Tropical Crop Legume Improvement - A Matter of Adaptation

Farrer Memorial Oration, 1986

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TROPICAL CROP LEGUME IMPROVEMENT - A MATTER OF ADAPTATION

FARRER MEMORIAL ORATION 1986

D.E. BYTH

The award of the 1986 Farrer Medal to me by the Board of the Farrer Memorial Trust is an honour which is deeply appreciated. However, I strongly believe that, in science, no individual stands alone and that any contribution inevitably reflects an active exchange and sharing of knowledge and concepts. My career in agricultural science, in research and in education, has been characterized by close interaction with numerous scientific colleagues in Australia and in other countries, with undergraduate and postgraduate students, research and academic administrators, and with representatives of the agricultural industries. I wish to acknowledge publicly the intellectual stimulus and guidance I have received continually from others, and to indicate that I regard this award as a recognition of the overall contributions that have grown from those relationships.

INTRODUCTION

In choosing the topic of this essay, I have sought to address the interests of a very diverse audience:- those who are not agricultural scientists and who may have little or no scientific training; others who are scientists but know little of agriculture and the scientific efforts which are mobilized to its support and development; and agricultural scientists from a wide range of professional interests. My objective is to use this topic to communicate some of the challenge and excitement of research and to touch on aspects of the role and contribution of agricultural science in contemporary society.

In a very real sense, plant production is central to the survival and welfare of man, and improvement in plant productivity undoubtedly has been a fundamental component in the establishment of the great agricultural industries of this country and remains essential to their continued viability and development. Despite the current downturn in the rural sector, the Australian economy remains heavily dependent on the agricultural industries for export income, employment and wealth creation, and will continue to do so for the foreseeable future. The reasons for this are clear - despite our relatively harsh and unfavourable environment, agricultural production is one of the things Australia does well on a world scale, and this reflects the dynamic industries, the enterprising nature of the Australian farmers and traders, and the contributions to research and development by agricultural scientists. Australian agriculture is, to a large extent, a high technology exercise and its products are high technology commodities. The development and application of appropriate technology has enabled us reliably to produce products of acceptable quality for the local and international marketplace and to market them in the face of intense international competition which often is heavily subsidized. This is no small accomplishment, and agricultural research has contributed substantially to the technological base that has made it possible.

In essence, Australian agriculture consists of dynamic industries which must continually develop and change to meet the challenge of a changing environment of production, marketing and demand. Research is necessary to enable the industries to meet these challenges, and to ensure conservation of our natural resources through the development of stable and environmentally acceptable systems of production.

The contributions of agricultural research to the economic and social development of this country have been immense, and this deserves greater community recognition. Equally, there is a responsibility on industry and government to ensure continuing support for the education and research needed to underwrite the future technological needs of the developing agricultural industries. This is a major challenge, and I confess to considerable unease regarding the prevailing preoccupation by government with the so-called "sunrise, high-technology" industries. Certainly, these areas require and justify research support, but this must not be at the expense of support for research within the agricultural industries upon which we are so dependent.

Another reason for choosing this topic is that it enables reflection on the work of the man whom we are truely honouring on this occasion - namely William James Farrer. Many in the audience will know little of him (apart from his appearance on the $2 note), and some attention to this man and his contribution is justified.

Farrer was undoubtedly a pioneer - one of the most imaginative plant breeders to work in Australia, and indeed his contributions had international significance. His tangible contribution was the breeding and naming of numerous cultivars of wheat, but this is dwarfed by the importance and impact of his intellectual contribution. Farrer conceptualized the need and opportunity for genetic improvement of an agricultural species, the need to identify and concentrate upon the primary factors limiting production, and the necessity to generalize this concept of crop improvement across the range of characters of that crop. The depth of insight involved in these concepts is impressive, particularly when they are put into an historical perspective. At the time, around federation, the scientific approach to agriculture was in its infancy and indeed the scientific world was just in the throes of rediscovery of Mendel's fundamental work in genetics and inheritance. Farrer was, indeed, a man ahead of his time.

Most importantly, his work exemplifies an intellectual flexibility, a willingness to modify the emphasis to address the primary problem. He recognised that the early wheat varieties from Europe were poorly adapted to Australian conditions, and that there was a need in Australia for varieties that could yield well and reliably in environments generally characterized by low inputs and severe stresses such as drought. He was one of the first plant breeders to become involved in cereal chemistry and the improvement of milling and baking quality of grain. He sought to combine improved grain quality with characters which may condition high yields in stress environments, such as early maturity, reduced tillering and narrow stiff leaves. This recognition of the opportunity for improvement of the adaptation of a crop to specific production environments, and that particular plant characteristics may influence that adaptation, is thoroughly modern in its concept. Contemporary agricultural scientists have developed upon his concern for improvement of adaptation, but his initial contribution remains classic and instructive.

PLANT IMPROVEMENT

Agricultural producers are concerned with the production of particular species over time and space, and as a result, a central objective of agricultural scientists is the improvement of the productivity of that species in specific environments and of its adaptation to a range of environments. In practice, performance can be improved either by changing the plant to make it more suited to its environment, or by modifying the environment to better satisfy the requirements of the plant, or both.

How do these changes occur?

Changes to the plant are possible only when there is genetic variability in the population for the ability to respond to a particular challenge or stress, and a permanent genetic change may be possible through selection of the superior group. This is the process of adaptation by which a population becomes progressively better adjusted to its environment. In a similar way, the environment may be modified to achieve a desired result. Agricultural production inevitably involves modification of the environment; for example, the use of cultivation, the application of fertilizers, chemicals and irrigation, the use of different sowing dates, and so forth. Each modification is designed to relieve a particular stress or limit to plant productivity, and the scale and nature of the modifications can vary hugely, e.g. intensive horticulture and floriculture vs. extensive wheat production.

For those cases where the differences in plant performance can be related mainly to one specific limitation (such as a disease which devastates production), then the strategy of plant improvement is relatively clear - either identification and incorporation of genetic resistance, or the use of cultural or chemical control measures. In these types of situations, the key to plant improvement is the recognition of the nature of the stress and of the extent of the adaptive response of genotypes to it. This allows definition of alternative strategies for resolution of the limit, and selection of the most appropriate of these.

More commonly, however, agricultural environments impose quite complex challenges with many factors varying simultaneously, and there may be a range of responses by different varieties to these challenges. In these situations, relative (rather than absolute) differences among varieties become important and the objective design of strategies for improvement becomes more complex.

Consider an example. All plants require water to grow and, in principle, the more water they have the better they perform. Suppose two farmers, one located in an irrigation area and the other in a semi-arid dryland area, decide to grow a particular crop. The season is dry in both areas, so that crop growth is restricted. The first farmer responds by irrigating his crop to relieve the stress - he seeks to improve productivity by modifying the environment to suit the needs of the crop. Such a response by the second farmer is not possible. He certainly could have attempted to increase the moisture available to the crop by modifying his farming system to store extra water in the soil. However the best option he has to improve productivity in that environment is to use a variety which is genetically superior in its tolerance of dry conditions - say, one that is deeper rooted and able to extract more water; or one which is earlier maturing so it avoids much of the drought; or one with more efficient leaf function which produces more growth than does a less efficient variety while using the same amount of water.

Clearly these two situations are in stark contrast with respect to the nature of the environmental challenge to the crop and the form of adaptation desired. The farmer with irrigation requires a variety which has a high yield potential and the ability to respond to inputs and favourable cultural conditions. The dryland farmer also has an interest in a high yield potential because occasional seasons in his area are highly favourable. However his over-riding requirement is for genetic tolerance of the water stress certain to be experienced in most years. It is obvious that quite different types of plants and production systems are needed for these two situations, and that quite different strategies of plant improvement are required for their development.

These examples are over-simplified, but they are real and I have posed them in order to establish three principles:

First, that agricultural environments vary hugely and that varietal performance in any environment is a complex function of many interacting factors.

Secondly, that improved performance is attained through the identification and resolution of specific limits to productivity and adaptation.

Thirdly, that agricultural plant improvement inevitably is multidisciplinary, in that it may involve manipulation of the genetics or the environment of the plant, or both; depending on the nature of the primary limit and the feasibility of alternative resolutions.

Agricultural production occurs in an incredibly wide diversity of environments which 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. This is the dynamic situation within which improvement in plant productivity must be sought, and it obviously is a complex and continuing challenge. There also is an international dimension to this, in that Australian arable agriculture is based almost totally on exotic species. There is active international exchange of genetic materials and scientific knowledge, but the relevance of the various national and international programs to the Australian agricultural situation differs greatly.

Deliberate plant improvement by man is not a new concept - indeed, primitive man initiated the process as soon as he commenced cultivation, and modern agricultural species are to a large extent a legacy of the influence of hundreds of generations of intervention by man. Even today, _ad hoc_ activity in plant improvement can be highly effective when it is directed at a specific problem. In some cases, that improvement can be extrapolated to other environments but more commonly, large interactions of variety x environment restrict the extent of technology transfer. Indeed, this was precisely the problem faced by Farrer - that the wheat varieties and technology of Europe were not relevant to Australian environments.

Simply, 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 time and space for an agricultural system characterized by great diversity and dynamic change of the production environment. 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 productivity and adaptation of the species. This has been and remains the primary objective in plant improvement research, and considerable advances have been made in recent years. However, for most of our crop plants, scientific knowledge of the interrelationships among plant characters influencing growth and development in particular environments remains severely limited. As a result, genetic models allow only a limited prediction of performance in different environments, and physiological models do not necessarily encompass the responses of other genotypes or the influence of untested environments. In turn, this restricts our ability to design objective strategies for the improvement of these crop species.

CROP LEGUMES IN FARMING SYSTEMS

A very large number of edible plant species are known and have been exploited by man throughout his history. However, for various reasons, our agriculture is now dominated by a relatively small number of groups of crop species. Of these, the legumes are among the most important and in fact, only the cereal grains (wheat, rice, maize etc.) and root crops (potato, cassava, yams etc.) have greater importance.

The importance of legumes as a component of farming systems has been appreciated by man since antiquity, both because they were a good food source and because they were recognized as contributing to the maintenance and restoration of soil fertility (Myers and Wood, IN PRESS; Wood and Myers, IN PRESS). We now know that this feature of legumes arises from the symbiotic activity of nitrogen-fixing bacteria in nodules on their roots. This ability of the legumes to fix atmospheric nitrogen and convert it into protein for the leaves and seeds enables them to flourish on soils low in mineral nitrogen and to contribute to the N balance of the whole farming system.

Legume seeds have been a vital component of human and animal diets for many centuries. We are now aware that this reflects a recognition of both the high concentration and quality of the protein in the legume seed, and the nutritional complementarity between the legume seed and cereal grain with respect to the amino acid composition of the protein.

A great diversity of crop legumes is exploited by man. The oil-bearing legume seeds such as soybean and peanut can be distinguished from those which contain little or no oil in the seed and which are collectively referred to as 'pulses'. Man has been most ingenious in developing methods of utilization of legume seeds which make them more palatable, increase their nutritional value or remove anti-nutritional factors (Plate 1). Legume seeds are eaten as whole green or mature seeds or after decortication and splitting; they can be cooked by boiling, roasting or frying; they may be sprouted, fermented, extracted for protein curds, artificial milk products and textured vegetable protein, and used as pulse flour in noodles; to mention only some of the range.

[TAKE IN PLATE 1 NEAR HERE]

It is clear that the crop legumes are an important protein source in human nutrition, particularly in those developing countries in which animal protein is in short supply or expensive and where vegetarianism is common. However, recent trends in human nutrition in some developing countries are disturbing. For example in India, since 1961 there has been a 10-15% increase in the per caput availability of cereals, whereas the per caput availability of pulses, which was already inadequate, has declined by 20% over the same period. This development was anticipated in the early 1970s by Norman Borlaug, the Nobel Laurete agricultural scientist and the father of the so-called green revolution in cereal production. Indeed, it is partly the development of higher yielding varieties and improved production practices for cereals that has displaced the crop legumes onto more marginal cropping land and reduced their production. The cost of production of crop legumes in many Asian countries is now substantially greater than that in the Western agriculture, and this further discriminates against local production and encourages imports. A number of countries of S.E. and S. Asia are now either self sufficient or even net exporters of cereal grains, but continue to import substantial quantities of crop legume seed or seed products for human and animal use. In view of the continuing growth of the human population and of the intensive animal industries in the developing world, an increasing demand for high quality vegetable protein appears assured. However, it is clear that this demand cannot be met from local production in those countries in the short term.

The solution to this dilemma advocated by Norman Borlaug in 1973 remains equally valid today, because it has not been accomplished. He conferred the title of 'slow runners' on the crop legumes and recommended implementation of high priority programs for their scientific study and improvement, with the objective of enabling a green revolution of crop legumes through higher yielding varieties and improved production technology. A number of programs of research into particular crop legumes have been established nationally and internationally, and a considerable amount has been accomplished. However, the scale of the initiative has been limited, the problem of crop legume improvement has transpired to be much larger and more complex than previously anticipated, and much remains to be done (Byth, Shorter and Sumarno, IN PRESS; Byth, Wallis and Wood, IN PRESS).

In Australia, legumes have had a major role in pasture improvement and also in ley farming systems in southern Australia. However, arable agriculture has been dominated by the cereal grains, and crop legumes have attracted significant commercial and scientific attention only in the last two decades. The increased interest in crop legumes reflects a number of factors including N fixation by the crop, an economic need to diversify agricultural production, recognition of the role of legumes in development of stable systems of land use, the high unit value of legume seed, and identification of local and world markets for human food and animal feeds.

Each of the crop legumes of current or potential value in Australia is a significant crop in some other part of the world. Therefore the problem of crop legume improvement is one of adaptation - of adapting crops which are components of agricultural systems elsewhere to the particular needs and limitations of Australian agricultural environments. In principle, this is exactly the same problem faced by Farrer with wheat at the turn of the century, and it continues to be a fundamental challenge for any new crop. Commercial adoption of a new crop is likely only if relatively simple, efficient, flexible and robust packages of variety and production technology can be developed for extension to farmers, which will complement or supplement existing production systems without radical change.

In this context, the adaptation of the tropical crop legumes present particular challenges. A large number of these species are traditional components of farming systems in the tropics and subtropics. However, despite their long history of use by man, each remains relatively wild and undomesticated for agricultural use, compared to the cereals. They are adapted to an agricultural environment very different from our own and commonly exhibit characteristics which are counter-productive for mechanized agriculture - such as a twining habit, very long crop duration, excessive vegetative growth, and shattering of the pods at maturity. In some cases, such as the winged bean, those very characteristics of value in subsistence agriculture may be exceedingly difficult to exploit in commercial agriculture. Other species exhibit adaptation to the short daylengths and continual warm temperatures of the low latitudes, and their relevance to the longer days and lower minimum temperatures of the Australian subtropics is questionable.

Simply, the tropical crop legumes have been subject to relatively little systematic study compared with the major cereals and the temperate crops in general, and our scientific knowledge of their production, improvement and use is quite limited. It follows that the adaptation of these crops to Australian agricultural environments is a major scientific challenge, and that sustained improvements and adoption will only arise from a determined effort to develop our scientific knowledge of them. There are significant national and international collections of genetic material, and even active research programs, for a number of these species. However, the fact is that these important crops are grossly under-researched and scientifically neglected internationally. There are severe limitations to transfer of appropriate technology in these species, and it is clear that Australian scientists and institutions must accept major responsibility for their scientific study and adaptation to

Australian agricultural environments.

IMPROVEMENT OF PARTICULAR SPECIES

Over the last two decades, Australian scientists have made significant contributions to the scientific study of a number of the more important tropical crop legumes. Aspects of two of these, soybean (Glycine max) and pigeonpea (Cajanus cajan), will be considered here as examples of the nature and challenge of research into crop plant improvement.

In many ways these species represent extremes of the tropical crop legumes. The soybean is an important oilseed legume which has been extensively researched internationally and which has been established as a significant crop of the Australian subtropics. By contrast, the pigeonpea is a pulse crop which is of more regional importance internationally, which has been subject to quite limited scientific study, and which is only now being introduced to Australian agriculture. In both cases, I will demonstrate briefly how the biology of these species can be manipulated to influence their productivity and adaptation, and how research can extend the adaptation and enhance their yield potential.

Soybean

Although the soybean has been grown since antiquity in parts of Asia, it is a comparatively new crop in Western agriculture. It has developed from a minor crop in the U.S.A. in the 1940s to become the third largest crop there, and there has been a parallel expansion on a much smaller scale in Australia since the 1960s. Soybean seed contains around 40% protein and 20% oil, and this contributes to its agro-industrial importance. The seed may be consumed directly or processed to produce oil and protein meal. The oil is used for both edible and industrial purposes. The protein is in demand for animal and human uses, and numerous other purposes.

The improvement of soybean productivity in the tropics and subtropics is a major and important challenge because of its current and potential importance as a crop there. Considerable potential also exists for expansion of soybean production in Australia, mainly in the tropics and subtropics (Chapman 1981). Substantial scientific knowledge of the production, improvement and use of soybean exists, but it is mainly derived from the U.S.A., all of which lies outside the tropics (Figure 1). Similarly the limited research base on soybean in Australia is located mainly in the subtropics and warm temperate regions. Clearly, the relevance of this knowledge to the lower latitudes is questionable, and there is a need to validate its extrapolation and to generalize its interpretation. These considerations have led Australian scientists to seek to develop a more fundamental understanding of the factors influencing soybean growth and development, and of genetic differences in these responses.

[TAKE IN FIGURE 1 NEAR HERE]

Phenology and adaptation

One of the most important influences on crop adaptation is the phenology of the variety - the phasic pattern of development of the plant from germination to flowering to maturity. Changes in the duration of the various phases of growth obviously can have a major influence on plant size, and short duration crops will be smaller and require much higher plant densities for optimum yield. Equally, control of crop duration may be necessary in order to avoid a particular stress (frost or heat wave) or to enable implementation of a particular farming system.

As always, control is the essence. In the soybean, phenology is strongly influenced by daylength and temperature, and there is substantial genetic variation for this response. This provides a basis for control and for prediction of phenology in different environments. Most soybean genotypes are quantitative short-day plants, which means they become earlier in flowering as the daylength is shortened by later sowings or when they are grown in lower latitudes. As a result of the effects of crop duration on plant size, there is a strong interaction of variety x photoperiod (sowing date; latitude) x plant density/arrangement for seed yield. This has been exploited to establish packages of technology which enable technically viable production of soybean virtually throughout Australia, at least for the summer season (Lawn and Byth, 1979). Other limits to productivity then can sensibly be investigated within these production systems.

Soybean improvement for growth during the short-day period of the low latitudes is a quite different and much more fundamental challenge, and one which is of major international significance (Lawn and Williams, IN PRESS). Soybean plants sown in the dry or winter season in the tropics experience a combination of environmental challenges not experienced in any other region - short and decreasing daylengths during the vegetative phase, relatively long and increasing daylengths during reproduction, low night temperatures during vegetative growth and early reproduction, and very high temperatures during late reproduction (Figure 2). In fact, these are essentially the reverse of the normal conditions of soybean culture, and it is not surprising that most improved varieties from elsewhere are poorly adapted to these conditions. Some accessions from tropical regions do have acceptable phenology under those conditions, but they usually also exhibit undesirable characters such as twining habit and shattering, as well as sensitivity to low night temperatures.

[TAKE IN FIGURE 2 NEAR HERE]

It is apparent that soybean improvement for the low latitudes is a major scientific exercise. Research is necessary to understand the ecophysiology of such adaptation and to identify characters of adaptive significance. Varietal improvement will require incorporation of genes conditioning characteristics such as acceptable habit, resistance to shattering, diseases and pests, appropriate seed size and quality, and tolerance of low temperature, into backgrounds with the appropriate phenology for those conditions. Aspects of this research have been initiated in Australia during the last decade and will have important implications both in Australia and throughout the tropics (Lawn et al. 1986).

Water management and the physiology of yield

In a similar manner, recent research into the water management of soybean crops has greatly broadened the range of adaptation of the soybean and increased our understanding of its physiology and genetic potential for seed yield.

It is common knowledge that waterlogging has detrimental effects on the growth of most plants. However, soybean plants were observed to respond favourably to prolonged waterlogging provided a mineral nitrogen supply was also maintained. Subsequent research has demonstrated that if waterlogging is commenced soon after germination by the establishment and maintenance throughout growth of a shallow watertable just below the soil surface (Figure 3), the soybean plant will acclimate itself to the waterlogged conditions and produce greater seed yield than conventionally irrigated plants. Indeed, seed yield increases averaging about 25% and ranging up to nearly 70% have been obtained experimentally in the field, and an experimental yield in the field in excess of 8 t ha^{-1} has been obtained which is probably a world record (Troedson _et al_. 1985).

[TAKE IN FIGURE 3 NEAR HERE]

It is apparent that this research has broken new ground and opened up new applications for the culture of soybean commercially. An obvious one is the integration of saturated soil culture of soybean into rotations with paddy rice (Figure 4). More importantly, the research has demonstrated both a greater yield potential for soybean than had previously been considered possible, and a remarkable responsiveness of the plant physiologically to what is really a rather prosaic change to its environment. Detailed studies of these responses have been most informative regarding the nature of the limitations to yield in soybean, and have important implications on soybean production and improvement internationally, and particularly in the tropics and subtropics (Troedson _et al_. 1986). Current research is designed to investigate the extent of genetic variability in the response of soybean to saturated soil culture, in the hope that genetic manipulation of even greater responses may be possible.

[TAKE IN FIGURE 4 NEAR HERE]

The soybean is one of very few crop legumes able to respond to saturated soil culture, and it is interesting to speculate on the reason for this. In Asia, the soybean commonly is grown in controlled waterlogged conditions such as on the bunds of rice paddies and it is possible that this adaptation was derived through long term selection by farmers. Research has shown that the ability to acclimate to saturated soil culture is a ubiquitous characteristic of the soybean and its annual wild relative, _Glycine soja_, but that none of the perennial _Glycine_ species exhibits acclimation (R. Hartley, _pers. comm._). It is tempting to speculate that the genes conditioning acclimation were the trigger initiating domestication of the soybean in the first place, and that

Western man has inadvertantly ignored this important attribute until recently.

Pigeonpea

The pigeonpea is a short lived perennial crop legume. It is the fifth most important pulse crop internationally, and is widely grown in the tropics and subtropics, particularly in the Indian sub-continent but also in parts of Africa and S.E. Asia and in the Caribbean. It is a typical pulse crop with 17-25% protein and no oil in the seed, which is eaten mainly as a dry split pea or as a green vegetable.

The pigeonpea has a number of advantages compared with other crop legumes for the semi-arid tropics. It is highly tolerant of water stress and low soil fertility, resistant to lodging and shattering, and has relatively low susceptibility to pre-harvest weathering of the seed. However, several factors have inhibited its adoption as a crop in Australian agriculture until recently, including susceptibility to frost, waterlogging and attack by insects during reproductive growth. Most importantly, the long crop duration of most varieties, together with their massive vegetative growth (Plate 2), restricted the relevance of the crop in Australian crop rotations and prevented mechanized harvesting. Furthermore, despite its importance in human nutrition, relatively little pigeonpea seed enters world trade and no international marketing system existed into which Australian production could be placed.

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Phenology and production systems

As for soybean, most pigeonpea genotypes are quantitative short-day plants, and phenology is influenced by photoperiod, temperature and their interaction. By consequence, strong interactions exist between genotype, sowing date and density/arrangement. An extremely wide range of phenology exists, ranging from less than 60 to greater than 200 days to flower and including insensitivity to photoperiod.

As a result, pigeonpea is used in a wide diversity of production systems internationally (Figure 5). In India, most production is from traditional intercrop systems involving very long season genotypes (9-11 months crop duration) grown in wide rows with another crop (commonly a cereal, sorghum or millet) in the interrow space (Plate 3). The cereal is harvested prior to flowering of the pigeonpea which then completes its crop cycle on residual moisture during the dry season. A great diversity of intercropping systems is practiced and research at ICRISAT has investigated optimal systems of management (Willey et al., 1981). While these cropping systems have particular potential in subsistence agriculture, they have little contemporary relevance in Australian agriculture.

[TAKE IN PLATE 3 AND FIGURE 5 NEAR HERE]

Pure-crop systems for pigeonpea are also used in India, with both full-season and short-season genotypes. As a result of phenological response to photoperiod and temperature, there is a need to optomize plant density and arrangement if high seed yields are to be obtained. In subtropical Australia, the photoperiod-sensitive cultivar Royes must be sown at or after the longest day in order to reduce crop duration and thus avoid excessive vegetative growth. However, even then, plant population must be varied from 50,000 plants ha^{-1} for sowings at the longest day to 250,000 plants ha^{-1} for sowings 2-3 months later in order to obtain optimum canopy development and maximum seed yield. These production systems have limited application in many Australian environments because of complexity of management, and because reproductive growth occurs during the driest and coldest period of the year. However, the system can be successful in warmer environments such as Fiji. The perennial habit of pigeonpea can be exploited through ratoon cropping in favourable environments (Figure 5) and experimental yields exceeding 4 t ha^{-1} $year^{-1}$ from two harvests have been achieved (Wallis et al. 1981).

More recently, photoperiod insensitive genotypes have been identified which flower in approximately 60 days and mature in about 120 days regardless of sowing date, provided temperature is not limiting. Short-season pigeonpea genotypes enable entirely new production systems and considerably broaden the adaptation of the crop, both into the higher latitudes and by allowing more flexible integration into crop rotations and mechanical harvesting. Ratoon cropping is again feasible in favourable environments (Figure 5). Recent research in Australia has concentrated on the genetic improvement of this type of material, and on development of appropriate systems of management (Plate 4). The potential for short-season pigeonpea is apparent, in that experimental yields of the plant crop in excess of 8 t ha^{-1} have been obtained (Wallis et al. 1983).

Research into short-season pigeonpea has added a new dimension to the exploitation of this crop internationally, by broadening its adaptation and by establishing that it has the potential for very high seed yields under favourable environments as well as great ability to tolerate stress of various kinds. Both forms of adaptation need to be exploited. However, improvement of pigeonpea is a particularly complex challenge because of the wide differences in phenology and habit, and its use in quite contrasting production systems (Byth 1981; Byth et al., 1981). Indeed, the differences in growth and development among cultivars of pigeonpea adapted to contrasting production systems are greater than those between pigeonpea and many other crops. Quite different environmental and physiological limits to productivity are likely to exist between systems, and genetic variability and parameters may also differ.

This suggests that improvement within different systems is likely to pose quite different problems, and that extrapolation of scientific knowledge between these systems will be limited (Lawn, 1981).

Despite recent advances, scientific knowledge of the physiological and genetic limits to productivity and adaptation of pigeonpea remains very limited. This reflects the status of pigeonpea as an under-researched crop which remains relatively primitive in its development for domesticated agriculture. Short-season pigeonpea essentially represents an entirely new crop which has a demonstrated potential in Australian agriculture, and current research is designed to provide a scientific understanding of yield accumulation and improvement within that type of production system. Other production systems, perhaps involving longer duration genotypes and even intercropping, have application elsewhere. There is a need for Australian scientists to also be involved in research into those systems because this ensures a broader perspective and experience of the genetic resources of the species and its relevance across a range of environmental challenges.

THE NATURE OF RESEARCH INTO CROP IMPROVEMENT

Much has been written and spoken in recent years regarding the organization and nature of research in Australia, and its appropriateness. A plethora of terms has been used, such as basic, fundamental and applied; strategic, tactical and mission-orientated; directed and curiosity-based; and up-stream and down-stream research. The distinctions are at best unclear, and the concepts often are vague. For example, the term "problem-orientated" research immediately raises the question of whose problem? and whose orientation? It is clear that a diversity of meanings can be attached to these terms. In addition, there are increasing pressures from industry and government to ensure greater relevance of research to current needs of industry, and this creates concern that the search for the more fundamental scientific understanding necessary to underwrite advances in the longer term may be neglected.

Research into crop improvement needs to be placed in context with these developments. In principle, crop improvement is a contemporary research activity which is future orientated and inevitably multidisciplinary. To the extent that it has a tangible objective, it may be said to be mission-orientated. However, it clearly also benefits from fundamental research into mechanisms where these constitute a limit to the productivity or adaptation of that crop. No research is conducted in isolation and in the case of crop legumes in Australia, much of the knowledge which has contributed to their improvement has been derived opportunistically from independent research programs primarily designed to gain a more fundamental scientific understanding of their biology.

While the primary objective of crop improvement is a pragmatic one (the achievement of an advance in productivity or adaptation), the really fundamental challenge is to generalize that advance across the whole range of systems of production and environments in which that crop may be produced. It follows therefore that the central issue in the objective definition of strategies of crop improvement research is the determination of the potential of the species for productivity and adaptation, and the attainment of a scientific understanding of the plant characteristics and enviromental factors which may limit expression of that potential.

This is a particular challenge with the tropical crop legumes:- because our scientific knowledge of them is limited; because they remain relatively wild and undomesticated; and because their wide range of habit and responsiveness to enviromental change conditions great flexibility of adaptation to a number of roles in farming systems. As a result, much of our knowledge of their production and improvement tends to be conditional and specific to a production system. Recent research by Australian scientists, such as that outlined above, has contributed substantially towards a more fundamental understanding of the factors influencing their growth and development, and of the extent of genetic variability for response to these factors.

The conditional nature of the needs and scientific knowledge regarding crop adaptation and improvement implies that no single system of research organization can guarantee access on demand to relevant knowledge. Curiosity-based disciplinary research may have no apparent contemporary relevance but is potentially invaluable in the longer term. Conversely, excessive emphasis on immediate industrial relevance in research can involve the danger of '*ad hocery*' and neglect of fundamental questions.

Simply, a proper mix of research in plant improvement is vital if contemporary opportunities are to be exploited and longer term advances assured. Research established to investigate a generalized problem of crop productivity commonly develops progressively to incorporate an integrated suite of investigations, often in several organizations, ranging from fundamental studies of physiology or genetics right through to the packaging and application of production technology for farmers. The basic motivation to establish and diversify such research is the *need to know* - the need to understand and relieve an identified limit to productivity or adaptation. However, in principle there is essentially no limit to the logical development of more fundamental studies from an applied research base centred on crop improvement.

CONCLUSION

In this essay, I have sought to demonstrate that crop improvement is a central objective through which appropriate research into various aspects of agricultural production can be integrated, and through this, to communicate some of the challenge and excitement of agricultural research and the relevance of its role in contemporary Australian society. I have attempted to show, using the tropical food legumes as an example, that the primary limitations to improvement of the productivity and adaptation of agricultural species are in the minds of men, rather than in the genetic and physiological diversity of the species.

I will finish by re-emphasizing the need for continued community support for education and research to underwrite the further development of our rural industries. Agricultural production is one of the few areas in which Australia has a comparative advantage in world terms, and there is an increasing need to sustain the high technology base of those industries on which the Australian economy remains so dependent. This will only result from an active commitment to advanced education and to an appropriate mix of fundamental and applied research into the problems of the agricultural industries. The industries, governments and the tertiary educational institutions carry major responsibilities in this regard. The Australian community must be made to realize the crucial role of education and research in our society. Education and research in support of our agricultural industries is neither a luxury nor an indulgence - it is vital to the continued viability of those industries on which we depend, and in that sense it is an essential investment in the future. We all bear responsibility to ensure that this investment is made.

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