they serve to demonstrate the importance of initial quality for longevity.

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Technical Factors Limiting the Implementation of Legume-based Milk-type Foods in Developing Countries

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DAIRY production in tropical developing countries is often limited by a number of developmental difficulties which can include availability and cost of suitable feeds and fodder, availability of farmer credit and poor infrastructure. As a consequence, milk is virtually unaffordable by the majority of developing country populations and particularly by low-income groups in urban centres. Additionally, the high incidence of lactose (milk sugar) intolerance in developing country populations can result in reduced acceptance and lower nutritional value of animal milks (Lee and Lorenz 1979), and consequently alternative lactose-free food products may be more readily received. In order to improve the supply of nutritious and low-cost foods, it has therefore been considered that milk-type products based on legumes and oilseeds, which are rich in proteins and fats, should be developed. Such products could be consumed directly, used to extend cow's milk or transformed by further processing, i.e. fermentation, to provide improved shelf life.

The wealth of information available from Asia concerned with the processing of a variety of products from soybeans may be applicable to other legumes and oilseeds. These are often produced in large quantities in many developing countries, where agronomic conditions do not favour soybean cultivation. In many developing countries, oilseeds such as sunflower and groundnut are also processed to provide edible oil, and the residual cakes, which are rich in protein, are most often used as animal feed. In India, cow's milk, extended with groundnut protein isolate, has successfully been developed (Chandrosekhara et al. 1971), but in most regions outside Asia the acceptability of legume based foods (soy milk, tofu, tempeh) is often limited. The characteristic, often beany flavours, the content of antinutritional factors, as well as indigestible oligosaccharides which may given rise to flatus, can all affect acceptability (Ferber and Cooke 1979). The physical stability of milk-type products is also an important quality attribute; different raw materials provide differing emulsion stabilities. Certain legumes (chickpea, pigeonpea, black gram) have been shown in preliminary studies to provide such weak emulsions that subsequent pasteurisation processes result in destabilisation. Incorporation of emulsifying agents or limited proteolysis to improve protein dispersibilities may have some potential stabilising effects (Caygill et al. 1981).

The considerable number of studies conducted in North America and elsewhere (Moretti 1981) have indicated the technical potential for the improved supply of food products based on soybeans. These products have nutritional and acceptability characteristics similar to cow's milk. However, additional studies along the following lines are required:

1. evaluating alternative raw materials grown in developing countries;
2. evaluating methods of improving consumer acceptability and product qualities;
3. evaluating the technical and economic feasibility for cow's milk extension (i.e. the dilution of cow's milk with vegetable oils and proteins).

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Nutritive Value of Green and Mature Pigeonpea Seed

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PIGEONPEA is mostly consumed in the form of cooked dhal (decorticated dry split mature seeds) along with cereals. In many countries pigeonpea, like garden pea, is consumed as green seed collected 25–30 days after flowering (Singh et al. 1984). In general, large-seeded varieties are preferred for this purpose. In some Caribbean and Latin American countries green pigeonpea is processed by canning or freezing. At ICRISAT, nine genotypes differing in pod and seed coat colour were studied for the nutritional quality of green and mature seed.

Green seed had more protein than mature seed (Table 1). Although the starch content was higher in mature seed the digestibility of the starch in green seed was almost 50% higher (Singh et al. 1984). Glucose, fructose and sucrose were the predominant sugars in green seed, and other results have shown that their concentrations decline as the seed matures. Up to 70% of the calcium in mature seed is lost when the seed coat is removed to make dhal. The iron content in green seed was significantly higher than that in mature seed.

TABLE 1. Mean values of various nutritional constituents of green and mature seed from nine pigeonpea genotypes.

Green/ Mature	Protein (%)	Starch (%)	Soluble sugars (%)	Seed coat (%)	Dietary fibre (%)	Calcium (mg/100 g)	Iron (mg/100 g)
Green	21.0	48.4	5.1	22.3	23.1	94.6	4.6
Mature	18.8	53.0	3.1	13.6	20.1	120.8	3.9
SD	0.50**	0.78**	0.18**	0.54**	0.60**	4.52	0.16**

The protein quality of green seed was better than that of mature seed in terms of protein content and digestibilty and the levels of the important essential amino acids, methionine, cystine, and tryptophan (Table 2). The levels of protease and amylase inhibitors, which interfere with the protein and starch digestibilities respectively, are lower in green than in mature seed.

TABLE 2. Mean protein digestibility, antinutritional factors and important amino acid levels of green and mature seed of nine pigeonpea genotypes.

Green/ Mature	Protein digesti- bility (%)	Trypsin inhibitor (Inhibitor units/mg meal)	Chymo- trypsin inhibitor (Inhibitor units/mg meal)	Amylase inhibitor (Inhibitor units/mg meal)	Poly- phenols (mg/g)	Lysine (g/100 g protein)	Met + Cys[1] (g/100 g protein)	Trypto- phan (g/100 g protein)
Green	66.8	2.8	2.6	17.3	8.6	6.9	2.7	0.9
Mature	58.5	9.9	3.0	26.9	10.6	6.7	2.2	0.8
SD	1.53*	0.55**	0.19	1.25**	1.10	0.09	0.15*	0.06

*$P < 0.05$, **$P < 0.01$, [1]Methionine + Cystine

Green pigeonpea seed is reported to have over three times more carotene than dhal and to have 250 ppm ascorbic acid compared with none in dahl (Gopalan et al. 1984). All these observations indicate that pigeonpea seed used green as a vegetable is nutritionally better than when seed is mature.

Gapalan, C., Rama Sastri, B.V., and Balasubramanian, S.C. 1984. Nutritive value of Indian foods. IIN, ICMR, Hyderabad, India. 204 p.

Singh, U., Jain, K.C., Jambunathan, R., and Faris, D.G. 1984. J. Food Sci., 49, 799–802.

Nutritional Quality Components of Pigeonpea and Chickpea

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PIGEONPEA and chickpea are major food legumes of India. Biological value (BV) and protein efficiency ratio (PER) of their proteins are lower than those of animal proteins (BV: pigeonpea = 57, chickpea = 68, milk = 84 and egg = 94, PER: pigeonpea = 1.5, chickpea = 1.7, milk = 3.1 and egg = 3.9 (Gopalan et al. 1980).

Jambunathan and Singh (1982) found that the protein content ranged from 15.5 to 28.6 percent in the germplasm of pigeonpea seed and cooking time varied from 24 to 68 minutes in 25 samples of pigeonpea split seed (dhal). In contrast, we found a narrow range for both cooking time and protein content in 10 elite pigeonpea genotypes and chickpeas (Table 1).

TABLE 1. Seed size, maturity, cooking and protein content in chickpea and pigeonpea.

	100-seed weight (g)	Days to maturity	Cooking time (min)	Expansion on cooking times	Protein content (%)
Chickpea:					
Mean	15.8	127	24	2.3	22.4
Range	11.0–23.5	118–137	16–28	1.4–3.0	21.0–24.3
LSD P = 0.05	0.51	4.15	2.82	0.3	2.82
Pigeonpea					
Mean	8.0	203	21.1	2.3	22.0
Range	5.9–11.4	123–259	15.0–27.0	1.3–3.2	20.0–23.8
LSD P = 0.05	0.78	3.56	3.03	0.3	0.72

Similarly Kabuli type (white seeded) L–550 chickpeas and bold-seeded chickpeas took less time to cook and showed better expansion on cooking than other chickpeas (Table 1). No association of seed size or maturity period was found in protein or cooking characters in chickpea. However in pigeonpea, in general, late maturity types had a higher protein content and took less time to cook and expanded more on cooking. Cooking time and protein content of early types (e.g. UPAS–120) suitable for double cropping, need to be improved through the introgression of genes from late types, like Type-7 and Gwalior-3.

Gopalan, C., Rama Sastri, B.V. and Balsubramanian, S.C. 1980. Nutritive value of Indian Foods, ICMR, Hyberadad, 5–6.
Jambunathan, R. and Singh, U. 1982. Symp. Pluse Production in India, 389–395.

Physical, Chemical and Nutritional Evaluation of Pigeonpea and its Processed Products in Indonesia

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TWENTY-THREE high-yielding lines from Australia and five local Indonesian varieties of pigeonpea were evaluated for physical characteristics i.e. size, shape, colour, weight and bulk density; chemical characteristics i.e. protein, fat, crude fibre and moisture, and overall nutritional quality. Dehusked grain was used for processing by boiling and fermentation to produce fermented pigeonpea or tempeh. The raw, boiled and fermented form was tested for biological quality, i.e. true digestibility (TD), biological value (BV) and net protein utilisation (NPU).

Processing of pigeonpea increased true digestibility (TD), assayed by rats, from 70.9% of raw to 84.7% of boiled and 86.6% of fermented grain. However, biological value (BV) decreased from 83.5% of raw, to 50.6% of boiled and 45.6% of fermented product.

All samples, both Australian and local Indonesian, had the same size and shape, but Australian lines were slightly higher in bulk density and weight of grain. The protein content of the Australian lines (17.4–22.2%) was lower than in the Indonesian local varieties (20.0–24.5%).

Tempe gude or pigeonpea tempeh was made by fermenting of pigeonpea by *Rhizopus* which is commonly used in making soybean tempeh. Two local Indonesian varieties from Kuningan and Wonosari were used in the study. Organoleptic tests indicated that the pigeonpea tempeh, even though less preferred than soybean tempeh, was still acceptable by panelists.

Various ratios of pigeonpea and soybean were used to produce tempeh (Table 1). Organoleptic tests revealed no difference between 2:1 soybean:pigeonpea tempeh and pure soybean tempeh (based on colour, appearance, texture of the raw tempeh and taste of the fried tempeh).

TABLE 1. Chemical composition of fresh tempeh.

Composition (%)	Tempeh A (Sb:Pp = 3:0)	Tempeh B (Sb:Pp = 2:1)	Tempeh C (Sb:Pp = 1:2)	Tempeh D (Sb:Pp = 0:3)
Moisture	62.4	64.6	64.2	55.6
Protein	21.7	17.4	15.6	11.8
Fat	3.9	0.6	0.4	0.2
Ash	1.3	0.9	1.0	0.6
Cr. fibre	2.0	1.4	1.3	1.2
Carbohydrate (by difference)	8.7	15.1	17.5	30.6

Note: Pp = Pigeonpea, Sb = soybean

The pigeonpea from Australia contained 22% protein, 2% fat, 54% carbohydrate and 10% moisture, Soybean Lokon variety contained 35% protein, 18% fat, 35% carbohydrate and 8% moisture.

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